ABSTRACT

Title of Document: **DO STUDENTS HAVE CULTURAL SCRIPTS? RESULTS FROM THE FIRST IMPLEMENTATION OF OPEN SOURCE TUTORIALS IN JAPAN**

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In the 1980's and 1990's, results from flurries of standardized exams reached the attention of ever-growing numbers of Americans with an alarming message: our children are not even close to keeping up with those in China, Japan, and Korea. As a step towards improving American classrooms, cross-cultural education researchers began to investigate differences in classroom structure, curricular content and focus, and attitudes and beliefs of students towards learning. Inspired American teachers tried to capitalize on these observed differences by making their classrooms look (for example) "more Japanese" and frequently met with failure. Researchers have used the differences in student beliefs as a justification for this

failure: "Japanese students believe different things about what classroom learning should look like than American students do. If you teach students in a way that clashes with their beliefs about learning, it's no surprise that the students don't buy in to it and the lesson doesn't succeed!" This message, in addition to the methods, analyses, and discussions surrounding the observations of student beliefs in general, has treated beliefs as being something determined by the culture in which the student grows up in, and as being stable and robust.

Curriculum developed and tested at the University of Maryland was implemented in the spring semester of 2011 at Tokyo Gakugei University. This curriculum focused on working in groups to draw upon one's own ideas and experiences to construct knowledge. Based upon available literature on the education system in Japan, we hypothesized that students would be entering the college classroom thinking of physics as something to be learned from authority, by listening to lectures and taking notes, and that they would be surprised by this new way of learning. For six months, I observed student reactions to the curriculum and confirmed these hypotheses.

Whereas the current perspective on student beliefs used by the cross-cultural education research community would have predicted that this curriculum incompatible with student beliefs about learning would have been a struggle, this was not what happened. This dissertation thus stands as a call to the community to reconsider the fluidity of student beliefs.

DO STUDENTS HAVE CULTURAL SCRIPTS?
RESULTS FROM THE FIRST IMPLEMENTATION OF OPEN SOURCE TUTORIALS IN JAPAN

By

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Dedication

To Professors Elby, Redish, and Hammer, who taught me what to teach, why to teach it, and how. To Professors Nitta and Uematsu, who welcomed change to their school. To my parents and to my brother, who built my character; to my wife, who inspires me; and to everyone who has cheered for me. To God, who made us all and brought us all together.

Table of Contents

I. Introduction

The cross-cultural education research field has found differences in the beliefs of American students and in Japanese students. These beliefs have been used to justify why a teacher cannot plug in an element of a Japanese classroom into an American classroom and reliably expect success: "Japanese students believe different things about what classroom learning should look like than American students do. If you teach American students in a way that clashes with their beliefs about learning, it's no surprise that the students don't buy in to it!" This approach treats students as having fixed and rigid (unitary) beliefs about learning and about the nature of the subject being learned. Stigler and others often describe these beliefs in terms of a "cultural script".

I will challenge this trend in the cross-cultural education research field with findings in cognitive science showing that student beliefs have the potential to be quite fluid, shifting from context to context. I will argue that either cultural scripts should be re-conceptualized to account for this fluidity, or that the cross-cultural education research field should adopt a more versatile framework with which to understand moment-to-moment variation in student beliefs.

To buttress this argument, I will present recent data I acquired from six months of implementing reformed physics curriculum at Tokyo Gakugei University. This curriculum, which had students work in groups on guided worksheets that had them draw on their own ideas and intuitions, was dramatically different from what students had previously experienced in physics classes and it asked them to treat physics and learning physics in a way that went against their expectations – that physics is learned by absorbing knowledge from the lecturing authority. Cultural scripts, as the cross-cultural education research community uses them, would predict the Japanese students to resist the curriculum because it did not match their beliefs about physics and how it should be learned, and to perhaps only come to change their beliefs after a "grieving process". Contrary to this prediction, students adapted very easily to the new style of learning. I will present student explanations for this ease.

I will show that these explanations for and the observations of student ease are not consistent with the idea of students having a rigid cultural script about learning, but that they are consistent with theoretical frameworks that treat students as having fluid beliefs, such as the resources framework. I will conclude that cross-cultural education researchers should expect student beliefs to be context-dependent.

A. Why Stigler introduced "cultural scripts" and how the notion has been subsequently taken up

People who study cross-cultural education even casually, particularly that involving Japan and China, are familiar with the books <u>The Teaching Gap</u>, <u>The Learning Gap</u>, and also with the TIMSS video studies that the books highlight. James Stigler at

UCLA is an author of both books and director of the TIMSS 1995 and TIMSS 1999 video studies.

In his various works, Stigler gives examples of failed attempts to reform American classrooms to make them look “more Japanese”. For example, in the paper “Teaching is a Cultural Activity”, Stigler and Hiebert provided an anecdote of an American fourth-grade math teacher who was involved in analyzing videos of Japanese classrooms. He was inspired by the teaching practice he observed, and decided to try implementing it in his own classroom. Instead of his usual practice of asking short-answer questions, he began his next lesson by presenting a problem and asking students to spend ten minutes working on a solution. The students reacted by waiting uneasily for the teacher to show them how to solve what, for them, was something that they could not do because they had not yet been taught how to do it. Stigler and Hiebert concluded that “Although the teacher [behaved like the one] in the videotape, the students… played their traditional roles and waited to be shown how to solve the problem. The lesson did not succeed.”(J.W. Stigler and Hiebert 1998)

Stigler has used these examples as motivation for introducing the concept of ***cultural scripts***. Parents, teachers, and students have “*cultural scripts*, generalized knowledge about the event that resides in the heads of participants. These scripts not only guide behavior, they also tell participants what to expect.”(J.W. Stigler and Hiebert 1998) Stigler and Hiebert explained that teaching and learning are cultural activities, similar to family dinner, and both have cultural scripts. Family dinner is so familiar that no one thinks consciously about what features comprise a typical one. Nevertheless, people certainly notice if the dinner doesn’t follow the expected pattern. The idea is that if, at dinner with your family, you’d get a menu, or, worse, a bill at the end, you too might react similarly to how the students in that fourth grade math class responded. The authors argued that “One of the reasons that classrooms run as smoothly as they do is because students and teachers have the same script in their heads; they know what to expect and what roles to play.” (J.W. Stigler and Hiebert 1998) On the other hand, if that script were to not be matched by the teacher, then the classroom would not run so smoothly. In this way, the failed attempts of teachers to implement Japan-looking features can be and has been explained.

The construct of cultural scripts has not ended with Stigler and his studies of K-8th graders(J.W. Stigler and Hiebert 1998; H. Stevenson and Stigler 1992; J. W. Stigler 2002; James W. Stigler and Hiebert 1999; James W. Stigler and Hiebert 1997); it has been applied by other researchers looking at college as well(Isabelle and de Groot 2008; Amit and Fried 2005; Fried and Amit 2003; Holland 2008; Zaman 2006; LeTendre et al. 2001; D. Clarke, Keitel, and Shimizu 2006; D. Clarke 2003; Chappell 2006). Other education researchers and teachers have used the idea of cultural scripts to explain resistance of their college students to reform attempts that go against the student beliefs of how learning should proceed. Chappell, for example, described his college students as undergoing a “grieving process” in adapting to a reformed geography class that utilized Problem-Based Learning. (Chappell 2006)

He wrote that this resistance was evidence that students are bringing in scripts about learning that conflict with the curriculum and that are negotiated as they manage change.

B. The problem with a *unitary* account of cultural scripts

Stigler and others use the concept of "cultural scripts" to describe a stable and rigid "system of beliefs" (Holland 2008) about learning, schooling, and knowledge that is stable across contexts. Note, however, that the definition "generalized knowledge about the event that resides in the heads of participants which guides behavior and tells participants what to expect" does not intrinsically imply that participants can only have *one* script about a given activity. Furthermore, in the field of cognitive science, the idea that a student has a stable and rigid system of expectations/ beliefs has been challenged, and mounting evidence suggests that student beliefs have the potential to actually be quite fluid. In the remainder of this subsection, I present some of these findings that contradict the idea that student beliefs are rigid.

Hutchison and Hammer (Hutchison and Hammer 2009), for example, recently reported findings from a course taught at the University of Maryland called Inquiry into Physics. The students are exclusively pre-service elementary school teachers, and the curriculum and pedagogy is designed to teach the students about the nature of science by having them build and test theories about, for example, how electricity flows in a circuit, through their own experimentation, observations, and argumentation. The authors showed their students to shift between stances about learning in the classroom. Although the students were most comfortable viewing classroom learning as "playing the classroom game", where a teacher asks a question, a student or students respond to it, typically with a single word or a short phrase, and the teacher evaluates whether the response is correct, Hutchison observed the students shift in and out of periods where they would instead propose different explanations and engage in discourse aimed at comparing their relative merits based on consistency with their observations. At these times, students were no longer expecting to play the classroom game; instead they had a stance that it was appropriate to make sense of phenomena.

Notably, students would switch back from time to time. During a unit on buoyancy, the professor (Hutchison) wrote the equation "density = weight / volume" on the board. Students protested that it should be mass instead of weight, and one student specified that they were used to seeing "d=m/v". This suggested that students were treating classroom learning as something where knowledge that is sanctioned by authority is what's most important, which is part of the typical "classroom game".

Researchers have documented other types of fluid shifts as well. Whereas Hutchison saw student beliefs about learning fluctuating from moment to moment, others have documented shifts that lead to a robust state that does not readily shift back. Hammer (David Hammer et al. 2005) gave the example of a student of his (Louis), who could readily replace his view about the nature of physics learning with a co-existing but dormant one. Louis explained in an interview that he began the class thinking that the way to learn physics is just as he did in chemistry class – by memorizing flash cards. When the professor (Hammer) advised him "When you study, try to explain it to a ten-year old," he was able to change his perspective about what it means to learn and study physics. Louis told the interviewer that he had, in fact, had experience working with children, and he had worked as a tutor. As such, he had tried to get his tutees to build off the knowledge that they already have. He was able to draw on those experiences to start doing the same thing in his own approach to physics. Here, like with Hutchison's students, the student beliefs about physics and about learning were not rigid and stable. They were fluid.

C. Cultural scripts could be fluid

I am concerned that Stigler and those who use his instantiation of scripts might see Hutchison's students playing the classroom game and conclude that that is their single (unitary) belief, which comes from their cultural script of schooling in America. Because they are not looking for variability in student reasoning, they would not see that the students are capable of treating the learning process as something where they use their own sense of what's reasonable as criteria for accruing knowledge. I am also concerned that teachers operating under the cultural scripts framework might try teaching as Hutchison did, find students to operate in the "classroom game" stance, and conclude that that is their cultural script and either abort their attempt (as Stigler's anecdotal fourth grade teacher did) or make the students suffer through it, hoping that their beliefs about learning would change by the end of the course (like Chappell). Mostly, I am concerned that teachers using the cultural scripts framework would refrain from even trying to impose this kind of learning on students because such a teaching style violates the cultural script.

In light of data by Hutchison and other researchers showing fluidity of beliefs, however, I argue that scripts could and should be re-conceptualized to account and expect context-dependency. Although there are various ways to reconceptualize cultural scripts, one example might be to say that Louis had *at least two* cultural scripts, and the experiences he called upon determined which one he activated.

D. Data from Tokyo Gakugei University 2011 justifies this reconceptualization

In February of 2011, I embarked on a six-month research project in Japan to study how students would respond to reformed physics curriculum (Open Source Tutorials), developed at the University of Maryland and translated into Japanese by the class professor, Haruko Uematsu, and me.

As part of the project, I interviewed 28 students as they were taking the class. The students consistently described their high school and/or college physics experiences prior to Physics Exercises (the course that utilized Open Source Tutorials) as being dramatically different from the new class. Tadao, for example, explained that the former style was that "The teacher would write on the blackboard and we would memorize it… there were a lot of calculations."

Open Source Tutorials, on the other hand, consists of guided worksheets completed in groups. These worksheets emphasize conceptual understanding and have students build physics knowledge by "refining everyday thinking".

Stigler's conceptualization of cultural scripts as unitary would predict that students would be surprised by Tutorials and that the curriculum would violate their expectations of what physics learning is (namely, rote memorization). The students would either fail to adapt (and would just wait for the answers to the worksheets from the instructor) or would undergo a grieving process in their adjustment (like Chappell's students).

In this dissertation, I will show that although this first prediction is correct, the second is not.

Students were surprised by Tutorials. I asked most of the 28 interviewees "When you entered this class, were you surprised?" All of those students answered "yes". Indeed, the class went against their expectations of what physics learning is.

However, students were not "perplexed" (pg. 182 of (Holland 2008)). Several data streams all show that students adjusted fairly smoothly:

- Video from the first Tutorial of students laughing and smiling as they had animated conversations about the subject content.
- My field notes that I wrote as I walked around the room on that day: "Happy and focused" and "Too easy?"[1]
- After the class, I met with the TA's and with Professor Uematsu, and they agreed that there was surprisingly low resistance.
- Students consistently reported in interviews that they enjoyed the new style of learning and / or that it changed their outlook on physics and physics learning

E. That year was not a fluke (data from 2012)

Although I was no longer able to observe the classroom with my own eyes or interview students, I created a survey that students taking the class in 2012 could complete online. Approximately fifty students (1/3 of the class) completed the survey. The survey contained a wide range of prompts including "Physics Exercises was different from previously taken physics classes (including college and high school)" and "Physics Exercises was different than my expectations before entering the class, and I was surprised." Almost every student said that the both statements either "Applies well" or "more or less applies".

Nevertheless, the curriculum was once again well received. The survey also asked the following prompt, which was based upon a true anecdote:

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[1] I had been not been expecting students to adjust as early as the first day and was surprised. It seemed so effortless to them that I was concerned that the subject content was not intellectually challenging enough.

"Two years ago, a Japanese physics teacher came to observe a class using Tutorials at the University of Maryland. Although he had an interest in that class, he decided that it would be problematic to try implementing that kind of teaching style in his own class in Japan. The reason is that, since Japanese students are not trained to think about their own ideas and make people around them listen to those ideas during class, even if the worksheet would say 'think about this question and please discuss with those around you,' he predicted that it would become nothing more than the students just quietly waiting for the answer from the teacher. In Physics Exercises, do you think up your own ideas and opinions and tell that thinking to the students near you? If so, to what degree was it easy to adapt to that way of learning?"

All but three students said that it was either "Easy to adapt" or "More or less easy to adapt".

If the construct of unitary scripts can't account for what happened at Gakugei, then what can?

F. Students have explanations for their adaptability to the unusual physics class

As part of the interview protocol, students in the 2011 class were asked why they thought it was so easy for them to adapt to this way of doing physics, despite expecting to find something so dramatically different like what they had previously experienced. Nao responded, "Physics Exercises is like elementary school. Even after so many years in middle and high school, we still remember this style." Kaede, who had also experienced this style of learning in elementary school, replied, "Since everyone has taken that kind of class at least once, I think it was easy to adapt to Physics Exercises."

Although it was not common for students to spontaneously mention primary school at this point of the interview, about half of the interviewees gave evidence for a connection between Physics Exercises and primary school at some point of the interview. For example, when I asked Tadao at the beginning of the interview to tell me about his elementary school, he replied that "We would talk together in a group… we got a lot of time to just think on our own [as opposed to listening to the teacher lecture]." When I later asked him to describe Physics Exercises, he said, "Physics Exercises feels like elementary school classes..."

Many of the interviewees (16 of 28), like Tadao, described an emphasis on student ideas in primary school. Most of that subgroup (12 of 16) found those primary school experiences to be similar to Physics Exercises.

Thus, it seems that students could overcome their expectations about physics learning in part because they had other, Tutorials-compatible expectations of what appropriate learning is.

G. Gakugei students were fluid like Louis (David Hammer et al. 2005)

Recent findings in education research and cognitive science have identified triggers that can allow students to shift from one view about the nature of knowledge and learning to another. Hammer's prompt to Louis of "When you study, try to explain it to a ten-year old," was a trigger that had a lasting influence, whereas Phelan's suggestion of "start with what you know" to students working on a rock cycle project (Rosenberg, Hammer, and Phelan 2006) led to what was likely only a temporary shift. In the case of the Gakugei students, seeing the learning environment in Physics Exercises as being similar to previously encountered ones was a sufficiently strong enough trigger that, when combined with other factors (such as the two stabilizers that I discuss in this dissertation), students became fairly stable in their sense-making approach to learning physics.

In addition to this trigger, my dissertation identifies two other factors that likely helped students smoothly take up the new view about the nature of physics and physics learning. Firstly, students (especially the majority who were going on to be primary or secondary school teachers) were able to easily see the Physics Exercises class as being relevant to their future goals. More than the content being learned, they saw the practice of explaining concepts in a common-sense sort of way to their peers as being practice for explaining science concepts to their own future students. Second, students received a consistent message from the educators (Professor Uematsu and the TA's) and the curriculum about how they should approach the material and what kind of reasoning was appropriate. It is likely that these factors acted as stabilizers for these students, to (perhaps unconsciously) reassure them of the validity of their new approach to physics.

Whether a change lasting for ten minutes or a semester, and whether because of triggers, stabilizers, or a combination of the two, the important connection between what was observed in Tokyo and the literature by education researchers in America is that the stances students have towards knowledge and learning are not rigid; rather, students view knowledge and learning in classes fluidly and dependent on context. (Rosenberg, Hammer, and Phelan 2006; David Hammer et al. 2005; Louca et al. 2004; Hutchison and Hammer 2009; Bing and Redish 2009; Edward F. Redish 2004)

H. Summary / Conclusion

The way that Stigler and others use the construct of cultural scripts would lead to a prediction that students have an expectation about physics learning such that, were the classroom to violate that expectation, they would resist the curriculum. Perhaps they would continue to "play their traditional roles"(J.W. Stigler and Hiebert 1998), be "perplexed"(Holland 2008), or maybe even suffer a "grieving process".(Chappell 2006)

In this dissertation, however, I will show that Gakugei students had their expectations violated, but did not resist the new approach, showing the limitation of a unitary view of cultural scripts.

I will argue, therefore, that cultural scripts be reconceptualized. If we conceptualize scripts as something that a student can have in manifold, then we can say that students had both a high school and a primary school script of physics learning. If such a modification is not acceptable to the cross-cultural education research community, then I argue that the cross-cultural education research field should adopt a different framework. In any case, my argument is that **cross-cultural education researchers should (i) expect a student's beliefs to vary across contexts and (ii) not be so quick to label a population of students as having *a* belief.**

II. Methodology

A. Study description

1. Materials used: Open Source Tutorials

Open Source Tutorials at the University of Maryland were developed as part of a project titled Learning How to Learn Science: Physics for Bioscience Majors (Edward F. Redish and Hammer 2009) "to promote students' epistemological development along with their conceptual understanding, as part of our response to research indicating that even the best reform materials don't typically improve students' views about the nature of physics knowledge and learning. " (Scherr and Elby 2007) OSTs aim to promote student discussions about, for example, the degree to which physics should make personal sense, and at the same time stress connecting everyday experiences and subsequent intuitions with formal physics knowledge. (A. Elby 2001; A. Elby et al. 2007; Edward F. Redish and Hammer 2009; Scherr and Elby 2007)

Professor Uematsu translated a selection of these guided worksheets and corresponding Tutorial Homeworks into Japanese, and I back-translated them into English to compare against the original materials. I then sent my comments to Professor Uematsu, and she made revisions. This selection included four tutorials that used hands-on experiments for exploring Newton's 3rd Law, pressure, and electric circuits.

2. Environment examined: the Physics Exercises classroom at Tokyo Gakugei University

In many Japanese universities, "butsuri gakuenshuu", or "Physics Exercises" serves as a time for students to solve problems related to material covered in a corresponding lecture. In other words, it is very similar to a recitation that accompanies physics classes in many American schools. At Tokyo Gakugei University, however, Physics Exercises stands alone as its own course that met for 90 minutes once per week. Students at Gakugei take a lecture-based physics course their first year, and Physics Exercises their first semester of sophomore year. Professor Uematsu had taught Physics Exercises for a few years prior to the Open Source Tutorials implementation in 2011, and had followed a more traditional approach of having students solve canonical physics problems.

When Open Source Tutorials were used in Physics Exercises in 2011, the 90-minute period included a 20-minute commentary on that day's contents that Professor Uematsu gave. Thus, students spent a period of 70 minutes working on each tutorial (in contrast to the 50 minute periods students spend at Maryland). Because the classrooms available were small, the students were divided into two adjacent classrooms that took place concurrently. Thus, Professor Uematsu gave the 20-minute lecture at the beginning of class in one classroom, and at the end of class in the other. In addition, there were on average 6 TA who circulated around the classrooms helping students resolve difficulties they were having understanding the material.

3. The study subjects: Pre-service teachers

Tokyo Gakugei University is one of Japan's most respected universities of education, and fifty percent of the students become teachers. The majority of the students taking Physics Exercises are in a teacher-training course to be elementary, middle, or high school science teachers, and they take the course because it is a necessary class for their teaching license. In that group is a mix of students who are majoring in physics, and there are many students who had taken no physics in high school.

For the most part, students described the physics class that they took their first year at Gakugei as emphasizing memorization and rote problem solving. Students who had taken physics in high school reported similar learning in those classes.

At the beginning of the spring 2011 semester, students in Physics Exercises were allowed to form groups of four with anyone they chose, and those groups were registered with the TA's and held fixed throughout the semester. Most of these students knew each other from previous science classes they had taken together, and many students chose to work with their friends. There were a total of about 150 students, averaging 25 students per TA. The ratio at Maryland is 12-24 students per TA.

B. Data collection overview

The original hypotheses of this research project were that the Gakugei students would enter the Physics Exercises classroom expecting to learn physics as they had done in previous physics classes: by memorizing the teacher's knowledge. We expected them to, generally, not be particularly engaged in the group-based learning that Tutorials ask of them. However, based upon existing literature describing Japanese primary schools as places where students work in groups carefully considering ideas of their own and their classmates, we predicted that we might observe moment-to-moment dramatic shifts in student behavior, if they were cued into remembering how they used to work in groups in primary school. In general, we were interested in seeing how students would behave when asked to learn physics in such a radically different way than they were used to, and we were interested in what their impressions of such a curriculum would be. We wanted to know if they saw similarities between this physics class and the learning they had done in primary school.

To explore these issues, it was necessary to observe students both in their classroom and also in clinical interviews. To observe the moment-to-moment shifting that we were anticipating, video data was the natural choice. I videotaped both classrooms for every tutorial, and I videotaped 28 interviews. To supplement my own impressions of how students were behaving in tutorials with the impressions of the educators, I videotaped all but the first two post-instruction debriefing sessions of the TA's with Professor Uematsu. I considered that one factor that would likely affect how students react to the curriculum would be how the TA's themselves react to it, so I videotaped every pre-instruction training meeting, where the TA's went through the tutorial together.

Every week, students wrote on the tutorial worksheets and, except for the first tutorials, submitted them to their TA's. In addition, they submitted graded homework assignments that they completed outside of class and quizzes and exams done in class. I scanned all of this student work in order to triangulate with the written data of students working in-class.

Primarily, this dissertation utilizes qualitative methods of video analysis for case studies. Although most of the data analyzed is from interviews, analyses of several excerpts from the videotaped classes are also presented in this dissertation. Although such a case-study approach can give the most rich and nuanced of a description, a shortcoming is that one is left wondering how generalizable the findings are. How many students are like the analyzed interviewee? I tried to compensate for this in part by reinforcing qualitative claims with results from quantitative methods used in addition to the video recording. Specifically, I created a survey to be administered the following year (spring 2012) to help show that the case studies were not idiosyncratic, but that certain patterns were rather widespread.

a) *Getting student consent*

Shortly before the first Tutorial, Professor Uematsu introduced me to the students, and I explained that the classrooms would be videotaped in part to help improve the curriculum for future generations of students, and I passed out consent forms for students to sign. I assured the students that their teachers would not know who had or had not signed the forms, and so their grades would be impacted in no way whether they signed or not. The consent form was translated into Japanese with the help of Dr. Maki Kishida, a graduate from the Linguistics Department at the University of Maryland, who grew up speaking Japanese and also speaks English fluently. The speeches that were given to the students at the beginning of the first class explaining the consent forms and the following week inviting students to participate in interviews were drafted by me and revised by Japanese colleagues interested in physics education research. The consent form and two speeches are available in appendix A.1, A.2, and A.3 respectively.[2] The following week, I invited students to sign up for interviews, and 100 of the 140 students did so.

b) *Technical details of video data collection*

I recorded data primarily using two Kodak Zi8 digital video cameras and corresponding Crown Soundgrabber microphones. Students in Physics Exercises were divided into two classrooms, S301 and S302, and both groups engaged with Open Source Tutorials simultaneously. Hence, I set up one camera+microphone in

[2] See also appendix A.4.a

each classroom. For the most part, I placed cameras near the front or the rear of the crowded classrooms, as out of the way of the circulating TA's as possible, and within reach of an electrical outlet to ensure that the camera batteries would not become exhausted. Thus, groups near the front and back of the classroom were targeted most often.

I asked students if it was OK with them that they be recorded, and, provided their consent, I taped the Soundgrabber to one of their desks. A couple of times, it was evident that the camera was interfering with student conversations (as evidenced, for example, by students making strange faces at the camera), and in such an event, I quickly moved the camera to another student group and avoided targeting that first group in subsequent weeks. Particularly towards the end of the semester, an additional criterion for targeting student groups was whether or not I had interviewed the students in a group or not. Especially after an interview that I felt had been particularly interesting, I would often try to record that student interacting with his peers in the class itself.

During interviews, I used one camera plus Soundgrabber, and I recorded secondary audio with a Livescribe Pulse recording pen. This secondary was useful for when I had trouble making out what a student was saying, and as a backup in case of camera failure.

C. Interview protocol creation and application

In interviews, I asked students to solve physics questions, and I asked them more conversational questions (for example, about their opinions and attitudes towards Physics Exercises and physics in general).

The interview protocol originated from prior work done by the engineering education research sub-group in the Physics Education Research Group at the University of Maryland. The original intent of that protocol had been to probe how students make sense of mathematics in the context of physics. Two prompts of that protocol were having the interviewee explain the equation v=v0+at and then solve the following physics problem (selected because it can be solved with various degrees of mathematical sensemaking(Hull et al.; Kuo et al.)):

> *Suppose you are standing with two rocks on the balcony of a fourth floor apartment. You throw one rock down with an initial speed of 2 m/s; you just let go of the other rock, i.e., just let it fall. I would like you to think aloud while figuring out what is the difference in the speed of the two rocks after 5 seconds – is it less than, more than, or equal to 2 m/s? (Acceleration due to gravity is 10m/s2)*

These two prompts were left in the protocol for the Gakugei study to shed light on student epistemology. The overall protocol was modified to include prompts specific to the original research questions of the project, particularly to probe prior experiences that students had in elementary school, and how they are responding to

Open Source Tutorials. The interview protocols were translated into Japanese, again with the help of Dr. Kishida.

1. The initial interview protocol

The following is the original interview protocol script:

> *Here's the consent form. It talks about our research project. Basically, we're interested in how undergraduates think about math that shows up in their engineering and physics classes. This interview is being videotaped, and there's a chance that clips from this interview might be shown at conferences on education. So by signing, you give permission to videotape this interview, and also to use clips at conferences.*
>
> *One of the things we're interested in is what, in general, school in Japan is like. So maybe we can start with elementary school… what was your elementary school like? How about junior high school, what was that like? How about high school? So overall, looking back on it, do you feel like junior high school and high school were kind of the same and elementary school was really different, or that elementary school and junior high school were kind of the same and high school was really different, or that junior high school was kind of in between the two, or that all three were different in different ways? So, the biggest change was going from (*for example, elementary school to junior high school*). Was that kind of a shock for you? Did you miss the* (for example, great conversations that you used to have in elementary school)?
>
> *So looking at elementary school (*and junior high school) *and high school (*and junior high school), *what do you think was the biggest difference? How about the way that the teacher taught the class, did that change at all? One thing I've heard is that teachers of elementary schools in Japan spend a lot of time exploring the ideas of students, whereas in high school the teacher spends most of the time lecturing to the students while students take notes. Did you find that to be true?*
>
> *Did you like the (*elementary school*) style better or the (*high school*) style better? How about now, looking back on it, what do you think is good about (*elementary school*) style and what do you think is good about the (*high school*) style? What do you think is bad about the two styles?*
>
> *So tell me about the physics class that you're taking now. Let me just remind you that your physics instructor, your TA, no one who has any control over your grades will watch the video or know anything that you say in here. And you aren't going to hurt my feelings, no matter what you say, so don't worry about that! So I encourage you to just be completely open. Let's say that there's a new student who is thinking*

about taking your physics class and they want you to tell them what the class is like before they sign up for it – what would you tell them? How does your professor teach the course? What have you found to be a useful way to learn the material? Do you think that the stuff you're learning makes sense, or is it just kind of bizarre stuff that just needs to be memorized? Can you give me an example? Do you feel that intuition is useful in the class?

OK, I'm going to ask you some questions about physics, and I want to tell you that I really don't care whether or not you answer them correctly. I just want to know how you're thinking about these problems. So don't worry about being right or wrong, and please talk aloud while you think. If you have any questions about the right answer, please ask me AFTER the interview and I'll be happy to answer your questions.

*(*Give velocity equation sheet, figure 1) *Here's an equation that you've probably seen before. V0 is the initial velocity, a is the acceleration, t is the time, and v is the velocity. How would you explain this equation to yourself? OK, now here's a different situation. Let's say that there was a 12-yr old, and he came up to you with this equation and asked you to explain the equation. What would you say to the 12-yr old? Now let's say that you're in physics class and you have an exam and on the exam is the question – "explain this equation". What would you write? So now let's pretend like you are in school, but instead of being in college, you are in elementary school and you're working with your friends. One of your friends asks you to explain the equation – what would you say?*

*(*Give Two Rocks Problem sheet, figure 2) *So here's a problem – you are standing on the fourth floor balcony and you have two rocks. You drop one rock and at the same time you throw the second rock straight down so that it leaves your hand with a speed of 2 m/s. After five seconds, how do the two speeds of the rocks compare? Is the second rock still faster than the first rock by 2m/s? Is it faster by less than 2 m/s? Is it faster by more than 2 m/s?*

*(*Give pressure equation sheet, figure 3) *Here's an equation that you perhaps have not seen before. Ptop is the pressure at the top of a lake, rho is the density of water, g is the acceleration due to gravity, h is the depth below the surface of the lake, and P is the pressure. Have you seen this equation before? How would you explain this equation to yourself? So now let's pretend like you are in school, but instead of being in college, you are in elementary school and you're working with your friends. One of your friends asks you to explain the equation – what would you say? OK, now here's a different situation. Let's say that there was a 12-yr old, and he came up to you with this equation and asked you to explain the equation. What would you say to the 12-*

yr old? Now let's say that you're in physics class and you have an exam and on the exam is the question – "explain this equation". What would you write?

*Have you had physics before? (*You didn't take it in high school? Why not?*) Do you think physics is difficult? If you work long enough on a physics problem, can you figure it out? Do you think that anyone can be good at physics if they just work hard enough, or is it something that only certain people can do? How much work do you think you need to do to be successful in the class? Do you work with other people in physics class? Why? If someone in your class were working on homework with another student, would you think that that's OK, or that that's cheating?*

You may have seen this equation in physics class:

$$v = v_0 + at$$

How would you explain this equation to yourself?

Figure 1. The velocity equation sheet

You are standing on the fourth floor balcony and holding two rocks. Let one rock freely fall. Throw another rock downward with a speed of 2 m/s. After 5 seconds, how are the speeds of the two rocks different? Is the second rock still faster than the first by 2 m/s? More than 2 m/s? Less than 2 m/s? (The gravitational acceleration is $10 m/s^2$)

Figure 2. The Two Rocks Problem sheet

You have perhaps not seen this equation before. It is an equation to know the pressure (P) beneath the surface of a sea or lake, etc.

$$P = P_{\text{at top}} + \rho_{water} g h$$

$P_{\text{at top}}$ is the pressure at the surface of the lake, ρ_{water} is the density of water, and h is depth.

How would you explain this equation to yourself?

Figure 3. The pressure equation sheet

2. How the protocol evolved

The interview protocols evolved throughout the course of the semester. I dropped prompts that eventually seemed to not be producing fruitful data (such as "in what manner does the teacher of Physics Exercises teach?"), and I added additional prompts to more fully probe potentially interesting findings. For example, when I saw that students appeared unexpectedly stable in the sense-making approach that they took in answering the various physics prompts (and when working through tutorials), I wanted to get information from them regarding their previous physics classes, and whether they were thinking about Physics Exercises as being a legitimate "physics" class or not. I thus introduced a series of prompts to have them compare Physics Exercises with previous classes, to ask them if they were surprised when they entered Physics Exercises, and if a part of that surprise was to wonder "Is this even *physics?!*" I then asked them what they think "physics" is.

When I asked this last prompt to Maeda, he offered that he has an impression of what physics is that began with his exposure to Physics Exercises. In response to this emergent, fruitful line of inquiry, I introduced prompts into the remaining interviews to evaluate whether or not Physics Exercises had changed the interviewee's epistemology about physics.

One change that occurred as early as the first interviewees was explicit instruction to the interviewees to only speak in Japanese. This was in response to the first interviewees who would occasionally use an English word; as they explained, they were interested in practicing their English. I considered that other students would likely try to use some English to help me understand. For the sake of obtaining data that was as unadulterated as possible, I started and continued to tell students at the beginning of the interview that although I will likely not know many Japanese words, I will correct for that by using my computer to look those words up on the Internet, during the interview. The interviewees agreed to only speak in Japanese for the duration of the hour-long interview.

3. Final interview protocol

This protocol evolved iteratively throughout the course of the semester. Furthermore, during the course of an interview, the protocol at that time was not followed strictly; not all prompts were used, sometimes other prompts were improvised, and the order of prompts was also somewhat variable. "OPTIONAL" refers to prompts that were less urgent and used as time permitted.

1. Explain consent form: the interview will be video recorded and consent will allow it to be shown at conferences, but anyone involved with the student's grades will not see it or know that the student participated in the interview
2. Request that interviewee only speak in Japanese during the interview
3. "I am interested in education in Japan in general. First, what was your elementary school like?"
    1. If needed: "I'm wondering how education prior to college affects a student's attitude towards college physics"
4. "How about middle school? High school?"
5. "In general, from the perspective of a college student, was there a school that stood out the most?"
    1. If so: "So then the biggest change would have been going from (e.g.) elementary school into middle school. Was that a shock?"
6. "If you compare primary school with secondary school, what was the biggest difference?"
    1. If student does not mention teaching: "Did the way of teaching change?"
        1. If student does not say this herself: "I heard that Japanese elementary school teachers ask their students what they are thinking, but in high school, the teacher basically lectures and students just quietly take notes. Was it really like that?"
7. If student identifies different styles of teaching: "Which style did you prefer? Why? From the perspective of a college student, which parts about (e.g.) the elementary school style are good? Which parts are bad? And for the (e.g.) high school style?
8. "What physics classes did you take in high school? Last year at Gakugei? This semester?"
    1. OPTIONAL, if student didn't take physics: "Why didn't you take physics in high school?"
9. Ask student about Physics Exercises, reminding her that her instructors will not see the video, so what she says will not impact her grades. Assure her that since you are not teaching the class but, rather, are researching it, whatever she says will not hurt your feelings.

    1. If needed: “Suppose a student is thinking about taking your physics class, but before signing up wants you to tell him about the class. Is there something you would say?”
    2. If student does not already say something: “Is there something good/ bad about Tutorial?”

10. OPTIONAL: “What is the teacher’s style of teaching? Have you found an effective way to learn the material? Is intuition helpful in class?”
11. “Is what you’re learning now making sense, or is it just something you need to memorize, even if it doesn’t make sense? Can you give an example?”
12. “How does the physics you took before compare with the physics you’re taking now?”
    1. If student does not already say so: “You described Tutorials as (e.g.) students thinking for themselves. Was that similar to previous physics classes you took?”
13. “When you first started this class, were you surprised? What was surprising? Did you think ‘What are we doing? Where are all the equations? This isn’t physics!’ “
    1. If yes: “At that time, what did you think physics is? What do you think now?”
    2. If no, but student used to hate physics: “When you say that you hate physics, what do you think ‘physics’ is? You think that way now? Did you think that way before Tutorials as well?”
14. Tell the student that you are now going to do physics problems, and assure student that it doesn’t matter whether she gives the correct answer or not. You are not interested in correctness, but rather how she is thinking, so she is to talk aloud while working. If she has any questions about the answer to the problems, she is to ask after the interview and you will gladly answer.
15. Give velocity equation handout (figure 1)and explain that a is acceleration, t is time, v0 is initial velocity, and v is velocity. “How would you explain this equation to a friend from class? To a 12-yr old? On a physics exam? To a classmate if you were in elementary school?”
16. Give Two Rocks Problem handout (figure 2)and describe the situation, gesturing how the rocks are released.
    1. “It looks like you solved this problem by (e.g.) substituting values into the equation for each rock, calculating 50 and 52, subtracting, and being left with a difference in speeds of 2 m/s. Is there another way to solve this problem?”
        1. Yes: Which solution do you do more often? Which solution do you prefer? OPTIONAL: Which one would you give a higher score if you were the teacher? If this were on an interview for a job in your research group, which applicant would you hire?

1. If student changed view towards physics: Remind student of what he said was his way of thinking before Tutorials and his way of thinking after Tutorials and ask if 1) explanation of velocity equation, 2) his original problem solution, and 3) his alternative problem solution, is similar to the before way of thinking about physics, the after way of thinking about physics, or neither.
    1. If no solution is "after": Can you solve the problem in an "after" way?
2. No and student changed view towards physics: Remind student of what he said was his way of thinking before Tutorials and his way of thinking after Tutorials and ask if 1) explanation of velocity equation, 2) his problem solution, is similar to the before way of thinking about physics, the after way of thinking about physics, or neither.
    1. If solution is not "after": Can you solve the problem in an "after" way?
        1. No: "One solution that another student gave was to say that the product at is how much the speed of each rock changes. Since the two rocks change their speed the same amount, the difference in the end will be the same as the difference in the beginning. Do you think this solution is close to the before way, the after way, or neither?"
    2. OPTIONAL: "Suppose you are an elementary school teacher and you want to explain to your students why it's still 2 m/s faster. How would you do that?"

17. OPTIONAL: Give pressure equation handout (figure 3) and explain that a is acceleration, t is time, v0 is initial velocity, and v is velocity. "How would you explain this equation to a friend from class? To a 12-yr old? On a physics exam? To a classmate if you were in elementary school?"
18. Explain that while observing students during Physics Exercises, you were surprised at how well students adapted to this new style of physics, although their previous physics experiences were very different. "Why do you think it was so easy to adapt?"
    1. If they talk about how the class is great: "But the same class is not as effective at (my school). Have you had an experience similar to this before?"
        1. If no: "Maybe not another physics class, but maybe in high school, middle school, or elementary school?"
            1. If no: "Have you experienced solving problems in groups before?" If student had previously described Physics Exercises

as such: "Have you experienced students coming up with answers in class themselves before?"

19. "Do you think physics is difficult? Why? Can anyone do physics if they try hard enough, or is physics something that only some people can do?"
20. OPTIONAL: "How hard does one need to try to succeed in physics? Do you do physics homework with other people?"
    1. If no: "Why not? If someone does homework with someone else, is that OK, or is that cheating?"

4. Technical details of interview administration

Along the same vein as asking students to speak only in Japanese, another attempt I made to get data that was as natural as possible was to refrain from looking up words or asking students to repeat or rephrase something for the first 5-10 minutes of the interview. My goal was to try and create an atmosphere where the interviewee would be more likely to use his or her own natural language instead of language modified for easier understanding.

In total, I interviewed 28 students. I chose these students from the list of 100 students via several lotteries at different points in the semester. I interviewed the first few interviewees during spring break, and I chose them by first sending an e-mail to the 100 students asking for students to respond if they would be around during the holiday term and interested in an interview. I explained that, from the students who responded, I would choose a few students randomly. I did something similar for a number of students to be interviewed after the course had ended. For the bulk of the semester, however, the 100 students were arranged in a random order by http://www.random.org/lists/. I then e-mailed these students three at a time to find a time that worked for them in the near future. Once the interview had taken place or the student had been unresponsive, the next few students on the list were invited for an interview.

5. Themes looked for in the interviews that informed the survey

I coded the interviews for the following themes:

- How did the student describe elementary and high school?
- How did the student relate Physics Exercises to other physics courses?
- How did the student explain the velocity equation and solve the Two Rocks Problem?
- Did the student's attitude about what "physics" is change?
- How did the student relate Physics Exercises to elementary school?

I will elaborate on each of these here.

a) How did the student describe elementary and high school?

I coded whether or not the interviewee described elementary school as having group work "freely" (up to and including prompt 5.1), with "light prompting" (prompt 6) or "moderate prompting" (prompt 6.1). Similarly, I coded for when (if ever) the student described elementary school as emphasizing deep thinking and / or ideas coming from the students, when (if ever) the student described high school as focusing on college entrance exams, and when (if ever) the student described high school as being lecture-based.

I coded whether or not the student agreed with prompt 6.1.1 (also called "the rumor" in this dissertation), and if the student did not feel that his own experiences reflected that rumor, if he at least understood the rumor. Yasu, for example, said that although he had heard that rumor as well, his own elementary school had been unusual.

b) How did the student relate Physics Exercises to prior physics courses?

I coded whether or not the student felt that the content in Physics Exercises makes sense (for example, in response to prompt 11). I coded whether or not previous physics classes had been lecture-based and I coded whether or not they had focused on memorization.

c) How did the student explain the velocity equation and solve the Two Rocks Problem?

For each of the audiences of the explanation in prompt 15, I coded whether the student explained the equation as a tool ("the equation is something to use to get v if you know the other things"), in terms of formal math (for example, how the equation is derived from the definition of acceleration or how the units work out), with the "at" term having conceptual significance ("this is how much the speed increases"), or something else.

I coded whether or not the solution to the Two Rocks Problem was entirely "plug and chug" (see the survey in section D.1 below, prompt #12, the first way of solving) for an example, "forms-based" (see the survey in section D.1 below, prompt #12, the second way of solving for an example), or whether it was a conceptual solution that did not involve the equation (for example, "If both rocks started at rest, they would fall in exactly the same way. If there's no gravity but you throw one with 2 m/s, it will always have that 2 m/s speed and the other won't move anywhere. Now, if you combine those two situations, the only thing that's different is that 2 m/s advantage.")[3]

[3] Conceptual solutions such as this use everyday reasoning. Although we can't know solely from personal experience that the acceleration of gravity is independent of speed, for example, it is everyday reasoning that the final amount of something that you have can be found by adding how much you change to what you start with.

I did not strive to be careful about coding *when* the student came to a conceptual solution on the Two Rocks Problem, because this code in general was less important for the claims I became interested in. The velocity equation prompts came to serve me best not as making claims about a student's ability to sense-make, but as a concrete tool to use in describing what the student now thinks "doing physics" is all about (code d). The claims that I do make with the approach that the interviewee actually did take in solving the problem are done via case studies, several of which appear in this dissertation in Chapter 6. In these case studies, I make clear at what stage the interviewee was solving the problem in what manner.

d) Did the student's attitude about what "physics" is change?

I coded for whether or not the student said that his attitude about what physics is changed or not (as a result of prompt 13). I coded for whether or not the student identified the plug and chug solution with her old epistemology about physics and a conceptual solution with her new epistemology (prompt 16). I coded for whether or not the student thought that everyone could do physics.

To get at this theme more directly, I introduced prompt 13 after Yasu for the remaining 20 interviewees and prompt 16 after Maeda for the remaining 14 interviewees.

e) How did the student relate Physics Exercises to elementary school?

When Manami freely mentioned how Physics Exercises feels like elementary school, I introduced prompt 18 to get at this theme more directly with the remaining 23 interviewees.

I coded for whether or not the interviewee at various points of the interview (prior to prompt 18, at prompt 18, 18.1.1, or 18.1.1.1) described the group work that goes on in Physics Exercises as being similar to what the student did in elementary school. I coded also for whether or not the way of using student knowledge in Physics Exercises is similar to what was done in elementary school.

D. Survey creation, validation, and administration

Most of the themes described above (all but c) fed into the survey creation. Through the interviews, I found many students who exhibited certain characteristics: it had been easy for them to adapt to Physics Exercises, the class changed their understanding of what it means to know and learn physics, they had had similar epistemological experiences in primary school, and (on a few spontaneous occasions that I did not directly probe in the interview protocol) they found the curriculum relevant for their own future ambitions. To see how widespread these characteristics were, I designed a survey for the 2012 cohort of students taking Physics Exercises. In this survey I also included prompts to see if students perceived, as I had, that the instructors were teaching in a way consistent with each other and with the curriculum itself.

1. First draft of the survey

The first draft of the survey (which was tested by two students (K and Y, pseudonyms) in Physics Exercises is as follows:

1. By filling out this survey, you swear that you are (write your name below).
2. What is your field of study?
3. What physics classes did you take in high school? (Physics 1, Physics 2, etc.)
4. Physics Exercises is markedly different from other physics classes I've taken: Strongly agree, agree, neutral, disagree, strongly disagree
5. Prior to signing up for Physics Exercises, had you heard anything about Physics Exercises (from upper classmen, for example?)
    1. If yes to the prompt 5: What did you hear?
6. Why did you decide to take this course?
7. Physics Exercises is not the class I was expecting it to be and I was surprised by the class: Strongly agree, agree, neutral, disagree, strongly disagree
8. Many students describe Physics Exercises as being dramatically different from other physics classes that they've taken and they are surprised by the style of the class. Nevertheless, in some classes that use Tutorial, students adapt to the new style of physics class very easily. In other classes that use the same worksheets, students have difficulty adapting. How easy has it been for you to adjust to Tutorial?: Very easy, easy, so-so, difficult, very difficult
9. What are the most important reasons (please list three) that it was easy or not easy for you to adjust?
10. Have you ever experienced something like Physics Exercises before? Perhaps in non-science classes, perhaps in elementary school, middle school, or high school? Please explain.
11. How much do you like Physics Exercises?: Physics Exercises is great!, I'm enjoying Physics Exercises, I don't have an opinion either way, I'm not enjoying Physics Exercises, Physics Exercises is awful
12. Please consider the following problem (the correct answer is already written immediately the problem, and you don't need to derive an answer yourself)
    ＊＊＊
    We have the equation v = v0 + at、 v is velocity, v0 is initial velocity, a is acceleration, t is time. You are standing on the fourth floor balcony, holding two rocks. Let one go naturally. You throw the other one downward with a speed of 2 m/s. After 5 seconds, how are the speeds of the two rocks different? Is the second rock still faster than the first rock by 2 m/s, just like that? Is it faster than 2 m/s? Is it slower than 2 m/s? (Gravitational acceleration is 10 m/s^2)
    ＊＊＊

Please consider two solutions to the problem at the same time.
＊＊＊
One student's answer (way of solving 1)
"First of all, the one you freely drop: being freely dropped means that nothing but gravity is working, so acceleration is a = g, equal to gravitational acceleration. And, this is v = v0 + at、a = g, therefore it becomes v = v0 + gt . And, now v0 was 0, so 0. g is 10 they write, so 10. In other words, this one is, after t seconds, v = 10 t . And, if it's after 5 seconds, 10 times 5, and this one is 50 m/s. This time, the second one, first of all, nothing but gravity is acting, so, a is g. Til here it's the same, but v0 is this time, it says that you will throw, so the initial velocity becomes 2 and, g is made 10, so v = 10t + 2. If you do that, if it's 5 seconds, 10 times 5 plus 2 is 52 m/s. 52 m/s minus 50 m/s ＝2 so, the first one is 2 m/s faster – just like that.
Another student's answer (way of solving 2)
The "at" part of v = v0 + at is the amount of change of the speed. And, for both, the accelerations are the same, so this one's acceleration, and this one's acceleration are both identical. Since the time of accelerating is also identical, at is also identical, so the amount of change to the speeds are the same. In other words, both rocks change their speeds exactly the same, so the difference in speeds doesn't change. If there is a difference in speeds at the beginning, and if both change in the same way, the difference in the end is the same as the difference in the beginning. Therefore, the difference in speeds is still 2m/s, just like that.
Please compare these two ways of solving. Do you prefer one answer more than the other? If so, please explain why. If not, please explain why not.

13. What does it mean to "understand" physics?
14. Some students say that "learning physics" is learning to use equations to solve quantitative problems, while others say that learning physics is learning why things happen the way they do. Other students say other things. To you, what does it mean to learn physics?
15. Did Physics Exercises change your view about what it means to "understand" physics and about what it means to "learn physics"?

    1. If yes to prompt 15: then what were your views before Tutorial?
    2. If yes to prompt 15: then what are your views now?
    3. If yes to prompt 15: This time, please consider problem solution 1:
       ＊＊＊
       We have the equation v = v0 + at 、v is velocity, v0 is initial velocity, a is acceleration, t is time. You are standing on the fourth floor balcony, holding two rocks. Let one go naturally. You throw the other one downward with a speed of 2 m/s. After 5 seconds, how are the speeds of the two rocks different? Is the second rock still faster than the first rock by 2 m/s, just like that? Is it faster than 2 m/s? Is it slower than 2 m/s? (Gravitational acceleration is 10 m/s^2)
       ＊＊＊

"First of all, the one you freely drop: being freely dropped means that nothing but gravity is working, so acceleration is a = g, equal to gravitational acceleration. And, this is v = v0 + at、a = g, therefore it becomes v = v0 + gt . And, now v0 was 0, so 0. g is 10 they write, so 10. In other words, this one is, after t seconds, v = 10 t . And, if it's after 5 seconds, 10 times 5, and this one is 50 m/s. This time, the second one, first of all, nothing but gravity is acting, so a is g. Til here it's the same, but v0 is this time, it says that you will throw, so the initial velocity becomes 2 and, g is made 10, so v = 10t + 2. If you do that, if it's 5 seconds, 10 times 5 plus 2 is 52 m/s. 52 m/s minus 50 m/s =2 so, the first one is 2 m/s faster – just like that.
Is the way of thinking of this approach close to your image before entering Physics Exercises? Or, is it close to your current way of thinking about physics? Or, is it not close to either?

4. If yes to prompt 15: This time, please consider problem solution 2:
＊＊＊
We have the equation v = v0 + at 、v is velocity, v0 is initial velocity, a is acceleration, t is time. You are standing on the fourth floor balcony, holding two rocks. Let one go naturally. You throw the other one downward with a speed of 2 m/s. After 5 seconds, how are the speeds of the two rocks different? Is the second rock still faster than the first rock by 2 m/s, just like that? Is it faster than 2 m/s? Is it slower than 2 m/s? (Gravitational acceleration is 10 m/s^2)
＊＊＊
The "at" part of v = v0 + at is the amount of change of the speed. And, for both, the accelerations are the same, so this one's acceleration, and this one's acceleration are both identical. Since the time of accelerating is also identical, at is also identical, so the amount of change to the speeds are the same. In other words, both rocks change their speeds exactly the same, so the difference in speeds doesn't change. If there is a difference in speeds at the beginning, and if both change in the same way, the difference in the end is the same as the difference in the beginning. Therefore, the difference in speeds is still 2m/s, just like that.
Is the way of thinking of this approach close to your image before entering Physics Exercises? Or, is it close to your current way of thinking about physics? Or, is it not close to either?

16. In elementary school, the teacher regularly asked students to come up with or focus on their own ideas as part of the learning process. (Strongly agree, agree, neutral, disagree, strongly disagree)

    1. If agree or strongly agree to prompt 16: The way that we focused on our own ideas in elementary school is similar to what we are doing in Tutorial: Strongly agree, agree, neutral, disagree, strongly disagree

17. According to a student from last year's Gakugei Physics Exercises class (Aoi), "(In elementary school), rather than 'answer the problem', there were a lot

of questions about how we solved it, and you think yourself how you could solve it, that is different from person to person, so I think that being able to say your own thinking was emphasized" What degree do you agree or disagree with the following statement? (Choose one) "As a general impression, my elementary school was also that kind of feeling" : Strongly agree, agree, neutral, disagree, strongly disagree

18. According to a student from last year's Gakugei Physics Exercises class (Nao), "Unsurprisingly, during the time of elementary school, you chat, and talk, and solve problems all together. Because we have that experience, even though so many years passed in high school and we are taking classes where the teacher is teaching uni-directionally, we were able to quickly adapt to Physics Exercises I think. Because we already experienced this experience around elementary school." What degree do you agree or disagree with the following statement? (Choose one) "I think like Nao." : Strongly agree, agree, neutral, disagree, strongly disagree
19. According to a student from last year's Gakugei Physics Exercises class (Kaede), "In elementary school, it wasn't a style of the teacher always teaching, and it was a class style of students talking amongst themselves, and everyone has come having taken that kind of class about once, so I don't think there are many kids who think "Huh, is this thing a CLASS?" Therefore, I think it was easy to take in." To what degree do you agree or disagree with the following statement? (Choose one) "I think like Kaede" : Strongly agree, agree, neutral, disagree, strongly disagree
20. Physics Exercises will help me in my future profession: Strongly agree, agree, neutral, disagree, strongly disagree
21. What profession are you pursuing?
22. If at all, how will Physics Exercises help with that?
23. Some TA's won't tell you the answer, but some will: Strongly agree, agree, neutral, disagree, strongly disagree
24. Please select the statement that is most accurate (I am very happy with my grade in Physics Exercises, I am happy with my grade in Physics Exercises, I am ambivalent about my grade in Physics Exercises, I am unhappy with my grade in Physics Exercises, I am very unhappy with my grade in Physics Exercises, I do not know my grade in Tutorial)
25. We are tested on what we learn through the worksheets: Strongly agree, agree, neutral, disagree, strongly disagree

2. Modifications to the survey

The survey above was the result of several preliminary modifications. First I showed the dissertation argument and the chief supporting data to my academic advisor. Then I made a rough draft of a survey and identified which questions I envisioned supporting the various claims I was trying to make, which the results from the interview codes described above supported – namely that

1. Students adapted quickly to the new style of learning, suggesting that they do not have a rigid view of what "learning physics" means. The

generalizability of the interview data was tested with what became prompts 4-8 and 11-15.4 in survey draft 1 above.

2. Students found Physics Exercises familiar because of previous similar experiences in primary school (prompts 9,10, and 16-19 in survey draft 1 above).
3. Students saw the course as being useful to their future goals as educators (prompts 9 and 20-22 in survey draft 1 above).
4. Students perceived a fairly consistent pedagogical message. This claim was supported less by my interview data than by my own observations of classrooms and TA meetings before and after class. I wanted to see if students perceived the unity of the educators as I was with prompts 9 and 23-25 in survey draft 1 above.

My advisor, after looking at my survey draft 0, then made suggestions regarding adding some prompts and rearranging the order of some prompts. For example, survey prompt 12 was originally not included in draft 0. It was my advisor's idea to have the two solutions side by side and ask students which one they prefer and why. I at first put that suggested prompt AFTER the two prompts asking students whether the solution is closer to their before or after way of thinking (prompts 15.3 and 15.4), but my advisor pointed out that doing so might bias the data on the prompt he had suggested. In other words, if students said "solution 2 (prompt 15.4) is more like the way of thinking I learned in tutorial", following up with "which solution do you prefer" might be the same as asking "do you like Tutorial?" Thus, that prompt was moved in front of the prompts addressing students' image of what physics entails and whether or not it changed as a result of Tutorial.

The survey asked students to rate how much they agree or disagree with statements made by three interviewees (prompts 17-19) from 2011. These statements reflected themes found throughout the interviews, and I wanted to try to measure how widely shared these views were. I checked these quotes with Professor Uematsu's transcriptions of the videos and modified them as needed. Professor Uematsu also suggested changes to make the Japanese more natural and grammatically correct.

Once these changes had been made, survey draft 1, which is above, was generated.

After experimenting with Survey Monkey to learn how to implement skip logic[4] and invite students to take the survey by e-mail, I sent out a request for student volunteers to take the survey before it was released to the whole class, and five students (K, Y, M, S, and YO – all pseudonyms) from the 2012 class responded. In order to validate and improve the survey, I interviewed these students on their responses to the survey, and modified the survey responsively.[5]

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[4] The path that a student goes on through the survey is determined by previous responses. If he answers "yes" to the first question #1, he then is presented with question #2. If he answers "no", he skips question #2 and goes on to question #3.
[5] See appendix A.4.b for details on administering the survey

3. Survey Draft 1 tested by K and Y

The first draft of the survey (available in appendix A.7) was given to two of the students to complete. The first student interviewed was K.[6]

I noticed several discrepancies between K's survey responses and the richer detail provided by the interview. Looking just at K's survey responses, I would have come to the following story:

- K had not encountered a class like Physics Exercises before, and he was surprised. He was not liking the class and he was not taking it in well: he was finding it difficult to understand what the worksheet questions are asking for and he was sometimes feeling like he isn't proceeding in the direction the Tutorials intend. Furthermore, his group mates were not doing a very good job of understanding the material so well.
- His attitude about physics didn't change. However, since he preferred the second, conceptual, solution to the Two Rocks Problem, it might be that he came in with a sophisticated attitude towards physics, in which case we wouldn't expect a change from Physics Exercises. He wrote, however, that "the way of thinking towards physics thought during high school strongly resists being pushed away" which suggests that he might have been seeing Physics Exercises as emphasizing a different way of thinking than his high school physics had.
- K strongly agreed that his elementary school was about students' own ideas and figuring things out for oneself. However, he did not see that as similar to what is going on in Tutorial.
- He was seeing Physics Exercises as relevant for his future profession as a middle school science teacher because he could get ideas for curriculum from the class.
- He was seeing consistency in the pedagogical message even though his grades weren't so good.

This story, however, leaves out several important details that were found in the interview.

First of all, although K reported that the class was difficult to take in for the reasons he reported, he also explained in the interview that his reasons for disliking the class are the exact same reasons. In retrospect, it would not have been strange if he had interpreted the two questions as being roughly the same in meaning. On the other hand, he described that he did not feel at all uncomfortable using his own ideas and opinions and sharing them with his classmates. Since the intent of prompt 8 was to gauge whether or not students experienced discomfort in adjusting to the new class style, it seemed that the question as is was not immediately capturing that. Specifically, the sequence of questions wasn't distinguishing between how easily K adjusted and whether or not he liked the class. And yet, the fact that the reasons given by K did *not* include things like "I feel uncomfortable

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[6] See appendix A.4.c for technical details

sharing my personal opinions" or "I don't feel like we're really learning anything, because it's all just our own ideas" (which we might expect from a student undergoing a "grieving process" for example(Chappell 2006)), the question might have actually affirmed that K did not resist the new style, despite his writing that he is not taking the class in well. Hence, it became an issue of whether or not to change this question to be more specific (e.g., "How hard was it for you to get used to thinking of your own ideas and sharing them with your classmates?")

I suggested an alternative prompt to Andy and Hideo, and they gave their support for the change. The new prompt (**prompt 8'**) became

> *"A Japanese physics teacher observed a class at UMD similar to Physics Exercises and remarked that he didn't think this style would work in his Japanese classroom. He suspected that students would be unwilling to think up their own opinions and ideas and share them with their classmates. Do you draw upon your own ideas and share them with your classmates in Tutorial? If so, how difficult was it for you to get used to doing that?"*

In addition, the reason why K did not find Physics Exercises similar to elementary school was completely missed by the survey, but readily available in the interview. Merely by asking him to explain his choice, he answered that whereas in elementary school, students would spontaneously voice their own ideas and opinions, in Physics Exercises it is a step-by-step guided process. Given this explanation for the difference, it seems likely that if I had specifically asked "you described Physics Exercises as focusing on students' own ideas. Have you experienced that before?" that he would have likely said, "Yes, in elementary school." It was thus considered to add a prompt asking how much the student agrees or disagrees: "In Physics Exercises, there is an emphasis on our own ideas", and if the student agrees, a subsequent prompt of "Have you experienced this experience of emphasizing your own ideas before?" These prompts would go in before the elementary school prompts and became **prompts 15-1 and 15-1.1**. Although the survey that Y (the second student to take the survey and be interviewed) filled out was identical to what K did, these changes were put into effect for M's survey validation.

a) Y was the second student to test the survey

Looking at Y's responses to Survey draft 1, the following conclusions could be drawn:

- Y had fairly low resistance to Tutorial. He found it easy to take in and liked the class, even though it was surprising and he had not had physics classes like it before.
- He reported that his answer of what physics is did not change as a result of Physics Exercises (he preferred the second solution like K, so he perhaps already had a sophisticated attitude about physics).
- He agreed that elementary school focused on student ideas, (which arguably could help make Physics Exercises more familiar). However, he disagreed

with the idea of Physics Exercises being like those elementary school classes. He also disagreed with Kaede and Nao (prompts 18 and 19).

- He was seeing Physics Exercises as perhaps being relevant to his future profession as high school teacher.
- He was feeling that there is discord across the TA's, but not between the tests and the in-class work.

From his interview, it became clear that Y had had unusual high school physics courses. He had attended a high school specializing in math and science education, and his physics teacher who had taught him both physics 1 and physics 2 had emphasized that learning physics changes the way you see the world. Although it hadn't happened everyday, he reported that he had experienced working in groups on worksheets in those physics classes, and there had been an emphasis on thinking one's own thoughts to reach a deeper understanding about confusing physics concepts. Hence, indeed, he already had had an expert-like attitude towards physics when he had entered Physics Exercises, and he had found Physics Exercises to be similar to his high school classes. His reason for answering on the survey that "Physics Exercises is unlike previous physics classes" is that he did not think to include high school in "previous", only prior college-level classes. This was an easy change to make and it was implemented for draft 3 of the survey.

In addition, he elaborated that the difference he perceived between TA's (how some will and some won't tell you the answer) is at the level of when TA's are checking student solutions (for example, at points of the worksheets where students are told to wait for instructors to come and check their progress thus far). Y explained that his group proceeds smoothly through Tutorials and that they don't actually ask the TA's for answers, but rather for confirmation. There are some TA's who will listen and immediately say "yes, that's right" and others who will say, "Why is that?" and make the students explain their reasoning step by step. It was considered whether or not to change this prompt (prompt 23) to be more specific that by "tell you the answers" it is meant "not as confirmation". However, since the goal of this question is to see whether or not students perceive pedagogical consistency across instructors, it was considered that it might be better to leave it open-ended and up to the student's own interpretation.

At that point, it was decided that this was the way to go after all. It was expected that, even with the wording being open, that most students would disagree, perceiving a vague sense of uniformity across instructors in this regard. It was expected that the students who did agree with the statement would be rather similar to Y; in other words, it was considered to be a fairly safe assumption that the TA's are not just blurting out answers in a traditional manner.

Furthermore, introducing an additional prompt into the survey to get at this seemed like it would only complicate matters. For example, a prompt (as was suggested by my advisor) of "If I ask the TAs to tell me the answer during a tutorial, some of them will" PRIOR to the current prompt 23 could cue students into thinking that prompt 23 was basically repeating itself and wash out any potential discord perceived in pedagogical messages. Similarly, placing it after the prompt 23 would likely have led Y to answer "yes" to this prompt as well, but this time skewing the meaning of the phrase "ask to tell me the answer" to fit the image solidified in his mind with prompt 23.

4. Survey draft 2 (with above revisions inspired by K) tested by M

As a result of the interview with K, I made the changes described above and gave this new survey (survey draft 2) to M for testing.

From M's survey responses alone, the tentative conclusions one might draw are that:

- M found Physics Exercises to be unlike other physics classes and she was surprised when she entered it, but she nevertheless found it easy to adapt. She used to think physics is about memorizing equations and solving problems (the plug and chug solution in prompt 15.3 is an example), but came to be able to understand physics while relating it to daily life.
- The way of focusing on one's own ideas in Physics Exercises, she said, is similar to how a teacher would call on students in class to give their own opinion. Her elementary school had been about the teacher making students come up with their own ideas and present them to the class, and Physics Exercises is like that.
- She said that she wants to be an elementary school science teacher, and that she thinks that Physics Exercises will help because she will be able to make studying fun for her students if she can connect it to daily life.
- She did see pedagogical continuity across instructors, but not so much between assessments and curriculum. However, she was also not satisfied with her grades, and so there could be affect affecting her judgment.
- One thing that remained a mystery was that she disagreed with Nao (prompt 18), but agreed with Kaede (prompt 19).

The interview revealed the reason for this last discrepancy: not only had M experienced something like Physics Exercises before in elementary school, but she had in middle and high school as well. She reported that although it became less common, students continued to be called on by the teacher to give their answers or opinions in class, and they continued to work in groups on solving problems, all throughout high school. Hence, when Nao talks about how middle and high school had uni-directional teaching without students talking and thinking for themselves, she naturally disagreed.

Although not relevant for M's case, it became clear that a student who had experienced a combined elementary and middle school, or for some other reason had had a constructivist middle school would similarly disagree with Nao. For the sake of such students, Nao's prompt was changed from "middle and high school" into just "high school".

Furthermore, M was unable to provide a convincing argument for the inconsistency between assessments and curriculum in Tutorial. Her first response was that although the quizzes are pretty fairly capturing the Physics Exercises content, the midterm exam, which was more heavily weighted, required memorizing some equations, and so if you didn't have some physics knowledge, you couldn't do well. I asked her for a specific example, and as she flipped through her exam, she changed her answer to be that, whereas Tutorials only had simple equations, like F=ma, the exam had a lot of equations, like x = v0t + 1/2 gt^2 and asked about things like "change in speed" and for that reason had been different than Tutorials.

It is possible that she may have said there was inconsistency between the Tutorials and midterms because one seemed so much harder than the other to her. No changes were made to the survey regarding these prompts 24-25; rather, it was noted that there would likely be many students who were simultaneously dissatisfied with their grades and who found the exams to not reflect what is learned in Physics Exercises who similarly might be answering the latter prompt for the same reasons as M.

5. Survey draft 3 (with above revisions inspired by K and Y) tested by S

Whereas survey draft 2 incorporated changes inspired from K's interview alone, survey draft 3 further built on draft 2 by incorporating changes inspired from Y's interview as well. This third draft was given to S for testing.

From S's survey results alone, we might conjecture the following about S:

- Although S had taken lots of physics before, Physics Exercises was different, and he was surprised when he entered the class. Nevertheless, he found it easy to adapt to the class and really enjoyed it. He liked being made to think and he liked working with his friends. Physics Exercises changed his attitude about physics. Whereas he used to think that physics is just "solving" (the plug and chug solution of prompt 15.3 is an example), he came to think that it is close to daily life (the conceptual solution of prompt 15.4 is an example).
- His elementary school did not really emphasize focusing on student ideas, and he did not agree with Aoi, Nao, or Kaede of prompts 17-19.
- He saw the class as relevant to his future profession as a teacher, because it was giving him practice in making students ask "why?"
- He saw pedagogical continuity within the class, both across educators and between educators and curriculum.

From the interview, however, one learns that although elementary school did in fact contain time for students to think on their own, it would be 30 minutes of student work, followed by teachers giving the correct answer. In S's mind, it is different than Physics Exercises, even though students were coming up with their own ideas. Thus, although he agreed that elementary school teachers did have students think up their own ideas, he did not agree that those ideas were emphasized in the classroom. Rather, it was just something students did, and it didn't seem to affect the teacher's trajectory much.

From this result, it was decided to split this question into two, one asking about the teacher making students come up with their own ideas (**prompts 16' and 16.1'**) and another about the teacher actually utilizing student ideas for the learning process (**prompts 16-1 and 16-1.1**).

6. Survey draft 4 (with above revisions inspired by K, Y, M, and S) tested by YO

Draft 3 was modified as a result of the interviews with M and S, and this (survey draft 4) was administered to YO.

From YO's survey results alone, one can make the following tentative conclusions:

- YO had taken physics classes before, and Physics Exercises was different than them and anything else he had previously experienced. Nevertheless, it was easy for him to adapt to the class because the content is what was done in high school, he enjoyed a good group dynamic, and he and his group mates were able to see the manner in which they were supposed to debate from the problem statements. Physics Exercises did not change the way that he thinks about physics. He preferred the plug and chug solution in prompt 15.3 because it is more reliable, although he admitted that he might do the conceptual approach if pressed for time - it's just more risky.
- He disagreed with the statement of teachers in elementary school making students think for the learning process, but he nevertheless did agree with Kaede (who said that the group work and thinking for yourself in elementary school helped make it easier to adapt to Tutorial.)
- He saw Physics Exercises as being relevant to his future as a teacher because "although real life has step-by-step discussing while narrowly focusing on a problem, Physics Exercises will help in discussing about problem solving."
- He reported that there is discrepancy in TA's telling vs. not telling the answers, and he was not feeling like the class assessments measure what is being learned in Tutorial.

The interview, however, revealed quite a bit about YO. First of all, YO's reason for disagreeing with Nao (who talks about elementary school having thinking for yourself and group work, but there being a gap between then and Tutorial) is that he didn't really feel that there was a gap. Although high school was aimed towards entrance exams, there were a few classes that he took in college with a total student population of only 5 or 6, which he also saw as similar to Physics Exercises and hence helpful for adjusting.

Although his elementary school did indeed have times that the teacher made students think up their own answers, the chief objective of the classroom, or so it felt, was to get the knowledge from the teacher and the textbook. He said that he would have agreed with the statement if "for the learning process" had been removed from prompt 16-1, and so the survey was revised to remove this phrase. After asking my advisor, Professor Uematsu, and Professor Nitta for advice, the two prompts used to gauge how constructivist elementary school was (and the corresponding prompts to compare with Tutorial) became:

> 16''. As a general impression, in my elementary school, the teacher would often make students think up their own ideas themselves (Applies well → Does not apply)
>
> 16.1''. If yes to 16'': The thing of students thinking up their own ideas in elementary school is similar to what we are doing in Physics Exercises" (Applies well → Does not apply)
>
> 16-1'. As a general impression, in my elementary school, the teacher was often using ideas that students had thought of themselves" (Applies well → Does not apply)
>
> 16-1.1'. If yes to 16-1': The thing of emphasizing student ideas in elementary school is similar to what we're doing in Physics Exercises." (Applies well → Does not apply)

To probe how much he (and perhaps Y in section 3.a above) really felt a pedagogical disconnect across the instructors, I asked YO if he felt that the teachers were teaching with differing philosophies, or with different goals in mind. He answered that he doesn't feel like there's a difference in philosophy across the instructors. The point to which TA's will confirm student answers and the amount that they probe student answers, however, is different. "The goal, if you will, the vector is the same, but it's like the scalar is different… the orientation, the orientation that they are pointed at is, well, the same, but that, well, depending on the TA, the amount is different." [00:26:57.28] Although no TA's will just directly tell students the answer, there are some TA's who feel "it's enough to just confirm their answers". Since the existing prompt 23 suggested that the instructors were sending mixed pedagogical messages, but the interview clarified that all of the instructors were enforcing the idea that student reasoning is important, we again considered whether to change this prompt. At last, we decided to change the prompt to (**prompt 23'**) "While doing Tutorials in Physics Exercises, if I ask "what is the answer to this part?", some TA's won't tell me but other TA's will."

Finally, regarding the assessments themselves, YO explained that if he were taking physics for the first time and had no prior knowledge about the material, then absolutely the quizzes and exams adequately measure what is being learned in Tutorial. His reason for disagreement was that, especially when grades become an issue, he felt like he was primarily using his previously learned physics to do well on the quizzes and exams. He explained that he also uses that prior knowledge while completing the Tutorial worksheets, and so he isn't really sure what is being learned in Physics Exercises, let alone whether or not it's being assessed on the exams. Since the goal of this survey question (prompt 25) is to see how well the assessments reflect the Tutorial curriculum, it was considered to change this question and it was changed to (**prompt 25'**):

> *"It is not fair that the content covered by exams and quizzes in some classes is different than the content learned during class. I want to ask*

to what degree exams and quizzes in Physics Exercises coincide with Tutorials. To what degree do you agree or disagree with the following statement: 'Even if you properly understand what is written on the Tutorial worksheets, it is not enough to get good grades on exams and quizzes in Physics Exercises.'"

7. Final testing for prompts 23' and 25'

Prompts 23' and 25' were e-mailed to the five survey validators, along with a request for a brief explanation of their choice. All but Y replied. Here, their responses are recorded:

a) K

To prompt 23', K replied, "Does not really apply. TA's basically encourage students to put out answers. Otherwise, there was a time when students' answers were mixed, and TA's first told students the answers, but then made students think about the reason." This was similar to his original selection on prompt 23.

From prompt 25', however, K replied with the opposite of what he had selected for prompt 25: "Applies well. On the last quiz, 'coefficient of friction', which was absolutely not covered, came out." It is possible that this quiz came after he took the first survey. Either way, at the time of taking the most recent survey (i.e., answering prompt 25'), he was clearly seeing a disconnect between the curriculum and the assessments, and this was being captured successfully by the new prompt.

b) M

To prompt 23', M replied, "Does not really apply. None of the TA's ever tell you the answer. However, I do receive hints and assistance in thinking." This was the same as what M had selected for prompt 23.

In response to prompt 25', M answered again consistently with her selection to prompt 25:

> *"More or less applies. Even on the previous quiz, words that I had never heard before came out in the exam problems, and since I hadn't done it in Physics Exercises, I absolutely couldn't do it. However, a friend who is good at physics knew it from the range he had learned in high school, and so he could do it, he said. There are a lot of problems that you can't do if you don't know equations, for example, and I think that there are a lot of people who can't get good grades even though they trying in Tutorial."*

c) S

The responses S gave to prompts 23' and 25' were the same as they had been for 23 and 25: "Does not apply. All TA's will teach hints and ways of thinking, but they will not tell answers." and

> *“Does not apply. If you strongly understand the class contents, it is reflected in exam grades. Or, this is an aside, but the homework worksheets also help class understanding. It’s because it becomes a chance to try out in reality the way of thinking that goes on during class.”*

d) YO

YO was the only one of the five who answered one of these two new prompts in a problematic way. Although his interview was consistent with what he answered for 23’: “Does not apply. Since I have never directly asked a question, I cannot confirm this”, his reply to 25’ required some consideration. He wrote:

> *“More or less applies. It is not known exactly to what degree our understanding is properly shown, but if you would expand an explanation in Physics Exercises, there is a tendency for there to not be enough answer time”*

I interpreted this response to mean, "In Physics Exercises, we think and describe a lot, but on exams, we don't have time to do that, so we have to just pull out memorized information. Therefore, the training we receive during a Tutorial is not sufficient to do well on the exams and quizzes." This interpretation would then imply that the survey question 25’ was getting the information needed: because of the time constraints in the assessments, the approach implicitly supported is different than that supported in the classroom itself. Triangulating that with his interview (discussed in section 6 above), this interpretation is consistent with him saying that on assessments, he just pulls out knowledge that he's learned in prior physics classes.

This interpretation is inconsistent, however, with his response to the interview question "imagine that you are learning physics for the first time in Physics Exercises, without having taken prior physics classes. What would you answer then?" which was that he would reply that the assessments absolutely measure what is learned in the class and that the material is very well represented by the assessments. However, the explanation that he provided for his selection to prompt 25’ gave no clues for how to get out of him in the survey what he had said in the interview – that the assessments *do* adequately measure what is learned.

It is possible that YO changed his mind about the issue in between the interview and answering prompt 25’, or that perhaps he somehow simultaneously was thinking "the assessments measure what is learned in class" and "we don't have time to think on the exams the way that we do during class, so it's not fair."

Although my advisor agreed with this interpretation, an alternative hypothesis that was put forth is that YO was merely complaining about time available on exams being too short. I reject this hypothesis, however, because, in YO’s complaint, he was discussing what goes on during Tutorials as well. It’s possible that he was complaining about exam time being too short, but it seems that that was put in contrast with the ample time available during Tutorials. In other words, he was seeing an unfair disconnect between the assessments and the curriculum.

It was thus concluded that all of the four respondents to prompts 23' and 25' had made selections corresponding to their written explanations, and we concluded that the data available supported the claim that the survey would adequately measure what we intended it to. The survey was then released to the 2012 Physics Exercises students at Gakugei on July 10, 2012.

8. Final draft of the survey

1. By filling out this survey, you swear that you are (write your name below).
2. What is your field of study?
3. What physics classes did you take in high school? (Physics 1, Physics 2, etc.)
4. Physics Exercises is markedly different from other physics classes I've taken: Does not apply, does not really apply, neither way, more or less applies, applies well
5. Prior to signing up for Physics Exercises, had you heard anything about Physics Exercises (from upper classmen, for example?)

    2. If yes to the prompt 5: What did you hear?

6. Why are you taking this course?
7. Physics Exercises is different than I was expecting, and I was surprised: Does not apply, does not really apply, neither way, more or less applies, applies well
8. Two years ago, a Japanese physics teacher came to observe a course using Tutorials at the University of Maryland. Although he had an interest in that class, he decided that it would be trouble to try implementing that way of teaching in his own class in Japan. The reason why is that since Japanese students are not trained to think about one's own ideas during class and to make those nearby listen, even if you write "Think about this question and have a discussion with those around you" on the worksheets, he predicted it would amount to nothing more than students just quietly waiting for the answer from the teacher. During Tutorial, do you think of your own ideas and opinions and tell them to the students around you? If so, to what degree was it easy to adapt to that way of learning? (Choose one from the following) (I don't really think up my own ideas and opinions and tell them to those around me, it was not easy to adapt, it was not really easy to adapt, neither way, it was fairly easy to adapt, it was quite easy to adapt, other (explain in about one sentence)

    1. If "fairly easy" or "quite easy": Why was it so easy to adapt do you think? (Give three reasons, and explain each reason with about one sentence)

9. Have you experienced something like Physics Exercises before Physics Exercises? Please also include and consider experiences other than physics classes (other science classes, classes other than science, elementary school, middle school, high school, for example). If you have such an experience, when and where was it?

10. In Physics Exercises, students focus on their own ideas and opinions: Does not apply, does not really apply, neither way, more or less applies, applies well

    1. Prior to Physics Exercises, have you experienced that focusing on one's own ideas and opinions like what takes place in Physics Exercises? Please also include and consider experiences other than physics classes (other science classes, classes other than science, elementary school, middle school, high school, for example). If you have such an experience, when and where was it?

11. Please consider the following problem (the correct answer is already written immediately the problem, and you don't need to derive an answer yourself)

    ＊＊＊

    We have the equation v = v0 + at、 v is velocity, v0 is initial velocity, a is acceleration, t is time. You are standing on the fourth floor balcony, holding two rocks. Let one go naturally. You throw the other one downward with a speed of 2 m/s. After 5 seconds, how are the speeds of the two rocks different? Is the second rock still faster than the first rock by 2 m/s, just like that? Is it faster than 2 m/s? Is it slower than 2 m/s? (Gravitational acceleration is 10 m/s^2)

    ＊＊＊

    Please consider two solutions to the problem at the same time.

    ＊＊＊

    One student's answer (way of solving 1)

    "First of all, the one you freely drop: being freely dropped means that nothing but gravity is working, so acceleration is a = g, equal to gravitational acceleration. And, this is v = v0 + at、 a = g, therefore it becomes v = v0 + gt . And, now v0 was 0, so 0. g is 10 they write, so 10. In other words, this one is, after t seconds, v = 10 t . And, if it's after 5 seconds, 10 times 5, and this one is 50 m/s. This time, the second one, first of all, nothing but gravity is acting, so, a is g. Til here it's the same, but v0 is this time, it says that you will throw, so the initial velocity becomes 2 and, g is made 10, so v = 10t + 2. If you do that, if it's 5 seconds, 10 times 5 plus 2 is 52 m/s. 52 m/s minus 50 m/s ＝2 so, the first one is 2 m/s faster – just like that.

    Another student's answer (way of solving 2)

    The "at" part of v = v0 + at is the amount of change of the speed. And, for both, the accelerations are the same, so this one's acceleration, and this one's acceleration are both identical. Since the time of accelerating is also identical, at is also identical, so the amount of change to the speeds are the same. In other words, both rocks change their speeds exactly the same, so the difference in speeds doesn't change. If there is a difference in speeds at the beginning, and if both change in the same way, the difference in the end is the same as the difference in the beginning. Therefore, the difference in speeds is still 2m/s, just like that.

Please compare these two ways of solving. do you prefer one answer more than the other? If so, please explain why. If not, please explain why not.

12. To what degree do you like Physics Exercises? (Choose one of the following) (I do not like Physics Exercises, I do not much like Physics Exercises, neither one, I more or less like Physics Exercises, I really like Physics Exercises)
13. What does it mean to "understand" physics?
14. According to some students, "to learn physics" means to learn the ways of using equations so as to solve problems. According to other students, it is to learn why various phenomena occur in the form they do. Other students have other impressions. What is it "to learn physics" to you?
15. Did your opinion regarding what the meaning of "to understand physics" and "to learn physics" is change because of Physics Exercises?

    1. If yes to prompt 15: then what kind of impression did you have?
    2. If yes to prompt 15: What kind of impression do you have now?
    3. If yes to prompt 15: This time, please consider problem solution 1:
       ＊＊＊
       We have the equation v = v0 + at 、v is velocity, v0 is initial velocity, a is acceleration, t is time. You are standing on the fourth floor balcony, holding two rocks. Let one go naturally. You throw the other one downward with a speed of 2 m/s. After 5 seconds, how are the speeds of the two rocks different? Is the second rock still faster than the first rock by 2 m/s, just like that? Is it faster than 2 m/s? Is it slower than 2 m/s? (Gravitational acceleration is 10 m/s^2)
       ＊＊＊
       "First of all, the one you freely drop: being freely dropped means that nothing but gravity is working, so acceleration is a = g, equal to gravitational acceleration. And, this is v = v0 + at、a = g, therefore it becomes v = v0 + gt . And, now v0 was 0, so 0. g is 10 they write, so 10. In other words, this one is, after t seconds, v = 10 t . And, if it's after 5 seconds, 10 times 5, and this one is 50 m/s. This time, the second one, first of all, nothing but gravity is acting, so a is g. Til here it's the same, but v0 is this time, it says that you will throw, so the initial velocity becomes 2 and, g is made 10, so v = 10t + 2. If you do that, if it's 5 seconds, 10 times 5 plus 2 is 52 m/s. 52 m/s minus 50 m/s ＝2 so, the first one is 2 m/s faster – just like that.
       Is the way of thinking of this approach close to your image before entering Physics Exercises? Or, is it close to your current way of thinking about physics? Or, is it not close to either?
    4. If yes to prompt 15: This time, please consider problem solution 2:
       ＊＊＊
       We have the equation v = v0 + at 、v is velocity, v0 is initial velocity, a is acceleration, t is time. You are standing on the fourth floor balcony, holding two rocks. Let one go naturally. You throw the other one downward with a speed of 2 m/s. After 5 seconds, how are the speeds

of the two rocks different? Is the second rock still faster than the first rock by 2 m/s, just like that? Is it faster than 2 m/s? Is it slower than 2 m/s? (Gravitational acceleration is 10 m/s^2)

＊＊＊

The "at" part of v = v0 + at is the amount of change of the speed. And, for both, the accelerations are the same, so this one's acceleration, and this one's acceleration are both identical. Since the time of accelerating is also identical, at is also identical, so the amount of change to the speeds are the same. In other words, both rocks change their speeds exactly the same, so the difference in speeds doesn't change. If there is a difference in speeds at the beginning, and if both change in the same way, the difference in the end is the same as the difference in the beginning. Therefore, the difference in speeds is still 2m/s, just like that. Is the way of thinking of this approach close to your image before entering Physics Exercises? Or, is it close to your current way of thinking about physics? Or, is it not close to either?

16. We are interested in what Japanese education is like. In the following questions, rather than your own opinions, tell us what was going on at your school. Talk about your school itself. To what degree do you agree or disagree with the following statement? "As a general impression, at my elementary school, the teacher often made students think up ideas themselves": Does not apply, does not really apply, neither way, more or less applies, applies well
17. As an overall impression, at my elementary school, the teacher often used the ideas that students thought themselves: Does not apply, does not really apply, neither way, more or less applies, applies well
18. According to a student from last year's Gakugei Physics Exercises class (Aoi), "(In elementary school), rather than 'answer the problem', there were a lot of questions about how we solved it, and you think yourself how you could solve it, that is different from person to person, so I think that being able to say your own thinking was emphasized" What degree do you agree or disagree with the following statement? (Choose one) "As a general impression, my elementary school was also that kind of feeling": Does not apply, does not really apply, neither way, more or less applies, applies well

    1. If "applies well" or "more or less applies" to prompt 16: The thing of students thinking up ideas in elementary school is similar to what we are now doing in Physics Exercises: Does not apply, does not really apply, neither way, more or less applies, applies well
    2. If "applies well" or "more or less applies" to prompt 17: The focus on student ideas in elementary school is similar to what we are doing now in Physics Exercises: Does not apply, does not really apply, neither way, more or less applies, applies well

19. According to a student from last year's Gakugei Physics Exercises class (Nao), "Unsurprisingly, during the time of elementary school, you chat, and talk,

and solve problems all together. Because we have that experience, even though so many years passed in high school and we are taking classes where the teacher is teaching uni-directionally, we were able to quickly adapt to Physics Exercises I think. Because we already experienced this experience around elementary school." What degree do you agree or disagree with the following statement? (Choose one) "I think like Nao." : Strongly agree, agree, neutral, disagree, strongly disagree

20. According to a student from last year's Gakugei Physics Exercises class (Kaede), "In elementary school, it wasn't a style of the teaching always teaching, and it was a class style of students talking amongst themselves, and everyone has come having taken that kind of class about once, so I don't think there are many kids who think "Huh, is this thing a CLASS?" Therefore, I think it was easy to take in." To what degree do you agree or disagree with the following statement? (Choose one) "I think like Kaede" : Strongly agree, agree, neutral, disagree, strongly disagree
21. I think that Physics Exercises is helpful for my future job: Strongly agree, agree, neutral, disagree, strongly disagree
22. Once you graduate, what kind of work do you want to do?
23. If you think it's not helpful, why do you think it won't help? In the case that you think it's helpful, in what way do you think Physics Exercises will help with that?
24. While doing Tutorials in Physics Exercises, if I ask "what is the answer to this part?", some TA's won't tell me but other TA's will: Strongly agree, agree, neutral, disagree, strongly disagree
25. Which of the following applies the best? (I am not satisfied with the grades I am getting now in Physics Exercises, I am not very satisfied with the grades I am getting now in Physics Exercises, neither way, I am rather satisfied with the grades I am getting now in Physics Exercises, I am satisfied with the grades I am getting now in Physics Exercises)
26. It is not fair that the content covered by exams and quizzes in some classes is different than the content learned during class. I want to ask to what degree exams and quizzes in Physics Exercises coincide with Tutorial.
    To what degree do you agree or disagree with the following statement: "Even if you properly understand what is written on the Tutorial worksheets, it is not enough to get good grades on exams and quizzes in Physics Exercises": Strongly agree, agree, neutral, disagree, strongly disagree

9. Survey administration

The survey settings were set such that students could not change their answers after coming to a later part in the survey.[7] I sent an e-mail to the Gakugei students where I told them that the survey is now available for them to fill out and also explained my relation to the class, since they had never met me:

To everyone,

[7] See appendix A.4.d for technical details

Hello. The survey should have been sent by Survey Monkey. If you don't mind, open that mail from Survey Monkey, click on the link, and please fill out the survey.

While filling it out, the thing to remember is that I didn't create Tutorial, and my goal is to generally create better physics classes, so if you fill out "I really hate this new physics class that came from America!" or "I really love it!", in other words, no matter what you write, you won't hurt my feelings, so don't worry about that!

In other words, as much as possible, it's OK to fill it out freely.

If there is not a contact from Survey Monkey, and if you do not receive a link that goes to the survey, please contact me immediately.

From Mike

In addition to the e-mail above, Professor Nitta made an announcement at the beginning of Professor Uematsu's class about the survey, and I sent a reminder e-mail to the students after he had made his announcement. In addition, when a student e-mailed me asking how he was supposed to take the survey, I sent another e-mail to the class to give a more thorough explanation of which e-mail they should open and how they should click the link that follows the sentence "The survey is here:"

E. Analysis of video data

Pretty much without fail, I took about 15 minutes after every interview talking to the camera with no one else in the room so as to record my thoughts about what had just happened. These 15-minute sessions included mistakes that I felt I had made during the interview, suggestions of how to perform better next time, comments on which prompts were useful and which prompts need to be changed, and general summarizing notes of what the student was thinking and of what the student was experiencing in Physics Exercises and had experienced prior to the class.

I then watched the video on InqScribe, while typing notes to myself on what stood out as being interesting, transcribing pieces of important dialog, and making a content log of conversation topics and prompts that took place in the interview.

1. Meetings with Professor Hideo Nitta

Professor Hideo Nitta in the physics department at TGU is an active member in physics education research and he was my research advisor in Japan. We met weekly for an hour or so to discuss how the interviews were going in general, and also for me to show data that seemed particularly interesting or difficult for me to interpret. I recorded his insights and suggestions in the InqScribe files, which I used for transcribing the video data. This also served as reassurance that I was, for the most part, understanding correctly what the interviewees were talking about during the interviews.

2. Meetings and presentations at the University of Maryland

Upon return to America after the completion of the six-month term abroad, I presented my data on numerous occasions to colleagues in physics education and science education at the University of Maryland and received their comments and suggestions on how to proceed. Particularly for data that I deemed as being pivotal to my arguments, I relied heavily on the insights of my colleagues. This included analysis of the interviews with Tadao, Miu, Madoka, and Rina, the data from the first two weeks of class to gauge how easily students were able to respond to the new class style, and also arguments that eventually were discarded, such as searching for context-dependency in student attitude about the nature of physics throughout the interviews.

These groups, which consisted of both graduate students and senior researchers, joined me in engaging in group video analysis (Jordan and Henderson 1995), creating various interpretations of student utterances and actions and then confirming, refining, or refuting them with additional evidence in the video. Our constant goal was to produce analysis that was both detailed and accurate, and to that end we constantly looked for not only confirmatory evidence that would support our developing claims, but conflicting evidence that would challenge those claims as well.

Then, I transcribed the portions of video that had seemed particularly important for telling the story of that student, striving to preserve as much nuance in the student's dialogue as possible as I translated into English.

3. Translating from Japanese to English

So that those who do not read Japanese might be able to appreciate my research findings and the stories told by the Gakugei students, it was necessary to detract from the authenticity of the data that this study procured. In translating from Japanese to English, nuances of the language were inevitably removed, and words that were not originally present were inserted so that the speaker's meaning could be more or less preserved. The speaker's "meaning", however, was interpreted, mostly exclusively by me, but on occasion by native Japanese speakers as well. This loss of fidelity is a necessary and inescapable consequence of translating data.

My transcription methods evolved over time, but consistently utilized InqScribe software. At first, I transcribed most of a given interview very coarsely in English, so as to map out more or less what the interviewee was talking about, and when. For more nuanced or difficult to understand sections, I would transcribe in Japanese from the start. For many of the utterances actually used, either quoted in this manuscript or referred to for arguments being made, I carried out a more involved process. For example, after transcribing in Japanese the following utterance:

jibun de kangaete, ano, jissai ni butsuri no, ano, kōshiki toka ga genjitsu no seikai de chanto "naritatteimasu yo" tteiu kotow o wakaru node kekkō wakariyasuku omoimasu.[8]

I translated more or less every word into English:

You think by yourself, uh, in reality, physics, uh, equations, for example, in the real world, properly "this is applicable, you know" is something I understand, so I'm thinking in a way that is pretty easy to understand.

I then considered that no native English-speaker would possibly say the above utterance, and so made changes until the English seemed reasonable: *You think by yourself, uh, in the real world... I am really understanding that the uh, equations, for example, of physics are applicable in the real world, so I'm thinking in a way that is pretty easy to understand.*

In the appendices are translations of transcripts. Many of these translations were created in the way just described.

a) The Contribution of Dr. Maki Kishida

Every excerpt of interview transcript or written survey responses that appears in this dissertation's body was first translated by me, and then given to Dr. Maki Kishida, a graduate from the Linguistics Department at the University of Maryland, who grew up speaking Japanese and also speaks English fluently. Dr. Kishida then either confirmed that the translation was adequate, or made small corrections. I made the changes suggested, and then put the revised data into the dissertation body. Thus, every quote or written response that you see in the body of the dissertation has been verified by Dr. Kishida.

In the appendices where I have raw data from videos or surveys, I have kept my original translations. Thus, if you are interested in gauging my Japanese ability to determine whether to believe my analysis or not, I encourage you to compare the data presented in the body of the dissertation with that which is in the appendix. None of Dr. Kishida's corrections were major, in the sense that it was not necessary for me to change the claims that I had previously made with my own translations.

[8] This romaji transcription is in the style advised by http://www.omniglot.com/writing/japanese_romaji.htm

III. Literature Review and Theoretical Framework

Cross-cultural education researchers who study student attitudes towards disciplines and courses generally operate under a framework in which students have opinions that are independent of context. For example, if a student writes on a survey that he "likes science", then these researchers generally assume that the student "likes science" not just at the moment when he was filling out the survey, but when he is in the classroom and when he goes home and talks to his parents as well. The main contribution of this dissertation will be to argue that such a framework brings with it certain disadvantages, such as an inability to explain the data that was collected at Gakugei. It will be argued that those in the field of cross-cultural education research, like other education researchers and cognitive scientists, can benefit from a framework in which students are viewed as having context-dependent attitudes towards a course or discipline. In section A of this chapter, I will present a brief review of relevant literature pertaining to theoretical lenses that disagree on the context-dependency of these attitudes. In section B, I will present a brief history of how the cross-cultural education research community has come to care about attitudes towards courses and disciplines, and I will show that the community treats these attitudes as stable or "unitary" (as opposed to fluid or "manifold") entities. Finally, in section C, I will examine the unitary framework cross-cultural education researchers tend to promote from the perspective of the ongoing debate on whether student attitudes are fluid or not, and a manifold framework will be suggested for cross-cultural education research. After showing and analyzing data from Gakugei in Chapters 5-9, I will champion the value of a manifold framework more strongly in the Discussion, Chapter 10.

A. Unitary and manifold frameworks

In this section, I will briefly review relevant literature from theoretical traditions that disagree on how fluid student attitudes are. Education researchers operating under a unitary framework tend to see students as rigid, in terms of their attitudes, conceptual understanding, or both. Those subscribing to a manifold framework, on the other hand, expect to find context-dependency in students' attitudes and beliefs, understanding of conceptual content, or both.

1. Unitary frameworks

A great number of people who address the question "how do students learn?" think of students as having a body of knowledge, in the form of subject content, attitudes, and beliefs, which does of course change as the student develops, but is stable across contexts. This body of knowledge, then, is either in alignment or misaligned with the canonical body of knowledge that the educator wants the students to learn. I now briefly review the notion of misconceptions that is popular in research on conceptual learning as an introduction to unitary frameworks. I will then discuss how this framework treats attitudes and beliefs.

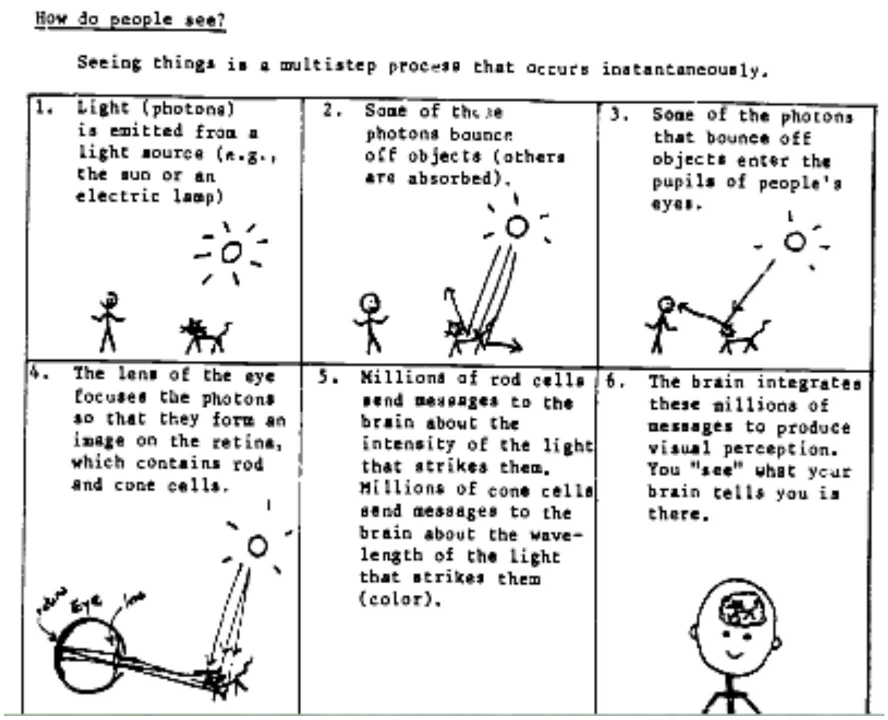
a) Those operating under a unitary framework ask "How to replace the wrong stuff with right stuff?"

Many education researchers who view student attitudes and conceptual understanding as being stable strive to replace misconceptions with conceptions that are canonically correct and misbeliefs (for example about the nature of physics) with expert-like beliefs.

Eaton et al (Eaton, Anderson, and Smith 1984), for example, advocate curriculum designed to replace student misconceptions with the scientific view. The authors ascribe everyday experience and "common sense" as sources of student misconceptions and point out that these misconceptions are particularly robust and resilient. If the curriculum does not explicitly challenge these misconceptions via contrasting the student views with the scientific view and showing why the scientific view is superior, then students will take whatever is learned and incorporate it in some way or another into their misconceived scheme. The article focuses on misconceptions related to sight (for example, that we see "directly"), but the paper also gives examples of student difficulties due to misconceptions in mathematics class as well. Students may learn how to solve a problem in a way that gives correct answers despite being fundamentally incorrect because their approach is grounded in a misconception.

> *"It takes more than a simple statement of the scientific conception to alter the beliefs of students like those described in this paper. Their strong commitment to their misconceptions and the subtle reinforcement prevented most of them from even realizing that an alternative way of understanding existed. The scientific conception must be carefully explained and contrasted with common misconceptions. They must understand how the scientific conception is different from and more adequate than their own, or they will probably not understand it." (377)*

The following is an example of a handout created to be used in the classroom by Eaton et al(Eaton and Others 1986):



The accompanying commentary for the teacher reads: “This handout illustrates the process of seeing. It is intended to reinforce the fact that vision is a result of the brain's detection of light waves that have been reflected off an object. It is also intended to clearly contrast the belief some students may have that we see directly.”(pg. 25)

Like Eaton et al, Posner et al (Posner et al. 1982) and Carey (Carey 1986) similarly advocate getting students to replace the wrong ideas with which they enter the classroom. In contrast to Eaton et al, however, Posner et al and Carey consider the rationality of the students’ prior ideas. For example, whereas Eaton et al writes "One way to help students might be to revise already popular science texts, to make explanations of scientific phenomena so crystal clear and reasonable that a misconception does not stand a chance," Carey would likely contend that because "light" has a different meaning to students, it would take more than this kind of intervention to succeed in helping with student misconceptions.

b) How does one get to the next stage?

Carey identified two kinds of conceptual change – strong restructuring and weak restructuring, which, although influenced by Piaget’s idea of assimilation and accommodation, do not necessarily correspond one-to-one with them[9]. Consider the question “this massive tree came from a little nut about this size. How did that happen? How is it possible to end up with something so much bigger than you started?” For imaginary child Bob, an explanation of “It’s a living thing. Living things grow. That’s just what they do.” is sufficient. When he is asked ten years

[9] Although Carey’s strong restructuring is accommodation, it seems that some forms of weak restructuring could be accommodation, whereas others are assimilation.

later, however, a suitable explanation in his mind now requires some explanation of the mechanism by which the amount of matter of the living organism came to change so dramatically. The change he has undergone regarding what constitutes an acceptable answer is an example of strong restructuring. On the other hand, if prior to reading a book about trees, Bob's answer to the question is "the tree eats dirt" and after reading his answer changes to "photosynthesis", then that would be an example of weak restructuring.

Carey identified an additional paradox with this prevalent framework: "to understand something, one must integrate it with already existing knowledge schemata. The paradox of science education is that its goal is to impart new schemata to replace the student's extant ideas, which differ from the scientific theories being taught." If a student has a misconception or misbelief, how can that be modified to arrive at a correct conception or productive belief? Carey resolved the paradox to a degree by noting, as Eaton *et al.* did, that what is learned in lecture will be incorporated into faulty infrastructure: "Information presented in science lessons is assimilated to existing knowledge structures, which differ in systematic ways from the knowledge structures the curriculum is intended to impart. Part of the paradox is solved." Furthermore, relations between concepts can change: "force, energy… can be identified in both novices and experts… these concepts are identical or can easily be translated from one system to the other." (1126) One can thus understand weak restructuring in terms of assimilating new information into existing (but faulty) knowledge structures and in terms of relations between concepts changing. Strong restructuring, however, remains a puzzle. Citing Kuhn 1982, Carey wrote: "In the strong view, successive conceptual systems differ in three related ways - in the domain of phenomena accounted for, in the nature of explanations deemed acceptable, and even in the individual concepts in the center of each system. These three types of differences sometimes result in one theory's terms not even being translatable into the terms of the other." How such changes as the paradigm shift from Aristotle to Galileo, for example, can occur is left unanswered.

Posner *et al.* (Posner et al. 1982) offered a similar account of conceptual change, and they argued that student attitude towards learning plays an important role in the process. Whereas Piaget had described assimilation and accommodation as occurring hand-in-hand, Posner *et al.* discussed these concepts as either one or the other occurring at any given time. "Accommodation is best thought of as a gradual adjustment in one's conception, each new adjustment laying the groundwork for further adjustments but where the end result is a substantial reorganization or change in one's central concepts."(223) They later defined accommodation as "fundamental conceptual change". The authors provided a list of criteria (pg. 214) necessary for accommodation to occur and central concepts to be accepted. For example, the new concept should be perceived as usable in the future as well as at the task at hand. The new concept must be "intelligible", which, as elaborated on pg. 216, seems to be a determiner for whether or not the new concept can fit into the existing central concepts.

> *"A conceptual change will be rational to the extent that students have at their disposal the requisite standards of judgment necessary for the change. If a change to special relativity requires a commitment to the parsimony and symmetry of physical theories (as it did of Einstein), then students without these commitments will have no rational basis for such a change. Faced with such a situation students, if they are to accept the theory, will be forced to do so on non-rational bases, for example, because the book or the instructors says it is 'true'"*

The paper gives an example of a student, CP, who, rather than a commitment to the parsimony and symmetry of physical theories, had a commitment to absolute time. As a result, she applied the new material into a pre-existing framework, keeping the idea of absolute time intact: "Because CP's commitment to absolute time is so strong, accommodation is a less attractive option than assimilation, and as a result she needs to be able to make her belief in absolute time and her understanding of special relativity consistent."(219)

The authors wrote that student dissatisfaction with existing central concepts is necessary for accommodation to occur, and that such opportunities present themselves when an *anomaly* (an event where one can't assimilate something like he thought he'd be able to) takes place. Educators should encourage students to care when they are faced with an anomaly, but at the same time recognize that because accommodation is difficult, there is a danger of students just concluding that physics is not related to the real world.

c) Summary: the "standard model" of conceptual change

The literature described thus far in this section is characteristic of what diSessa and Sherin (A. A. diSessa and Sherin 1998) referred to as the "standard model" of conceptual change for how deeper, structural learning takes place (what Carey called "strong restructuring"). diSessa and Sherin summarized that "conceptual change is very often understood as involving changes in 'the very concepts' at the 'core' of a conceptual system, the very 'terms' in which the world is understood. When this foundation of terms changes, everyone seems to agree that this is difficult, and we call it conceptual change." They pointed out that even in Carey's later work (Carey and Spelke (1994)), there remains a focus on core concepts and conceptual change.

The impact of this standard model persists into the present. For example, something very similar to Posner *et al.*'s strategy of getting students to find dissatisfaction with their existing central concepts and *then* providing them with canonically correct central concepts that can explain the anomaly can be seen in Tutorials in Introductory Physics, developed by the Physics Education Group at the University of Seattle, Washington (McDermott and Shaffer 1998). The tutorials are used at many institutions and follow a pattern of *Elicit, Confront, Resolve* to help students develop conceptual understanding.

Although this standard model attends specifically to conceptual change, the change in the Gakugei students that I write about in this dissertation was not a conceptual one, but rather a change in view towards the nature of physics and physics learning. However, there are theories parallel to the standard model in how a student can go from a misbelief to a productive belief. For example, just as an education researcher operating under a unitary framework might classify a student as having a stable misconception that we see directly, others might identify her as having a stable attitude that physics is fun, or a stable belief that the best way to learn physics is by memorizing everything the teacher says.

Within the realm of student attitudes, viewpoints, and beliefs, education researchers are often most interested by ones that are *epistemological*[10] in nature. Because of that interest and also because the data I present deals with epistemological change, the bulk of the literature review I present will specifically discuss epistemological beliefs. In the next two sections, I will discuss two conceptualizations of epistemology, both of which are unitary like the standard model.

d) One class of unitary framework has epistemology developing in uni-dimensional stages

The idea that epistemology develops in uni-dimensional developmental stages was advanced by the work of Perry (Perry 1970) which in turn influenced many other researchers (King and Kitchener 2004; King and Kitchener 1994; Belenky et al. 1986). Perry developed and administered a survey to 313 first-year college students to ask questions like "The best thing about science courses is that most problems have only one right answer". From the student results, he invited 55 students to participate in interviews and 31 accepted. He began his interviews with the question "Would you like to say what has stood out for you during the year?" (pg. 7) When Perry conducted his research, the popular perspective had been that people prefer different ways of thinking (for example, "dualistic, right-wrong thinking") as a result of personality differences and this was the premise that began Perry's study. From the interview transcripts, however, Perry concluded that there was a

> *"coherent development in the forms in which they functioned intellectually, in the forms in which they experienced values, and in the forms in which they construed their world... tendencies toward dualistic thinking and tendencies toward contingent thinking now appeared less as the personal styles we had originally conceived them to be and more saliently as characteristics of stages in the developmental process itself." (pg. 8)*

In Perry's model, epistemological change comes about through cognitive challenges in academia, employment, or elsewhere. Like Piaget's theory, learners respond to

[10] In this dissertation, I use the word "epistemology" to mean one's views about the nature of knowledge and knowing (Hofer and Pintrich (1997) pg. 119)

their environment either by assimilation – taking new experiences into their existing cognitive frameworks, or by accommodation – changing the framework. There are 9 positions within the scheme, but they are commonly lumped together into four categories:

- *Dualism* (positions 1 and 2): Something is either correct or incorrect. Truth is held by authority, which gives it to the learner. In position 2, "The student perceives of diversity of opinion, and uncertainty, and accounts for them as unwarranted confusion in poorly qualified Authorities or as mere exercises set by Authority 'so we can learn to find The Answer for ourselves.'" (pg. 9)
- *Multiplicity* (positions 3 and 4): In position 3, although truth can be found, it is not necessarily the case that an authoritative figure knows it. In position 4, there are some areas where there is no absolute answer and all views are equally valid.
- *Relativism* (positions 5 and 6). A major shift happens in position 5 because the individual comes to perceive himself as a creator of meaning. By position 6, people come to see knowledge as context-dependent and realize a need to choose one's own beliefs.
- *Commitment within relativism* (positions 7-9): In these positions, people forge commitments to values, careers, relationships, and personal identity. These stages differ from previous stages in that they are less structural and more qualitative. In stage 7, the student "makes an initial Commitment in some area" and in stage 9, "The student experiences the affirmation of identity among multiple responsibilities and realizes Commitment as an ongoing, unfolding activity through which he expresses his life style."(pg. 10)

In a study designed to validate his scheme, Perry selected 109 first-year students. Of those, 24 were women, but only two of them were included in the study results. Nevertheless, Perry claimed that his findings for men were consistent with what he saw in the women as well. This was a point of criticism in the late 1970s and provided motivation for Belenky et al. to launch a study on "women's ways of knowing" (Belenky et al. 1986).

> *"While a few women were included in Perry's original study as subjects, only the interviews with men were used in illustrating and validating his scheme on intellectual and ethical development. Later, when Perry assessed the women's development with the aid of his map, the women were found to conform with the patterns that had been observed in the male data. While this strategy enabled the researchers to see what women might have in common with men, it was poorly designed to uncover those themes that might be more prominent among women. Our work focuses on what else women might have to say about the development of their minds and on alternative routes that are sketchy or missing in Perry's version." (pg. 9)*

The researchers interviewed 135 women, with a single interview lasting from 2 to 5 hours, and began the interview in an open-ended manner similar to Perry's: "What stands out for you in your life over the last few years?"(pg. 11) Interviewees were also asked prompts related to "self-image, relationships of importance, education and learning, real-life decision-making and moral dilemmas, accounts of personal changes and growth, perceived catalysts for change and impediments to growth, and visions of the future." (pg. 11)

The authors initially attempted to analyze their interview data with Perry's scheme, but found that it fit poorly.

> *"There were digressions of thought ("Do you want me to talk about what society says or what I think?"), twists and turns in perspectives, themes (for instance, the importance of firsthand experience and of gut reaction), and elaborations of points of view that we simply had not anticipated." (pg. 14)*

They thus developed a new scheme of five epistemological perspectives, which, unlike Perry's, are not stages where "each position is an advance over the last"(Belenky et al. pg. 14), but are nevertheless argued to be connected to individualized "developmental sequences and trajectories". (pg. 15)

- *Silence*: Person listens passively to external authority
- *Received knowledge*: Similar to Perry's *dualism*, ideas are either true or false. With Perry's male subjects, however, when the interviewee would choose the "right" answer, he would be viewing himself in alignment with authority. Women in Belenky et al.'s study, on the other hand, did not show this identity with authority.
- *Subjective knowledge*: Similar to Perry's *multiplicity,* knowledge is still true or false, but truth can now come from within the self. Whereas Perry's men talked confrontationally about having a "right" to one's own opinion or not giving in to authority, women "remained concerned about not hurting the feelings of their opponents by openly expressing dissent." (pg. 84)
- *Separate knowing*: This perspective manifests itself in critical thinking; it is impersonal and detached. "While subjectivists assume everyone is right, separate knowers assume that everyone-including themselves-may be wrong" (Belenky et al., 1986, p. 104).
- *Connected knowing*: Here, the knowing is personal and empathetic in nature. Understanding is valued over judgment. "Connected knowers develop procedures for gaining access to other people's knowledge." (pg. 113)
- *Constructed knowledge*: Belenky et al. saw this perspective as indicating post-formal operational thought. Here, the individual is a constructor of the knowledge. Truth is dependent upon one's frame of reference, and that frame of reference itself is constructed. One of the interviewees, Erica, was classified as being in this perspective when she said "We can assume that something exists out there – but something is thinking that something exists. Our consciousness is part of the world. We are creating the world at the same time we think about it." (pg. 132)

King & Kitchener (King and Kitchener 2004) emphasized that their reflective judgment model (RJM) diverges from Piaget in that they do not think of students being *in* a given developmental stage at any one time. Rather, they subscribe to the complex stage model of Rest 1979, which explains why someone who typically uses Stage 4 assumptions can also make statements that seem more like Stage 3 and Stage 5 assumptions. King and Kitchener cited Wood 1997 for experimental data validating this idea. From 1,995 student scores across four problems, Wood constructed a "percent stage utilization score" which indicated how much time the student's behavior was consistent with each stage. King & Kitchener 2004 quotes earlier work to recount how, "Based on these patterns, King, Kitchener, and Wood (1994) suggested that development in reflective thinking be characterized as

> *'… waves across a mixture of stages, where the peak of a wave is the most commonly used set of assumptions. While there is still an observable pattern to the movement between stages, this developmental movement is better described as the changing shape of the wave rather than as a pattern of uniform steps interspersed with plateaus.' (p. 140)"*

Subtly but notably, although King and Kitchener did recognize that students have different attitudes in different contexts, this is the result of contextual support and practice. Student attitude was treated like a wave function that does not change across contexts, even though the attitude that comes out of that wave function is less predictable than, for example, Piaget would theorize.

While chapter 3 of King and Kitchener 1994 describes these seven stages that children progress through in detail, the stages are also summarized in King & Kitchener 2004. With disclaimers about loss of information, the article summarizes the stages by grouping them into three levels.

- *Prereflective thinking level (stages 1-3)*: here, "knowledge is assumed to be certain, and accordingly, that single correct answers exist for all questions and may be known with absolute certainty, usually from authority figures." Evidence is not used in reaching a conclusion; rather, one just relies on one's own bias or assertion of beliefs.
- *Quasi-reflective thinking level (stages 4-5)*: one recognizes that "uncertainty is a part of the knowing process" and that knowledge is a constructed abstraction. Learners here see that beliefs are not just to be accepted from others, but rather that there can be different beliefs that are equally valid. "Those using quasi-reflective assumptions are aware that different approaches or perspectives on controversial issues rely on different types of evidence and different rules of evidence, and that factors like these contribute to different ways of framing issues." In these stages, evidence is seen as important in the knowing process. It is in these stages that most college students spend most of their time.
- *Reflective thinking level (stages 6-7)*: this is "indicative of the kind of reasoning many colleges aspire to teach". Although a link between evidence and conclusions begins to develop in stages 4 and 5, these final stages are characterized by evidence being used explicitly and consistently to support

conclusions. “Because new data or new perspectives may emerge as knowledge is constructed and reconstructed, individuals using assumptions of reflective thinking remain open to reevaluating their conclusions and knowledge claims.” People in these final stages continue to recognize knowledge as constructed, but they also see it appropriate to scrutinize, judge, and synthesize the constructed knowledge.

In the Reflective Judgment Model, the role of evidence in making conclusions evolves as the student’s epistemology passes through developmental stages. Kuhn (Kuhn 1989) similarly looked at how the use of evidence and theory evolves in a stage-like way.

Kuhn had children look at the behavior of balls in a computer program as different variables were changed. While scientists would conclude that all the dark balls being in one pile serves as evidence that color matters, Kuhn argued that students weren't able to just refer to the evidence; rather, they had to bring in a personal theory. She argued that both children and scientists make models to reflect nature; however, the tools they use to make those theories differ, and at the heart of it is an ability to reason about whether evidence supports one theory over another. To be able to keep evidence and theory separate and apply one to the other, it is necessary to treat ideas as objects, or to be metacognitively developed. "The scientist (a) is able to consciously articulate a theory that he or she accepts, (b) knows what evidence does and could support it and what evidence does or would contradict it, and (c) is able to justify why the coordination of available theories and evidence has led him or her to accept that theory and reject others." A person who is metacognitively developed can tell you why he believes something, be it because of data or theory. But metacognition is something that can be developed only through strong restructuring.

In this past subsection (e), I have reviewed some literature from education researchers and cognitive scientists who theorize student epistemology as developing in stages. Perry classified his interviewees as being in one stage at a given time, and theorized that all people follow the same trajectory of cognitive development. Belenky *et al.* argued that their interviewees, who comprised a more diverse population than Perry’s undergraduate students, had variability in the order in which they traversed their stages. King and Kitchener showed that a person is not always in a given stage, but sometimes behaves in a lower or higher stage. What is shared by all these theories, however, is the idea of a linear trajectory, (whether in the form of a point or of a wave), for example, from dualism to relativism, or from not having metacognition to having metacognition. In all cases, context-dependency is not at the foreground of the discussion.

The idea that epistemology develops uni-dimensionally, however, has been argued against (e.g., (Schommer 1990), Hofer and Pintrich (1997)) and a model whereby development proceeds along multiple dimensions has instead been proposed.

e) Another class treats epistemological development as being across a multi-dimensional span of "beliefs"

Hofer & Pintrich 1997 provides a review of the experimental methods, results, and conclusions of stage theorists like Perry, Belenky *et al*., Magolda, King and Kitchener; as well as that of Kuhn and Schommer, and identifies issues in the research that has been done on epistemology thus far. The authors pointed out, for example, that there is disagreement about whether epistemology is "a cognitive developmental structure, a set of beliefs, attitudes, or assumptions that affect cognitive processes, or a cognitive process itself." (pg. 111) They also pointed out that there is disagreement about whether beliefs about "learning, intelligence, and teaching should be considered as central components of epistemological beliefs."(pg. 116) Although these beliefs do not necessarily fit together into stages, they are nonetheless unitary in that students are assumed to have rigid and set beliefs at a given time. The models of the researchers described by Hofer & Pintrich are intended to apply all the way from early childhood through adulthood.

They put forth the idea of thinking of the construct of epistemology as *personal theories*, in parallel to conceptual change literature, like Carey 1985, and argue that such a notion is "a good compromise between the overly general stage models that do not allow for within-stage variation in the structure of beliefs (i.e., the problem of horizontal decalage) and models that suggest that epistemological beliefs and thinking can be orthogonal dimensions and do not necessarily have to cohere into some more comprehensive structure."(pg. 117)

Regarding which areas to count as pertaining to epistemology, from their summaries of previous researchers on epistemology, they removed the aspects that were not shared across models (like Schommer's *fixed ability*), as well as those that dealt explicitly with educational experience or learning rather than knowing (like *role of the instructor* in Magolda's framework and *quick learning* in Schommer's model) and grouped the remaining categories into two areas, beliefs about the nature of knowledge, and beliefs about the nature or process of knowing. They further proposed two dimensions for each of these areas:

- <u>Beliefs about the nature of knowledge</u>
    - *Certainty of knowledge*: ranges from thinking that there exists absolute truth to the more expert view that knowledge is tentative and evolving
    - *Simplicity of knowledge*: ranges from the nature of knowledge being an accumulation of facts to the more expert view of knowledge as highly interrelated concepts
- <u>Beliefs about the nature or process of knowing</u>
    - *Source of knowledge*: Is knowledge from external authority who then transmits it to the learner? Does the individual have the ability to construct knowledge in interactions with others?
    - *justification for knowing*: To what degree does the person evaluate evidence and justify their conclusions? There is a progression from "dualistic beliefs

to the multiplistic acceptance of opinions to reasoned justification for beliefs."(pg. 120)

The beliefs that were removed that deal with learning, teaching, and intelligence "may be related to the core dimensions but are peripheral to an individual's theory". They posited their model as hypothetical and in need of being tested empirically.

(1) These researchers learn about "beliefs" by directly querying their research subjects

Songer and Linn (Songer and Linn 1991), Schommer (Schommer 1990), and others studied epistemology by asking research subjects directly about their beliefs. If a student replies on a survey that "it is better to memorize facts than try to understand complicated material", then it is assumed that that is what the student believes, and it is assumed that that belief is fairly consistent in the student's thinking.

The subjects of the Songer and Linn 1991 study consisted of 153 middle school students who were participating in the Computer as Lab Partner curriculum. Students were given 21 short-answer and true-false questions in a survey form about the nature of science and scientific knowledge, the role or work of scientists, and what it means to learn science, both within and outside of the classroom. (pg. 769) Many items yielded answers that didn't vary across the students, and other items produced answers that were not relevant to science beliefs. Eventually, nine such items were used to determine student epistemology, and five of them are provided as examples (numbered here to refer to later):

1) When understanding new ideas, memorizing facts is better than trying to understand complicated material.
2) Learning science for me is most like…
3) The science I learn in school has little or nothing in common with my life outside of school
4) Describe something you learned in a science class which you could use to explain events outside of school.
5) Describe something you learned in a science class that you will never use to explain events outside of school.

The students who answered at least 8 of the 9 questions "productively" were classified as the group with *dynamic beliefs* and they comprised 15% of the total. These students indicated that they "viewed science as understandable, interpretive, and integrated with many activities in the world around them."(pg. 769) The 21% of students who, for the majority of the 9 questions, answered unproductively, were classified as having *static* beliefs. These students "largely viewed science knowledge as static, memorization intensive, and divorced from their everyday lives."(pg. 769) The majority of students who had "some dynamic beliefs, some static beliefs, and some uninterpretable beliefs" were classified as *mixed*. (pg. 769) Some example responses that correspond to dynamic beliefs are "No, facts change" for question 1, and "There isn't one. Everything you learn is science is based on true life" for question 5. Examples of "static" responses are "Yes, when I was in 7th grade and we had an exam coming up, I would memorize facts and I would get a good grade on the test" for question 1 and "Memorizing words and facts. That is how I learn science, that is how I learn it best" for question 2. Beginning on pg. 772, the authors explain that the fact that the majority of students were in the mixed group reflects that the researchers' "criteria for static and dynamic views of science were relatively strict." They reference a figure that has five additional questions that were given to students:

6) Scientists can look at the same experiment and reach different conclusions.
7) Scientists expect one principle to explain many scientific events.
8) Scientists disagree about explanations for scientific events.
9) To verify their findings, scientists compare their results to those of others.
10) The science principles in the textbooks will always be true.

The authors described that students were coded as *dynamic* if they saw scientific knowledge as being controversial, with different scientists comparing notes and drawing different conclusions even from the same data. These students recognize that scientists use evidence to help resolve such controversies, and that it's better to understand ideas than to memorize facts, because science principles in textbooks might not be correct. (pg. 772) Students with static beliefs, on the other hand, expect scientific ideas in textbooks to be true and hence think the best way to learn science is to memorize facts. The role of scientists then is not to debate alternative perspectives or find underlying principles between various phenomena, but rather to add to the store of knowledge. These students "do not expect principles to explain a broad array of events… deny the integrative function of scientific knowledge acquisition… [and] cannot differentiate between established scientific ideas and current scientific controversies." (pg. 772)

Songer and Linn asked students direct epistemology-based questions and interpreted the results in terms of broad categories even though, as Hammer and Elby argued (D. M. Hammer and Elby 2002), the students gave responses and patterns of responses that did not fit neatly into those categories.

(2) Epistemological beliefs specific to physics

Specific to the discipline of physics, Hammer's dissertation (Hammer 1991) pioneered a discussion of how individual epistemological beliefs play a role in learning physics (D. M. Hammer 1994). He argued that, if the goal were to get students to genuinely learn physics, then it would be worth cutting out physics content from the curriculum so as to have time to explicitly address student beliefs in instruction. If a student believed that physics is a coherent body of knowledge instead of a collection of only loosely related pieces, she would be more inclined to make predictions, for example. Hammer further pointed out a study that showed that students who viewed physics as being coherent got better grades in a physics course. (pg. 21) He argued that students might have knowledge and abilities they do not use because of what they believe about physics. Hammer ascribed beliefs along certain dimensions, and he claimed those beliefs to be fairly consistent within the context of the physics course that he looked at.

To draw his conclusions, Hammer interviewed six students in their first semester of college physics for a total of about ten hours each. In explaining his methodological choice, Hammer argued that case studies can provide greater depth than surveys, and that "remarks made spontaneously and unselfconsciously [were] most useful and credible, because they were most likely to indicate matters the subjects themselves considered relevant."

Like Songer and Linn, Hammer used explicit epistemological statements of students as evidence for their epistemology. However, he also attended to "tacit" epistemologies, looking at the epistemology in action, by examining how students approached physics problems he gave them in the interview.

Hammer presented a map of the spectrum that spans student epistemological beliefs (beliefs about knowledge and learning). Student epistemology was classified along the dimensions of *independence* or beliefs about learning physics (is learning physics about one's own independent understanding or about getting information from authority?), *coherence* or beliefs about the structure of physics knowledge (is physics knowledge a coherent system, or is it a collection of isolated pieces?), and *concepts* or beliefs about the content of physics knowledge (is physics a body of equations and formulas, or concepts that are made manifest in the form of formulas?)

Hammer (D. M. Hammer 1994) described how, setting out on the research project, it was hypothesized that student epistemological beliefs could be described with three axes:

> *"1) beliefs about the structure of physics knowledge, as a collection of isolated pieces or as a single coherent system;*
>
> *2) beliefs about the content of physics knowledge, as formulas or as concepts that underlie the formulas;*
>
> *3) beliefs about learning physics, whether it means receiving information or involves an active process of reconstructing one's understanding."*

The results of the research, however, showed that this framework was not adequate. For example, many students think of physics as conceptual and coherent because authority has told them that physics is so. They don't, however, think that it's their own responsibility for having conceptual/ coherent understanding. This was termed "weak coherence/ weak concepts." The first is between "pieces" and "coherence" along the first axis and the second is between "formulas" and "concepts" on the second axis. Furthermore, rather than making sense out of things, one of Hammer's interviewees (Daniel) would simply play back demonstrations he had seen in his mind. In this way demonstrations were useful because they helped in remembering that facts are grouped together in a cluster. This was classified under "apparent concepts", which was also placed between "formulas" and "concepts" on the second axis, and it indicates a belief that physics knowledge is incidentally associated (pg. 23).

Redish, Saul, and Steinberg (Edward F. Redish, Saul, and Steinberg 1998)[11] acknowledged that the best way to really get at student beliefs is through interviews like what Hammer carried out; however, they argued that for the sake of characterizing the beliefs of a large sample of students, interviews become too time-consuming and expensive. The authors introduced the MPEX, or Maryland Physics Expectations survey, which consists of 34 items with a Likert scale to probe "student attitudes, beliefs, and assumptions about physics". In addition to the three dimensions of epistemology Hammer's dissertation looked at, the MPEX measured the dimensions of *reality link* or "beliefs about the connection between physics and reality" (is it useful to think about experiences outside the classroom when doing physics?), *math link* or "beliefs about the role of mathematics in learning physics" (does formal mathematics represent physical phenomena, or does it merely serve for calculations?), and *effort* or "beliefs about the kind of activities and work necessary to make sense out of physics" (do students expect to have to think carefully and metacognitively?)

The MPEX was given to 1500 college students who were taking introductory physics at six schools as a pre- and post-test. Quality of the survey was determined by over 100 hours of survey validation interviews where students were asked to explain how they understood the survey statements, to explain their selections, and to give examples from class. So as to be able to make claims about whether student beliefs are "expert" or not, the survey was also given to five groups for calibration. The group that was deemed the most expert also agreed better than 80% with the survey creators on which survey answers are favorable. The largest gap between experts and novices were the following two items from the *independence* cluster:

#1: All I need to do to understand most of the basic ideas in this course is just read the text, work most of the problems, and/or pay close attention in class.[12]
#14: Learning physics is a matter of acquiring new knowledge that is specifically located in the laws, principles, and equations given in the textbook and in class and/or in the textbook.

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[11] This article states in a footnote that "The ability of an individual to hold conflicting views depending on circumstances is a fundamental tenet of our learning model", suggesting the paper to be in a manifold epistemology theoretical camp. However, the authors nevertheless utilized surveys and analytical techniques that are the same as those used by researchers who subscribe to a unitary beliefs framework, and so it is described in this section.
[12] Note that questions such as this one do not probe a student's attitude about the nature of physics knowledge and learning in isolation. Specifically, the answer to this question will also be influenced by the student's view on the specific professor and class structure.

From interviews, the researchers saw that "students who disagreed with both these items were consistently the most vigorous and active learners."

The researchers found that not only was there a large gap between student and expert expectations, but that student expectations only get worse as a result of their physics course. Every school saw a decline in *reality link*, for example. The study concluded by standing up for these students that teachers might otherwise give up on. Students enter their college physics classes having obtained good grades in classes throughout their academic careers by playing a "school game" that did not involve sense making. "As has been demonstrated in many areas of cognitive psychology and education research, changing a long-held view is a nontrivial exercise. It may take specifically designed activities and many attempts."

In summary, in both general epistemology studies (like that of Hofer and Pintrich and Schommer) and science-specific studies (like that of Songer and Linn and early work by Hammer and Redish), we see researchers categorize student epistemology as lying along multiple dimensions, each dimension consisting of beliefs that are somewhat independent of other dimensions. They focus on the assortment of beliefs that students have, rather than focusing on developmental limitations that parallel the development of the human brain. However, each belief in this assortment is treated as unitary, and the student is characterized fairly generally (although Hammer points out that his conclusions are limited to the context of the physics class he looked at).

f) Contribution of research on stages and beliefs

In the next section and elsewhere, I will discuss the limitations of unitary frameworks and argue in favor of a manifold view. Before I do that, however, I want to acknowledge the huge advances that have resulted from research based on the unitary perspective.

Hammer (David Hammer 2000) wrote that this research assuming students to have epistemological beliefs and misconceptions, be it through a progression of stages or not, has "been productive for curriculum development as well as in motivating the physics teaching community to examine and reconsider methods and assumptions". Although instructors often subconsciously make the assumption that students have the conceptions that are necessary for learning new material already established, this research has made it clear that often, students do not have the correct conception of, for example, force.

It has also been made clear that, from daily experiences and intuition, students do not enter the physics classroom as a blank slate – they have a great deal of knowledge about how the world works that is different from what the teacher aims to teach. Rather than concluding that students lack common sense altogether, the findings on student epistemology can inform teachers of an alternative explanation: students do not believe that common sense is relevant to physics learning. This would particularly be true if the students believe (and it's been argued that many do) that physics is about memorizing formulas passed down by the teacher. Hammer and Elby (D. M. Hammer and Elby 2002) pointed out that "a perspective on students as having epistemological beliefs can provide an alternative interpretive lens for teachers to use in understanding their students' ideas and behavior, in assessing students' abilities and needs, and in adapting their plans and strategies for instruction."

Hammer and Elby also pointed out that the research done on misconceptions provides material to facilitate discussions with teachers about the existence of student intuitions about physics content that plays a role in their learning of new material. Similarly, the idea of student beliefs is a notion that is common-sensy enough to serve as a means of communicating about student epistemology. Since many teachers do not consider that students will enter a classroom with epistemological predispositions let alone that these epistemologies will influence how they interact with the course material, the research findings described thus far and the accompanying theoretical constructs are vital.

g) Summary and limitation of unitary frameworks

The research cited above, whether thinking of students as having beliefs or as progressing through stages of epistemological development, considered students to have *one, context-independent* epistemology towards a particular idea (the nature of knowledge in physics, for example) at a time. This theoretical perspective on epistemologies mirrors the corresponding framework for understanding students' conceptions. Beliefs (or, correspondingly, conceptions) are the basic unit of epistemological (cognitive) structure, and a novice belief (misconception) hinders a student from proficient learning (correct understanding).

The framework of this theoretical camp is aptly suited for, for example, a student who robustly and consistently thinks that physics principles hold little relevance or correspondence to his everyday surroundings, and so he shouldn't be concerned if he gets a result in physics class that goes against what he thinks would happen "in the real world." There is mounting evidence, however, to show that although a student might think this way while, for example, solving a plug and chug homework problem, she can nevertheless think that physics formalism does describe real world phenomena when she is having an engaging discussion with her TA. For such cases where a student thinks one thing about the nature of physics in one situation but another thing in a different situation, this framework is less productive.

2. Manifold frameworks

There is an alternative theoretical camp to that mentioned thus far. Those who subscribe to a framework of *manifold epistemologies* (in contrast to those of *unitary epistemology* described in the previous section) consider that a student does not so much as *have an epistemology* towards something, but rather has pieces of epistemological knowledge that can assemble into what can appear to be seemingly contradictory views towards, for example, the nature of physics knowledge, depending on the context. A knowledge-in-pieces framework for describing student conceptions similarly accompanies this knowledge-about-knowledge-in-pieces framework. It can become the case that a student will have a robust belief (or, correspondingly, conception); however, the manifold framework treats this as a special case, and allows the flexibility to consider cases where student attitude (or comprehension) is context-dependent and localized in time. With a manifold framework, there is limited value in asking survey questions like "do you think of science knowledge as being something that is handed down from authority?" because what a student answers on the survey need not have relevance to their actions in the classroom, which is where such a view would actually have an impact. Even within the confines of the classroom, a student's actions may show context-dependency marked by different epistemological stances.

Regarding the knowledge-in-pieces framework, there are various theoretical constructs that talk about knowledge as being made up of smaller and more general pieces than (mis)conceptions. One of the most popular examples is that of diSessa's phenomenological primitives, or p-prims, which are small knowledge structures that serve as the building blocks of cognition. (Andrea A. diSessa 1993) They are "often self-explanatory and are used as if they needed no justification." (pg. 112) For example, *Ohm's p-prim* includes the idea that "increased resistance leads to less result" (pg. 217) and is basically used without justification for it's viability. Other knowledge-in-pieces frameworks include Minsky's multiple "agents" acting in a "complex society of processes" (Minsky 1986, 1), Minstrell's facets of knowledge (Minstrell 1992), Tirosh's intuitive rules (Tirosh, Stavy, and Cohen 1998), and Thagard's "explanatory coherence" of "propositions." (Thagard 1989) Locally coherent network of these smaller-grained units can form cognitive units corresponding to "concepts". (A. A. diSessa and Sherin 1998)

Regarding manifold epistemologies, however, fewer frameworks exist. One candidate (about which much has been written and which this dissertation will utilize) is the resources framework (D Hammer 2004; David Hammer 2000; Edward F. Redish 2004; David Hammer et al. 2005; E. F. Redish and Smith 2008; Bing and Redish 2009). This framework will be introduced and expanded upon in section b. First, however, I will provide some examples of context-dependent epistemology that has been documented in literature.

a) Case studies of context-dependent epistemology

At the University of Maryland, we have observed that students can have multiple epistemological stances available to them, with different stances triggered in different contexts. We and other researchers have found much evidence that the views and attitudes espoused by students (about learning, physics, physics class, etc.) are dependent on the activity in which they are engaged and the context in which cognition is taking place. (Rosenberg, Hammer, and Phelan 2006; David Hammer 2004; Louca et al. 2004; David Hammer et al. 2005; Bing and Redish 2009; Hutchison and Hammer 2009; Andrea A. diSessa, Elby, and Hammer 2002) For example, during interviews, many of our engineering students act *as though they had* the belief that equations are plug and chug tools when asked to explain an equation to themselves. However, when asked to explain the equation to a child, they act consistently with a belief about equations describing motion occurring in the real world. As an extended example, diSessa et al 2002 is presented here.

(1) Extended example: diSessa et al 2002

The intent of diSessa et al.'s study was to challenge categorical characterizations of beliefs (like "weak commitment to principles") via observations of context dependency and to this end focused on a case study of an interviewee. The original intention of the interviews was to study variability in conceptual understanding and to support the development of the framework of p-prims. It was seen, however, that epistemology played an important role in the dynamics of the interviewee's conceptual fluidity and so the interviews were analyzed to look at epistemology as well.

The interviewee, J, was a first-year undergraduate doing fairly well in an introductory physics course. diSessa conducted seven interviews with J, each lasting about an hour. Each interview was videotaped, transcribed, and watched several times, while making notes. "Roughly speaking, we reviewed the data, looking for hypotheses about J's epistemological knowledge. Then we collected data, positive and negative, relevant to each hypothesis. Finally, we rejected hypotheses that were sufficiently undermined and refined those that passed the preliminary data test." J was chosen over other interviewees because "her tendencies seemed more pronounced than what we've seen in other students."

The authors found eight behaviors across the interviews that were "epistemologically loaded":

> *"1. Shifting Interpretations: J gives contradictory accounts of the same situation on different occasions.*
>
> *2. Splitting Concepts: Technical terms, most notably "force," are used in multiple situations in ways that imply different core meanings. It is as if J thinks there is a range of fundamentally different kinds of forces.*
>
> *3. Migrating Language: J uses alternative technical terms (force, momentum) in the same contexts as if the terms were interchangeable.*
>
> *4. Weak Commitment to Principles: J denies or demotes known-to-be-sanctioned physical principles because she feels her context-specific understanding is adequate.*
>
> *5. Discounting Details in Explanations: J does not appear to feel she is bound to justify the existence of elements in her explanations.*
>
> *6. Hedging: J frequently and explicitly shows limited commitment to what she is saying, or she provides explicit notification of vague meaning.*

7. Strong Commitment to a View: J is, on occasion, capable of careful, conscious consideration leading to strong personal commitment to particular ideas.

8. Reflective about Learning: J thinks about learning and has drawn many sensible lessons from her experience."

The authors pointed out that although the first six behaviors may suggest that J has certain unitary beliefs about the physics knowledge, behaviors 7 and 8, which show up in different contexts, seem to go against generalizations that would be drawn from categorizing her as having those beliefs. At times, J acted as though she had the belief that physics principles can be discarded in situations where they make things confusing and when she has an alternative and sensible solution to the problem. For example, although she asserted that she believes Newton's 3rd law to be true…

*"J: …I mean, it's hard to convince someone that right now the chair is pushing on me as hard as I'm pushing down—130 pounds… I think that's something that once you've taken physics, that's totally normal. But if you said it to someone off the street, I think they'd say, 'what are you talking about? No it's not. You know, obviously it's not pushing; there's nothing to push it up.' But it **is**. [emphasis added.]"*

… she rejected it when thinking about the force a pushed book exerts on a hand, because she was thinking that motion requires a net force and that if N3 held, then the book would not be moveable. "Rather than try to reconcile this inconsistency, which could have led her to revise her misunderstandings, she chose to abandon the third law, deciding that it must not apply in this situation."

In other contexts, however, she did not seem to have this belief. Rather, when thinking about Newton's second law applying to the motion of the book, she resolutely tried to reconcile her own understanding that the book's constant motion requires a force with F=ma, which would predict that the force would lead to acceleration. For example, she reviewed the logic of her thinking that if something is accelerating, you would be able to see it speeding up: "It's like you see accelerations, you feel acceleration. It's not like this book is really accelerating, and we just don't see it" and she was not uninvolved or careless in her learning:

"J: I want it to be true, but there's just no way it is, you know. Like to me you look at F = ma, and there's a force and that has to mean acceleration [no hedging here]. But then it's easy to say 'that's true,' but I mean there's no way it is."

The authors concluded that J "sometimes takes strong stands, unlike what Hedging and Weak Commitment to Principles suggest" and hence that "the evidence of richness and context-sensitivity undermines characterization of J's epistemological behavior in terms of global traits or systematic beliefs. In other words, we use J to argue that a categorical approach ignores details essential to a causal understanding of intuitive epistemology."

(2) Other examples of context-dependent epistemology in brief

J was studied partly because she is unusual in some ways. However, she was not unusual in the context-dependency of her epistemology. Lising and Elby wrote about Jan, a third-year undergraduate at the University of Maryland, was willing to approach problems using everyday and intuitive reasoning in the context of an interview but rejected such an approach when working on guided worksheets with her classmates during recitation. (Lising and Elby 2005) Rosenberg et al. documented an 8th grade science class that was studying the rock cycle, where a group of students who were approaching their project in an unproductive manner changed their epistemological stance towards the activity when the teacher suggested that they "start with what you know". (Rosenberg, Hammer, and Phelan 2006) Ryder et al. interviewed 11 students in their final year at the university and found that the students "drew upon a range of views about the nature of science, depending on the scientific context being discussed." (Ryder, Leach, and Driver 1999)

b) Introducing the resources framework

The resources framework is used to explain both context-dependent epistemology and context-dependent conceptual understanding. Bing and Redish describe the resources framework as "an associative network model with control structure and dynamic binding." (Bing and Redish 2009) I provide elaboration on what this means in the following paragraphs.

The resources framework is an *associative network* of small pieces of knowledge, analogous to the network of neurons in the brain. Just as activated neurons in one area can lead to or inhibit activation of neurons in other areas, activation of a resource can likewise trigger or repress other resources from becoming active. Learning is visualized as having connections between groups becoming strong and robust, so that such linking reliably occurs. Resources can *bind* together, ranging in clump size from a resource that is just a little larger than its constituent resources, to a reliable understanding that a table exerts a normal force on an object sitting on it. Binding also happens with various strengths.

As an example of a strong bind, consider the following figure of colored words of colors:

The challenge is to say the color of each word out loud as quickly as possible. Thus, the top row would be read "green, yellow, white, pink, orange", etc. In the 1930's, Stroop discovered how surprisingly difficult this task was for literate people, and the effect was named the "Stroop Effect".[13] This test is challenging in part because the word "blue" is coupled so strongly in the mind to the color blue.

The resources framework is *dynamic* – activated or inhibited associations can change in a moment's notice. Epistemological resources, for example, can come together with other resources (epistemological or conceptual) to form in-the-moment views or attitudes.

Unlike beliefs, an epistemological resource cannot be described as expert-like or novice-like, but rather its usefulness depends on the context and how it combines with other resources. An example that Hammer and Elby (D. M. Hammer and Elby 2002) provided is of the epistemological belief of "knowledge is received" that literature claims is counter-productive. Overusing resources such as Accumulation and Propagated stuff and underusing Formation, Checking, and Fabricated stuff could materialize this "belief". However, *Accumulation* is also utilized when gathering information for writing a literature review and *Propagated stuff* is useful when relaying a message from one person to another. Clearly such resources cannot be described as inherently counter-productive. The context of the situation is a key factor in determining what particular conglomeration resources will form.

I elaborate on what is meant by "control structure" in the next section, where I show the parallel between the resources framework and framing.

c) Link of resources framework to framing

Epistemological resources help control what conceptual resources a person calls upon (and does not call upon) in the moment, because they affect that person's perceptions of an event. For example, a student who perceives a classroom as being an appropriate place to reason about the instructor's lecture (rather than taking notes verbatim) will be more inclined to call on conceptual resources that could help with such reasoning, including intuitive ideas from everyday life such as the notion that the harder you push something the faster it goes. This relates to the

[13] http://faculty.washington.edu/chudler/words.html#seffect

control structure of the framework, regarding which Bing and Redish wrote "In the pre-frontal cortex perceptual information is mixed with long-term memory to prime appropriate actions. The evaluation of a perceived situation affecting action is a well-documented component of behavior in mammals… Control structures rely heavily not only on activating association, but also on inhibition." Redish described the resources framework as having "two basic structures… Association of resources provides the structure of knowledge appropriate to a given situation, while the control structure is associated with attention, context dependence, and goal-oriented decisions."(Redish 2004)

The presence of a control structure allows the resources framework to be well-described using the language of *framing* as found in the fields of sociology (Goffman 1974), sociolinguistics (Tannen 1993), and cognitive science (Minsky, 1985; Schank, 1990). As Hammer et al. put it, "we take framing as the activation of a locally coherent set of resources, where by "locally coherent" we mean that in the moment at hand the activations are mutually consistent and reinforcing." (David Hammer et al. 2005) Note that Hammer and Elby, in their discussions of framing, do not make the connection to the resources framework via such a top-down control structure. Rather, a bottom-up version of the resources framework is taken to mesh well with framing without connecting to parts of the brain. For my main point, which is distinguishing between unitary and manifold frameworks, this difference is not significant.

d) OK, we can understand the resources framework in terms of framing… but what is framing?

Framing, in essence, is an interpretation of an event, an often-subconscious answer to the question "What is it that's going on here?" (Goffman 1974). Bateson provided a classic example of how a monkey can interpret the bite from another monkey as being in the frame of play or in the frame of fighting. (Bateson 1972) To know what a person's words mean, you need to know the frame. The words "nice work" can be interpreted as praise, joking, or criticism, depending on the frame of the listener.

The answer to the question "what is it that's going on here?" comes with certain aspects of the situation becoming salient while others are backgrounded. Bateson wrote that "frames are inclusive, i.e., by excluding certain messages certain others are included…" (pg. 187) He paralleled these "psychological frames" with a frame around a picture, which is

> *"a message intended to order or organize the perception of the viewer… [it] says, 'Attend to what is within and do not attend to what is outside.'… Perception of the ground must be positively inhibited and the perception of the figure (in this case the picture) must be positively enhanced"(pg. 187)*

Thus, framing restricts the dauntingly long list of options for what might "be going on" to a shorter, manageable one. In this way, framing serves as the *control* *structure* that is a characteristic of the resources framework. (Bing and Redish 2009; Edward F. Redish 2004)

(1) Prior experiences are integral to framing

The concept of framing can explain how the same event can be interpreted in myriad ways, depending upon the observer. Of critical importance are the past experiences of the interactee and in what ways they are deemed to be similar to the event. It is this body of experiences that comes to bear in making sense of a new situation, in the usually subconscious decision of what parts of cognition to activate, and which to inhibit. Tannen (Tannen 1993) provided an overview of theoretical work relevant to framing and wrote:

> *"What unifies all these branches of research is the realization that people approach the world not as naïve, blank-slate receptacles who take in stimuli as they exist in some independent and objective way, but rather as experienced and sophisticated veterans of perception who have stored their prior experiences as 'an organized mass,' and who see events and objects in the world in relation to each other and in relation to their prior experiences… At the same time that expectations make it possible to perceive and interpret objects and events in the world, they shape those perceptions to the model of the world provided by them. As Bartlett put it, one forms a general impression… and furnishes the details which one builds from prior knowledge." (pg. 20-21)*

When talking with a friend, we have an "organized mass" of prior experiences with that friend and expectations pertaining to the friend's personality. We also have a frame into which we are placing the current experience of talking with the friend, and that frame is affected by those experiences and expectations.

It is because of this influence of prior experiences and expectations on our perception of what's going on that we are able to adapt adroitly to new experiences. For example, although it may be the first time for the customer to enter a particular restaurant, if the customer has been in other restaurants before, she will not likely be confused, because she knows what to expect at a restaurant in general. (Schank and Abelson 1975) In fact, stories like the following make sense so perfectly as to be boring:

> *John went into the restaurant. He ordered a hamburger and a coke. He asked the waitress for the check and left.*

The authors note that the presence of a waitress and of a check are so familiar from our previous experiences that they can take *the* to introduce them without explicit introduction. The very notion of being in a restaurant implicitly introduces these objects. (pg. 151)

Cues such as whether people are standing in line ordering food or the presence of a podium with a person standing behind it interact with our previously formed notions of what constitutes "a restaurant" and we quickly form expectations about what will happen next, such as whether to look at the wall to consider what to order or to wait for someone to come to bring us to a table. An insightful metaphor provided by Bateson in his 1955 writings (and then used later by Goffman) is that of brackets used by mathematicians. An event is analogous to the bit of equation contained within brackets, but the meaning is transformed by a frame depending upon the operator acting on those brackets (raising it to some power, taking the square root, etc.)

Tannen oversaw and analyzed a study where small groups of young women in America and Greece were shown a six-minute film without dialogue (but with sounds) involving a boy who steals a basket of pears from a man who is picking them off a tree.(Tannen 1993) The participants were then asked to describe the film to someone who had not yet seen it. Since the American subjects and the Greek subjects had shared very different past experiences, we might expect those experiences to influence their framing of the task (describing a movie) differently. Indeed, Tannen concluded that the participants had different opinions about what they should be doing. In the study, the film viewers told a researcher (who supposedly had not seen the film) what the movie had been about, and it is from these reports that the data was taken. Both American and Greek women were framing the activity as being part of a research experiment. Tannen used statements like "…has anybody told you that before? Or you're not supposed to tell me that?" as evidence for this framing. Within that frame, Americans tended to frame the activity as telling a story about a film, and were hence forthcoming about places where their expectations of what should be in a movie were violated. As such, they criticized various parts of the film, for example, that the sounds were unusually loud. The Greeks, on the other hand, had no comment about the sound track or any criticism of the film *as a film,* but rather framed the activity as interpreting what meaning the film contained. Many viewers spoke about their own life experiences and interpreted a great deal from the film. They inferred emotions that characters had, for example, about the man picking the pears: "that he gathered these the harvest, was something special for him… it was worth something. He lived that which he did, he liked it."

Tannen's study illustrated an important characteristic of *framing* – prior experiences play a pivotal role in how someone frames a new one.

(2) Framing is context-dependent, fluid, and ongoing

Framing can be used to discuss not only how personal history influences student behaviors, but how student attitudes (for example, towards physics) can change as well. MacLachlan and Reid (MacLachlan and Reid 1994) analyzed framing theory across the various disciplines in which it is used and reviewed the contributions of the theorists mentioned above and others. One common theoretical thread between Bateson, Goffman, and Tannen mentioned in chapter 3 is the fluidity with which framing occurs. Framing is not something that happens once at the start of a new event. Rather, throughout the process, participants continually reevaluate their framing and alter it as needed. This, conceptually, is analogous to the fluidity characteristic of the resources framework.

Tannen and Wallat (Tannen and Wallat 1993) described how one's *schema* (collection of knowledge) pertaining to an experience and the frame in which the experience occurs are considered in regards to occurring experiences, and both are revised continuously. Tannen (Tannen 1993) wrote, "a person's perception of the world proceeds automatically so long as expectations are met, while she is stopped short, forced to question things, only when they are not"(pg. 17) This questioning is a back-and-forth process between the specific aspects of the situation that is causing the uncertainty, and the individual's frame and schema, which determine in what context to place those aspects. So, for example, a student may leave high school and enter a physics classroom in college with the schema of physics being about plugging variables into the equation that has all the right letters, doing some algebra, and getting an answer out. She might frame the physics classroom as being a place where this is what is done. However, if the teacher provides experiences that contrast with these expectations, the schema and frame of the student will have an opportunity to adjust.

As MacLachlan and Reid (MacLachlan and Reid 1994) pointed out, Bateson and Goffman's notions of framing are similarly fluid (pg. 46). Bateson (Bateson 1972) considered the manipulation of frames for the purpose of helping patients with psychotherapy:

> *"applying this theoretical approach to the particular phenomena of psychotherapy… (b) Is there any indication that the techniques of psychotherapy necessarily depend upon the manipulation of frames and paradoxes? (c) Is it possible to describe the process of a given psychotherapy in terms of the interaction between the patient's abnormal use of frames and the therapist's manipulation of them?" (pg. 190)*

Goffman (Goffman 1974) provided an example of how adroitly one's framing can change in the conclusion of his book.

> *"… any more or less protracted strip of everyday, literal activity seen as such by all its participants is likely to contain differently framed episodes… A man finishes giving instructions to his postman, greets a passing couple, gets into his car, and drives off… the traffic system is a relatively narrow role domain, impersonal yet closely geared into the ongoing world; greetings are part of the ritual order in which the individual can figure as a representative of himself, a realm of action that is geared into the world but in a special and restricted way. Instruction giving belongs to the realm of occupational roles, but it is unlikely that the exchange will have occurred without a bordering of small talk cast in still another domain. The physical competence exhibited in giving over and receiving a letter (or opening and closing a car door) pertains to still another order, the bodily management of*

> *physical objects close at hand… (Note that all these differently framed activities could be subsumed under the term "role" – for example, the role of suburbanite – but that would provide a hopelessly gross conceptualization for our purposes.)" (pg. 561)*

MacLachlan and Reid criticized Goffman, however, for assuming that there are two levels– the individual and the social – and that these are independent of each other.

> *"For Goffman, frames are vulnerable to manipulation by con men, swindlers, hoaxers, and practical jokers. Those broader socio-political frames (gender, race, ethnicity, class, and the various institutional frames) that control the range of meanings available to us are referred to only incidentally, if at all. The problem is that by omitting a critical account of such wider frameworks, he helps to foster an illusion of individual autonomy."(pg. 60)*

With a unitary epistemology framework, one might describe Tannen's movie experiment as indicating that "Americans think of movies as something that is to be criticized" or perhaps "Americans think that their role in watching movies is to critique them." Tannen's conclusion and the conclusion a researcher using a manifold epistemology framework would reach is something closer to "in the context of this interview task with this interviewer and this movie, the Americans may have thought that their role was to critique the movie, perhaps because that's how they thought they would impress the university researcher." In another moment, the research subjects might perceive their role as being something altogether different.

e) Epistemological framing

Epistemological framing (David Hammer et al. 2005; Edward F. Redish 2004) is a specific kind of framing – it answers the question "what kind of knowledge/learning is appropriate here?" Like customers at restaurants, students frame what is going on in class, and that framing is dependent upon their past experiences. By college, most students no longer need to be explicitly told to be seated before a lecture begins, and many students will even open a notebook and write in it without being instructed to do so. Students have expectations that they will sit, watch, and listen to a professor for an hour or so. As framing generally is, epistemological framing is fluid. For example, Hutchison documented students framing the class at times as a place to play the "classroom game" (where they often expect knowledge to come in the form of a formula from authority) and at other times as a place to "make sense of phenomena" (where knowledge can come from anywhere, and the students play the role of producing and assessing that knowledge for whether or not it matches what they believe and understand). (Hutchison and Hammer 2009) His and many other studies have documented that these stances are not rigid; rather, students frame science classes fluidly and dependent on context. (Rosenberg, Hammer, & Phelan 2006; Hammer et al 2005; Redish 2004; Louca et al 2004; Huchison and Hammer

2009; Bing and Redish 2009). Bing and Redish 2009 will be described here in some detail.

(1) Extended examples: Bing and Redish 2009

This article discussed looking for warrants (explicit comments about "*why* something should be believed or not") that students give for their approach to using math in solving a physics problem as evidence for their epistemological framing of the problem. To this end, the authors looked for instances where students were misunderstanding each other.

> *"Such framing confusions are common sources of disagreements, even in non-physics settings. Many mathematical disagreements physics students have with each other reduce to the first student essentially saying 'Look at this math issue this way' while the second student is claiming 'No, you should be looking at it this other way'. The students are debating which aspects of their mathematical knowledge are currently relevant. Examining the warrants physics students use in their mathematical arguments offers a good window to how they are currently framing their math use."*

The article was centered upon a case study taken from the dissertation of Bing. The dissertation collected approximately 80 hours of video data of upper-level undergraduate students (most of them physics majors) solving physics homework problems together. Bing was present while the students were being videotaped, and his notes on what arguments, debates and misunderstandings were taking place allowed these 80 hours to be narrowed down to 50 snippets of film. This subset "was meant to offer the best evidence for deciding whether a set of common framings exist and, if they do, what they specifically are." To accomplish this task, the authors performed an iterative methodology that they called a "knowledge analysis" until the categorization of warrant types had evolved to a point that it could capture warrants found in newly analyzed video.

As a result of this analysis, four main clusters of warrants students use (often implicitly) for their mathematics emerged from the data. These clusters correspond to four commonly found framings: *Calculation* is evidenced by the warrant "correctly following algorithmic steps gives trustable result", *Physical Mapping* ("Goodness-of-fit between math and physical observations or expectations attests to a result"), *Invoking Authority* ("Authoritatively asserting a result or a rule gives it credence"), and *Math Consistency* ("Similarity or logical connection to another math idea offers validation").

The case study was of a group of students working on solving a problem about work done on a rocket ship by an asteroid as the rocket moves from point A to point B along two different paths. The problem asked students to calculate the work along the two paths. S1 claimed that the work should be different along the two paths. S2 rejected this claim, quoting the rule "work is path independent". S1 rejected this in turn because "this path [points to the two-part path] is longer". S2 seemed to ignore this argument when he repeated "Work is path independent. If you go from point A to point B, doesn't matter how you get there, it should take the same amount of work."

At this point, the authors argued that the two students seemed to be talking past each other because their epistemological framings were different. Whereas S1's unspoken warrant of "the particular mathematics being used should align with the physical systems under study" (specifically, the work calculation should reflect the fact that the one path is longer) reflects a framing of *Physical Mapping*, S2's unspoken warrant of "sometimes previous results are simply taken as givens for speed and convenience" (here, the previous result being that work is path-independent) indicates a framing of *Invoking Authority*.

S2, however, did not stay in this frame. At last, S1's move of drawing a short distance, r, and a longer distance, R, and asking "OK, then you tell me this then; work is force times distance, right? … So if you're going this *r*, and you're going this *R*, which one has more work?" - which was his most explicit bid to frame the activity as *Physical Mapping* - tipped S2. S2 asked "if there's constant force?", finally addressing a physical detail relevant to S1's physical mapping.

The authors concluded that although "sometimes a student's framing can exhibit considerable resistance to change," the students are seen to "frame and reframe their activity." They argued that "epistemological framing negotiation and communication can be a powerful dynamic in physics students' work" and that students "exert various pushes and pulls on each other as they try to negotiate a common epistemological framing... When a common framing is established, the conversation tends to be richer and more efficient."

f) Benefits of conceptualizing epistemologies as manifold resources rather than unitary beliefs

This dissertation centers on what attitudes students have towards physics knowledge and learning. However, as described in the first part of this section, this question can generally be answered with a unitary framework and without the need to invoke a framework of manifold epistemologies. What is to be gained from a framework of manifold epistemologies, especially when the unitary theoretical tradition has already contributed a great deal to research and pedagogical practices? Although the advantage of a manifold framework will be argued more heavily and connected to the data collected at TGU in the Discussion, here I provide some of the arguments given to prefer a manifold framework in general.

Regarding accounts of conceptual understanding, Hammer (David Hammer 2000) pointed out that unitary frameworks provide limited information regarding student knowledge and learning.

> *"First, they provide no account of productive resources students have for advancing in their understanding. Second, descriptions of student difficulties provide no analysis of underlying mechanism, while the perspective of misconceptions cannot explain the contextual sensitivities*

of student reasoning, such as the empirical fact that substantively equivalent questions, posed in different ways, can evoke different responses from the same student."

Similar to Smith, diSessa, and Roschelle's (Smith, diSessa, and Roschelle 1993) argument against the idea of misconceptions, Hammer pointed out that while many advocates of (mis)conceptions claim to be constructivist, they are left with Carey's paradox of how you can build something that is a correct primary element if you start with an incorrect primary element. The only solution is that students must "have in their prior knowledge the raw material for that construction… in its emphasis on difficulties and misconceptions, physics education research has mostly overlooked the task of studying and describing this raw material."

This sentiment was echoed by Hammer and Elby (D. M. Hammer and Elby 2002) who applied it to epistemology.

"… in considering naïve epistemologies to be made up of constructs such as 'knowledge is certain,' current perspectives on epistemology offer no account of what may be the raw material from which students could develop new structures, such as that 'knowledge is contingent on context and perspective.'"

They argued that many who use a unitary framework do so as a default presumption, and that although they may never explicitly say that students have only one belief, their use of questionnaires and clinical interviews presumes that what students say reflects their epistemology across contexts.

Louca et al. (Louca et al. 2004) pointed out that thinking of students as advancing in epistemological stages provides little theory on mechanism for how this change takes place and thus little guidance for teachers. They wrote that a manifold framework like the resources framework "involves opening up the 'black box' of a developmental stage and exploring the finer grained cognitive elements within." Furthermore, they argued that a unitary framework simply couldn't explain much data that has been observed.

Louca et al. gave such an example of what cannot be explained with a unitary framework in their case study of Miss Kagey. Miss Kagey prompted her 3rd-grade science students to discuss the mechanism by which leaves turn color. Students were hung up on explanations that were teleological ("In the winter I don't think the tree needs the leaves") or anthropomorphic ("They get really old and they're dying") in nature and Miss Kagey tried several interventions to help them change their approach. Her first attempt was to compare the kind of answer she was looking for with an example of describing being hungry:

"… 'Why are you hungry?' And you say, 'I'm hungry because I haven't eaten since eight o'clock in the morning or six o'clock in the morning.' And the second question says 'How—what is going on inside of your body that's making you hungry?' You can say, 'The food already went into my stomach, my stomach already digested it, and now my stomach

is empty and that's why I'm hungry.' So, you are talking about what's going on. 'What things are going on inside of the leaf—what things are going on inside of your body to make you hungry?' "

This intervention, however, had only marginal benefit on getting the students to think mechanistically. It was when Miss Kagey used an alternative analogy, however, one that was taken from everyday life where students would have been prone to already be thinking mechanistically, that she was able to change their approach to the material:

"Say I'm making cookies for my birthday because my birthday is coming up, right Kristina? And so I was making cookies for my birthday and the question was 'Why am I making cookies?' What's the answer? Because it's my birthday. How am I going to make these cookies? Well, I'm going to put together a bunch of ingredients, put them inside of a bowl, mix it all up, put it into the oven, take it out of the oven, lay it out to cool off. They are two different questions."

After giving this example, the students began to think mechanistically about the leaves changing color. Louca et al. discussed how a unitary framework would not have much to say in explaining why the more everyday analogy was able to change the way students were thinking about the nature of the leaf-related knowledge when a similarly mechanistic analogy (about stomachs) was unable. The resources framework, however, triumphs in such cases.

Hammer and Elby (D. M. Hammer and Elby 2002) contended that a manifold framework can have advantages over a unitary framework in terms of elegance as well, using the work of Linn and Songer as an example. Linn and Songer (Linn and Songer 1993) expanded upon previous work (Songer and Linn 1991) to see if scientific views of 8th graders become more sophisticated as the result of a one-semester science course that was designed to "teach about the nature of scientific investigation". A total of 181 8th graders were given pre- and post-tests and surveys. Like in the 1991 study, the researchers coded a large number of students as "mixed". Expanding on the 1991 study, however, Linn and Songer used interviews to probe into what was going on with these mixed students.

Of the 181 students, 25 were selected at random for short clinical interviews where students explained their answers to a few survey items and the interviewer asked clarification or follow-up questions. For example, to a survey response of "scientists can reach different conclusions about experimental results", student justifications included "because everybody has a different opinion" and "they can find something in the experiment, and then a week later they can find something else." The authors, using such statements as evidence, declared that "these student responses, classified as mixed, may be more accurately described as *relative* views of science: These students seem to believe that all explanations are equally plausible."(pg. 63)

The authors declared the class to have had successes: "Several students who at the pre-test indicated that there was no relationship between science learned in school and life outside of school, by the posttest were able to give examples of this relationship."(pg. 66) At the same time, however, "some students who abandoned a static view of scientific knowledge turned instead to a view that might be classified as radical relativism. These students had no criteria for comparing explanations and no ability to distinguish established and controversial ideas."(pg. 69) Hammer and Elby (D. M. Hammer and Elby 2002) argued that

> *"Interview questions set in the context of discussing whether the heart pumps blood, or whether the Earth is round, would undoubtedly activate epistemological resources corresponding to static beliefs. Our point is that a unitary ontology pushes researchers to cubby-hole students into categories such as 'relativist' or 'radical relativist,' rather than exploring the possibility that students' 'beliefs' really are mixed, due to the activation of different epistemological resources by different questions."*

(1) What happened at Gakugei looks more like "transfer" – is a manifold framework still better suited?

My argument for the necessity of a manifold framework for explaining my observations would be more clear if, like diSessa et al.'s student J described above (Andrea A. diSessa, Elby, and Hammer 2002), my interviewees demonstrated different epistemologies from context to context within an interview or a class period. However, unlike J and much of the other work described above (Rosenberg, Hammer, and Phelan 2006; David Hammer et al. 2005; Edward F. Redish 2004; Louca et al. 2004; Hutchison and Hammer 2009; Bing and Redish 2009; Lising and Elby 2005; Ryder, Leach, and Driver 1999), I did not observe TGU students shifting moment to moment in their stance towards learning or in their attitude about the nature of knowledge. Rather, I saw students pulling out what appeared to be an intact epistemology that they had previously acquired (interviews suggest that this occurred when they were in elementary school), and invoking it soon after entering the class. Although they may have put it on the side during their time in high school to adopt a different epistemology about physics and physics learning (which interviewees claimed they had prior to Tutorial), it was as though their entry into the Physics Exercises classroom reminded them of something that they already "had".

The literature on the resource framework can speak to such phenomena as this as well, however, in terms of coherences of epistemological resources (D. M. Hammer and Elby 2002; D. M. Hammer 1994; Andrew Elby and Hammer 2001; David Hammer et al. 2005; A. A. diSessa and Sherin 1998). In the language of Bing and Redish (Bing and Redish 2009), the TGU students' epistemological resources (pertaining to the appropriateness of classroom learning being constructivist) were tightly *bound* together into a coherence, and this coherence was brought into play in the Physics Exercises classroom. In the words of Hammer et al., "With reuse, a set of activations can become established to the point that it becomes a kind of cognitive unit, and so a kind of resource in its own right." (David Hammer et al. 2005)

These locally coherent activations appear very similar to epistemological beliefs or to the idea of *cultural scripts* that will be discussed below. The important difference, however, is the ease with which such "beliefs" that would have been developed in the cram-school-style learning environment of high school (as described in interviews) were displaced with contradictory beliefs in the Physics Exercises classroom.

The data that I will show is similar to that presented regarding Louis in Hammer et al. (David Hammer et al. 2005). Louis began his college physics course with the approach of memorizing everything in the textbook. Having received a pitiful score on a midterm exam, he approached the professor (Hammer) for help in how to approach the class. Hammer advised Louis to imagine he was explaining everything to a child. With this small intervention, Louis was suddenly able to dramatically change the way he was thinking about knowledge in the course and to correspondingly change his grade. Louis explained that as both an older brother and as a former tutor of children, he had experience with explaining things to a child. He was explicit that he had framed tutoring as helping tutees build on the knowledge that they already knew, and it is likely that he had formed a corresponding epistemological stance about knowledge being something that one constructs from what one already knows. It is likely that the presence of that (albeit inactive) well-compiled network of epistemological resources enabled Louis to easily take his professor's advice (essentially - "tutor yourself!")

Similarly, I will show that TGU students found the tasks involved in Physics Exercises and the process of building upon their own knowledge to be reminiscent of what they did during their elementary school days. I will argue that it is likely that they formed a constructivist epistemological stance at that time about the nature of classroom learning in general. It was this present (albeit, like Louis, inactive) stance that allowed them in part to adapt so easily to the Tutorial style of learning.

While a unitary account of this phenomena would address the concept of transfer, Hammer et al. (David Hammer et al. 2005) suggested several ways in which the resources framework outperforms unitary frameworks in explanatory power. While the unitary view of transfer looks only at what conditions under which knowledge is or is not transferred, "The manifold view of resources, activations, and frames subsumes those conditions as special cases, while gaining us a language and framework for thinking about cases where the relevant knowledge is less intact or less tied to specific contexts." A manifold view can address the mechanism by which knowledge is transferred to what extent, for example.

3. Summary of part A

In this part of the literature review I have outlined two traditions of theory that describe and explain how students learn and what attitudes they have about learning.

Traditionally, learners have been studied as though they have a single, or unitary, conception and attitude about a particular issue. In this tradition, a student consistently and robustly has a (mis)conception, for example that seeing is a direct process where objects are visible because they themselves are a source of light, or a (mis)belief, for example that physics is a collection of unrelated formulas and principles to be memorized from authority. More recently, however, there has been a growing amount of data showing that many learners are not consistent in either their conceptions or beliefs, but rather that both depend upon the context in which the learner is placed. Although the former camp has been helpful for both educators and researchers alike, the story of the TGU students that this dissertation will tell is better captured by the latter camp's framework.

Note that although most of the articles on manifold epistemology that I described above see students shifting moment by moment in their epistemology, I did not observe this kind of behavior in the TGU students. I instead observed what appeared to be a more dramatic one-time shift in stance or approach towards learning physics that occurred at the very beginning of the semester. Although the unitary explanation of transfer can be used to explain this phenomenon, a manifold framework like the resources framework has more explanatory power as explained in the subsection above. (David Hammer et al. 2005)

B. The cross-cultural education research community uses a unitary epistemology framework

In this section, I will present some pertinent features of the history that has led up to the important role that epistemology plays in the field of cross-cultural education research today and I will show how the field treats epistemology as a unitary construct.

U.S. interest in cross-cultural education research grew dramatically as a result of observations that American children are not performing nearly as well on standardized exams (mostly mathematics) as children elsewhere, particularly those in various Asian countries.

Wanting to know *why* there exist these differences in achievement, there has been a corresponding increase in interest in any other differences that might be associated with this learning gap. Hence, education researchers have studied differences ranging from classroom structure to salaries and training that teachers receive. Intuitively, another obvious place to look for differences that might be responsible for differences in learning are student attitudes, including epistemology - the views of the students towards the nature of learning in general, and towards the nature of the school subject's content knowledge itself.

In talking about student beliefs (epistemological and otherwise), cross-cultural education researchers treat them as unitary things that can be discerned from surveys. Differences on surveys from across countries have suggested that these beliefs are cultural in nature. These beliefs (for example) about what learning in a classroom *should* look like are understandably tied to a person's "mental picture of what teaching is like." (J.W. Stigler and Hiebert 1998). This picture about cultural activities (like school learning) is called a ***cultural script***. "Cultural activities are represented in cultural scripts, generalized knowledge about the event that resides in the heads of participants. These scripts not only guide behavior, they also tell participants what to expect." (J.W. Stigler and Hiebert 1998).

Researchers use "cultural scripts" to explain why many attempts to reform American classes to be more like Japanese classes fail: American students have different beliefs (about how mathematics should be taught) than Japanese students do. Thus, one can't just start teaching American students like Japanese teachers teach their students - at least, not without putting in significant work to change the beliefs of the students.

In what follows, I will present a review of some major standardized exams that demonstrated U.S. children to be behind and hence caused concern. Following that, I will present other observations that cross-cultural researchers have found, including pertaining to student attitudes and beliefs (including those that are epistemological). I will then show how many reformers trying to make a class that looks "more Japanese" have failed, and that many education researchers attribute these difficulties to students having "a cultural script" about what learning should look like.

1. International exams and surveys that will be discussed below

IEA (International Association for the Evaluation of Educational Achievement)
http://www.iea.nl/completed_studies.html

- **SIMS (**1980–1982): 8th and 12th grade mathematics in Belgium (Flemish), Belgium (French), Canada (British Columbia and Ontario), England and Wales, Finland, France, Hong Kong, Hungary, Israel, Japan, Luxembourg, Netherlands, New Zealand, Nigeria, Scotland, Swaziland, Sweden, Thailand, and United States.
- **TIMSS 1995:** 4th, 8th, and 12th grade science and math classes in Argentina, Australia, Austria, Belgium (Flemish), Belgium (French), Bulgaria, Canada, Colombia, Cyprus, Czech Republic, Denmark, England, France, Germany, Greece, Hong Kong, Hungary, Iceland, Indonesia, Iran, Ireland, Israel, Italy, Japan, Korea, Kuwait, Latvia, Lithuania, Mexico, Netherlands, New Zealand, Norway, Philippines, Portugal, Romania, Russian Federation, Scotland, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Switzerland, Thailand, and United States.
- **TIMSS 1995 video study**: 8th grade mathematics in Germany, Japan, and the United States (directed by James Stigler[14])

[14] http://www.psych.ucla.edu/faculty/faculty_page?id=63&area=4

- **TIMSS 1999:** 8th grade math and science classes in Australia, Belgium (Flemish), Bulgaria, Canada, Chile, Chinese Taipei, Cyprus, Czech Republic, England, Finland, Hong Kong SAR, Hungary, Indonesia, Iran, Israel, Italy, Japan, Jordan, Korea, Latvia, Lithuania, Macedonia, Malaysia, Moldova, Morocco, Netherlands, New Zealand, Philippines, Romania, Russian Federation, Singapore, Slovak Republic, Slovenia, South Africa, Thailand, Tunisia, Turkey, and United States.
- **TIMSS 1999 video study**: 8th grade mathematics in the United States, Australia, the Czech Republic, Hong Kong SAR, Japan, the Netherlands, and Switzerland (directed by James Stigler)

Educational Testing Service (ETS)
(http://www.nap.edu/openbook.php?record_id=9174&page=48)

- **IAEP – I (1988):** 8th grade math and science classes in Ireland, Korea, Spain, the United Kingdom, the United States and Canada.
- **IAEP – II (1991)**: 4th and 8th grade math and science classes in Brazil, Canada, China, England, France, Hungary, Ireland, Israel, Italy, Jordan, Korea, Mozambique, Portugal, Scotland, Slovenia, Soviet Union, Spain, Switzerland, Taiwan, and the United States.

In both IAEP's, students were given math and science achievement tests, a survey about their attitudes towards math and science, and a questionnaire about what they do in their free time

Organisation for Economic Co-Operation and Development (OECD)
http://www.pisa.oecd.org/pages/0,3417,en_32252351_32235731_1_1_1_1_1,00.html

- **PISA 2006:** 15-yr olds' proficiency in reading, math, science, and problem solving in 57 countries.

The Relevance of Science Education (ROSE) advisory group
http://roseproject.no./

- **ROSE :** 15 yr. olds' attitudes towards science in 40 countries

2. Standardized international exams show US students to be behind

When results from TIMSS 1995 were made available, America was shocked to see how relatively poorly students in the US perform in math and science classes compared with foreign counterparts. (James W. Stigler and Hiebert 1999) In both elementary and middle schools, Japanese students were found to be near the top compared to the other countries investigated. However, the study "reveal[ed] few surprises" (Silver 1998) in that it was completely consistent with prior reports of how the US ranks internationally as seen with SIMS (McKnight and others 1987) and the first and second IAEP's (Lapointe and others 1989; Lapointe and others 1992). Since that time, Japanese students have continued to vastly outperform

American counterparts on standardized exams (Judson and Nishimori 2005) and, according to PISA, in group problem-solving as well.[15]

3. Observations about curriculum, classrooms, and culture

Often concurrently with international exams, surveys are given out to probe what could account for differences in achievement. Many of these surveys are geared towards teachers or administrators to look at differences in the curriculum and how class time is arranged. Generally speaking, TIMSS and SIMS found that K-8 mathematics curriculum in the U.S., rather than building on itself in growing sophistication, was more unfocused and repetitive than most countries. This seemed to correspond to the U.S. practice of breaking up a topic into an excessive number of sub-points about that topic: depth of student understanding was being sacrificed for the sake of wide coverage. (Silver 1998) At the same time, TIMSS showed the U.S. K-8 math curriculum to be less demanding than many foreign counterparts. Based on an examination of textbooks used in 8th grade, it was discovered that many 8th grade math teachers in the U.S. focus on arithmetic at the expense of algebra, geometry, and measurement. (Silver 1998) Japanese K-8 math teachers, on the other hand, have the greatest coverage of algebra, geometry, and other topics. (McKnight and others 1987)

Other methods for researching potential causes of the achievement gap have included video surveys (most notably, the TIMSS 1995 video study and the TIMSS 1999 video study) and interviews. The TIMSS 1995 video study, which looked only at 8th graders, showed that while 11% of class time involved homework in some way in America, only 2% of class in Japan involved homework, and Japanese students never worked on the next day's homework during class. Furthermore, American and German 8th-grade mathematics students follow the teacher through solutions of problems posed in class. Japanese 8th graders, in contrast, must invent their own solutions and are then provided time to reflect on and discuss other students' solutions so as to increase their understanding of different solutions. (J.W. Stigler and Hiebert 1998) This approach of probing a problem "through deliberative group discussion and teacher-pupil exchange… thus spend[ing] considerable time on reflecting, examining, and digesting the problem" has been called "sticky-probing" and was found to be common in Japanese 4th grade classrooms (math and otherwise) as well. (Hess and Azuma 1991)[16] Whereas lecture in U.S. middle school classrooms typically begins in the formal mathematics world ("today we are going to learn about 'division'. Division uses this symbol here"), Japanese classrooms

[15] http://client.viewontv.com/oecd/031207_pisa2006/index.php?lang=ja

[16] Although there exists a stereotype that Japanese schooling is predominantly lecture-based, this is characteristic only of secondary education and beyond. When Japanese students enter high school, they encounter a markedly different learning environment. Instead of group discussion, class is dominated by lecture. (Rohlen 1983). Twenty years later, Judson found that high school instructors of advanced math classes (in both Japan and America) spend most of the class lecturing. (Judson and Nishimori 2005)

begin with a contextual situation that students can engage with ("suppose you have six cookies for you and your three friends to share. How would you do that?")(James W. Stigler and Hiebert 1999)

Regarding science classes, the TIMSS 1999 video study found that Japanese 8th grade classes excelled at developing science content conceptually and coherently.

> *"A typical Japanese lesson used an inductive, inquiry-oriented approach, focusing on just one or two main ideas that were developed in depth and supported with data, phenomena, and visual representations. Thus, students had opportunities to work independently on hands-on, practical science activities that were preceded and followed by discussions that helped them link these activities to science ideas." (Roth and Garnier 2006)*

Although US 8th grade science classrooms also had hands-on opportunities, they were not as prevalent, and were intermingled with a collage of other activities including independent activities (including reading and writing), playing games, seeing dramatic demonstrations, and going on field trips. U.S. science teachers "did not typically use these various activities to support the development of content ideas in ways that were coherent and challenging." (Roth and Garnier 2006) Hess and Azuma cited a study conducted twenty years prior by Azuma and Walberg that found sticky-probing to be common in Japanese science classrooms in fifth grade as well. (Hess and Azuma 1991)

Going another step deeper, researchers, asking why classes are structured differently, looked to the classroom instructors and to the context surrounding the classrooms. According to Stigler and Hiebert, American education researchers carry prestige while teachers in the U.S. are often neither respected nor trusted. In general, American teachers are not given much time to prepare their lessons or improve their teaching. Many American teachers are weary from the frequent curricular reforms that America has recently been seeing. They are not entrusted with the time and other resources needed to learn how to properly apply these reforms. Furthermore, teachers are not given the opportunity to reform the system themselves. (pp. 172-173 of (James W. Stigler and Hiebert 1999)) Teaching as a whole and thus teachers in Japan are more respected than in America. The TIMSS 1995 video study showed that Japanese 8th grade math classes are never interrupted, for example, by lunch-count monitors.(James W. Stigler and Hiebert 1999)

One of the distinguishing features of Japanese pre-high school education is ***lesson study***, an institution used by Japanese teachers for more than 100 years. In lesson study, teachers work in a small group to prepare a detailed plan for a single lesson. They have an all-encompassing goal (like for students to become independent learners) and a research question (like how to help students better understand functions). The group plans the lesson over several meetings. Then, one member of the group teaches the research lesson while the other teachers observe. Lesson study is widely practiced in Japanese elementary and middle schools, but it is implemented by only a few Japanese secondary schools and no known Japanese universities. (Alvine et al. 2007) One factor that greatly aids Japanese lesson study is the common curriculum that the teachers all share. In Japan, the Ministry of Science and Education must approve all textbooks used. In America, on the other hand, curriculum is controlled by thousands of state and local school boards. (Judson and Nishimori 2005)

So far I have given some brief history of cross cultural comparisons and observations that have been made leading up to cross-cultural education researchers coming to care about epistemology. Now, I will discuss how this research field has studied epistemology.

a) Epistemology enters the picture

It is in this realm of discussing classroom instructors and the context surrounding the classrooms that teacher beliefs and beliefs of the surrounding culture naturally begin to become relevant to the discussion. Included at least to a degree within those beliefs is epistemology.

Beliefs are usually taken-as-is directly from answers that people fill out on surveys or are inferred from watching actions of teachers. These beliefs are then discussed as though they are rigid and unitary. In The Teaching Gap, Stigler and Hiebert described a questionnaire that 8th grade math teachers completed asking "what 'main thing' they wanted students to learn from the lessons." Many Japanese 8th grade math teachers answered on the survey that they want their students to learn to think in a new way. Sixty-one percent of U.S. teachers, on the other hand, listed skills. The authors noticed how many US 8th grade teachers try to increase student interest in mathematics through non-mathematical ways, such as talking about interesting but unrelated topics or by situating the mathematics in a real-life context, like measuring the circumference of a basketball. It was concluded that "[Many US teachers] wanted the students to be able to perform a procedure, solve a particular kind of problem, and so on. [They] also seem to believe that learning terms and practicing skills is not very exciting." (pg. 89 of (James W. Stigler and Hiebert 1999)). Stigler and Hiebert refer to a teacher's manual in a popular Japanese textbook that encourages teachers to have students come up with their own solutions and then compare them as a class and to allow students to make mistakes and examine the consequences. The authors concluded that "Obviously, struggling and making mistakes and then seeing why they are mistakes are believed to be essential parts of the learning process in Japan."(pg. 91 of (James W. Stigler and Hiebert 1999)) From observations of Japanese teachers following this protocol, the authors concluded that "One can infer that Japanese teachers believe students learn best by first struggling to solve mathematics problems, then participating in discussions about how to solve them, and then hearing about the pros and cons of different methods and the relationships between them." (pg. 91 of (James W. Stigler and Hiebert 1999))

These beliefs give explanatory power for differences observed in the classrooms. For example, The Teaching Gap points out that the act of teaching students a way to solve a problem and then making students repeat the solution process over and over again is consistent with the importance 8th grade math teachers ascribe to becoming proficient at skills. Stigler argued that the use of visual aids (*e.g.,* overhead projector slides) as a means to guide and control attention is consistent with the impression teachers have that these rote drills are not very interesting to students. Similarly, the Japanese 8th grade math teachers' use of the blackboard as a cumulative record of what has been done and what results have been gleaned in that day's lesson can be explained by their belief about the importance of progressing through a morass of possible solutions before reaching a satisfying conclusion.

Beliefs about the role student differences in ability play in the classroom also have explanatory power for differences observed. On the questionnaire given to the 8th-grade math teachers, there was a question that asked teachers to select all the factors (out of a list of 16) that limited their effectiveness in the classroom. Practically tied for being most prevalent with the US teachers were lack of student interest and the range of abilities among students in the same class (45% chose this). From this, Stigler and Hiebert concluded that "Many US teachers believe that individual differences are an obstacle to effective teaching… This belief says that the tutoring situation is best, academically, because instruction can be tailored specifically for each student or small group of students."(pg. 94 of (James W. Stigler and Hiebert 1999)) The authors reported that apparently Japanese 8th grade teachers, on the other hand, value differences amongst students, because it allows for greater diversification of possible solutions to the vexing problems that they pose. While American teachers will often try to avoid student frustration (via one-on-one tutoring or otherwise), Japanese teachers perceive it as a natural part of progress and expect their students to become frustrated.(James W. Stigler and Hiebert 1999) Biggs identified an additional reason for "Confucian heritage culture (CHC)" teachers to have students of mixed ability in groups: they believe that education should reduce differences across individuals because "the goals of education incorporate the good of the state, defining the potential of the individual within the needs of the state."(Biggs 1998)

Biggs, in addressing Western misperceptions of CHC classrooms and why CHC students can have difficulty in Australian classrooms, wrote about cultural differences in epistemology of CHC teachers and students versus Western counterparts. CHC students and teachers believe that repetition plays an important role in learning. "In the West, we believe in exploring first, then in the development of skill; the Chinese believe in skill development first, which typically involves repetitive (not rote![17]) learning, after which one would have something to be

[17] Biggs cited Hess and Azuma 1991, which discussed this in more detail. The role of repetition in Japanese classrooms is "a route to understanding", not to be done mindlessly by rote, but rather with active engagement from the students. "Procedural mastery was seen as an essential route to conceptual understanding." They argued that sticky probing, which appears to be the complete opposite of this

creative with." Also, CHC learners believe that learning should proceed with the teacher as the authoritative leader and he described CHC students as "idealizing a warm hierarchical relationship." (Biggs 1994)

All of these results from teacher surveys and observations of classrooms have been interpreted in a unitary way – there was no discussion of how the teachers' responses might be affected by the fact that they are completing a survey for the education researchers observing them, or any other acknowledgments of context dependency. Furthermore, differences observed have been attributed to cultural background of the teacher and students. That is, because the teacher or student grew up in America or in a Confucian heritage culture, he has certain beliefs about teaching and learning.

b) Examples of other cultural beliefs analyzed as unitary

Although not epistemological, there are many other beliefs that have similarly been gleaned from surveys and have been analyzed as unitary constructs. Researchers have looked not only at teachers, but at children and parents as well. Hess and Azuma cited a survey conducted by the Japanese Office of the Prime Minister that had Japanese and American mothers select "the three most important items out of 13 that described desirable characteristics of children." From this and similar data, the authors concluded that Japanese parents believe that children should develop "skills that promote group cooperation and compliance with authority" whereas "American mothers expect children to develop initiative and verbal assertiveness."(Hess and Azuma 1991)

Many researchers have documented differences in beliefs held by teachers, students, and parents about the cause of student success and failure in school.(Biggs 1998; Biggs 1994; Hess and Azuma 1991; HW Stevenson and Stigler 1992) To quote Biggs, "… people in CHCs attribute success to effort, and failure to lack of effort, whereas Westerners tend to attribute success and failure to ability and lack of ability, respectively."(Biggs 1994) This perspective is unitary – it associates a fixed belief with a culture.

Pages 99-102 on The Learning Gap is the beginning of a section titled "Beliefs of Children, Mothers, and Teachers" in The Learning Gap. It discusses several surveys that were given in the US, China, and Japan to first and fifth graders and to their mothers. Fifth graders in Sendai, Taipei, and Minneapolis were given a survey on which they were asked how much they agree with the statement "the tests you take can show how much or how little natural ability you have." Sendai and Taipei children disagreed more readily than Minneapolis children. On a scale with 7 being "strongly agree" and 1 being "strongly disagree", Sendai fifth graders averaged a

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pedagogical practice, is an extension from the "thoroughness that comes from repetition and the emphasis on understanding."

little under 3, Taipei children a little under 4, and Minneapolis children a little under 5.

In summary, cross-cultural education researchers have studied beliefs about innate ability and effort, interest in science and school in general, beliefs about the value of a field to society, student drive to succeed in a field, and beliefs about how much confidence to place in that field's experts, and they have studied them just as Stigler and Hiebert and Biggs studied epistemological beliefs of teachers about learning in general and about the nature of mathematics – as unitary things that are not affected by context. For example, there is consistently no recognition of the possibility of survey or interview dynamics. And, again, these beliefs are based broadly upon societal influences.

c) Summary of why/how cross-cultural education researchers deal with epistemology

Thus far, I have shown a major cause for American cross-cultural education researchers to be interested in schooling-related beliefs, including epistemological ones. Standardized international exams revealed U.S. students to perform more poorly than children in other countries, such as Japan. To try to find out why, researchers looked to differences in attitude towards learning and towards specific academic subjects. These attitudes have been treated as unitary and have been determined largely by survey, with no consideration of context dependency in either the means of data collection or the interpretation of that data.

Next, I will show how many attempts to make reformed classes that are more like Japanese classes have failed. I will show how attempts to explain these failures have catalyzed deeper entrenchment into a unitary view of epistemology for the field of cross-cultural education research: "Of course you can't just teach the class the way Japanese teachers do! Your students have different beliefs about what role they should play in the classroom because they have different beliefs about what learning should look like!" The main point of this section (Part B) of the literature review is to show that the cross-cultural education research community treats epistemology as a unitary construct.

d) Failure in adopting Japanese practices has made cross-cultural educators more committed to a unitary epistemology framework

In this subsection, I will make a four-part argument to show that efforts to adopt best practices from Japanese classrooms have reinforced (or at least failed to dislodge) the unitary view that the cross-cultural education community utilizes. First, I will set up this argument by showing that people have indeed called for reform in the spirit of "make our classes more like Japanese classes!" Second, I will show that many changes have taken place that, in effect, fulfill those calls for reform. Third, I will show that these reforms are unpredictable in their outcome on student learning. Although some reforms have been effective, others that similarly make American classes "more Japanese" have been detrimental to student learning.

(More importantly, since one doesn't usually discover why such a reform does work even when it does, teachers are at a loss for knowing which reforms to implement and which not to.) Fourth, I will discuss how Stigler has accounted for these difficulties of adopting reforms in terms of cultural scripts, which are a unitary construct.

(1) Observations of classroom differences inspired Americans to call for Japanese practices

In response to the observations described in the previous section, state and nation-wide reforms have been proposed to improve curriculum and education practice by making them "more Japanese". Some reforms would not be so difficult to realize. For example, Silver encouraged stopping the practice of school staff interrupting class, for example, to collect lunch money. (Silver 1998) Other reforms, like his recommendation of adopting a Japan-like national spirit of "everyone can do mathematics if they try hard enough" may be more difficult to realize.

Reforms recommended in McKnight's report on SIMS included eliminating "the excessive repetition of topics from year to year... A more focused organization of the subject matter, with a more intense treatment of topics, should be considered."(pg. 15 of (McKnight and others 1987)) Silver repeated this call for reform, suggesting more focused lessons, with fewer ideas that are discussed in more depth. He advocated contextualizing the mathematics as Japanese instructors do, to make it be more interesting yet challenging.(Silver 1998) A Research Report by the College Board described the NCTM standards as promoting the idea that time spent in U.S. math classrooms with rote memorization and practicing lower-level computational skills would be better spent engaging with open-ended problems featuring making hypotheses, testing those hypotheses, and communicating ideas so as to enhance conceptual understanding. (Burton et al. 2002) In addition, reformers have called for teaching more advanced topics earlier, as Japanese educators do. Another reform proposed by SIMS, for example, was to not have arithmetic continue to play such a large role in junior high school, because it gives students entering high school "very limited mathematical background"(pg. 15 of (McKnight and others 1987)).

In summary, although math education researchers have advocated such reforms prior to comparative studies with Japan, observing Japanese classroom has helped to inspire reformers to call for lessons that are "discussed in more depth", motivated with contexts of a real-world problems, and involving the communication of one's own ideas.

(2) Many reforms have taken place that satisfy these calls for reform

Many reforms have taken place, at least at the official level. Observations of how American students are faring in comparison to foreign counterparts were pivotal in the development of legislation requiring states to create subject standards (Nichols

III 2008; Nichols 2007) and requiring state assessments of students to reflect those standards through No Child Left Behind. (Nichols 2007)

Much new curriculum has been designed, including College Preparatory Math (CPM). What makes CPM similar to other nations' math programs such as Japan's is that student teams are an essential component to the curriculum. The curriculum uses the math teacher as a facilitator that takes students on "guided investigations" of math problems. Students typically only work through a few math problems a day in teams, rather than the more traditional math method of working individually on numerous math problems. CPM focuses on problem solving and mathematical concepts instead of mathematical procedures."(Nichols 2007)

(3) The success of such reforms has varied

Whether inspired by observations of Japanese classrooms or by unrelated factors, many reforms that have attempted to make U.S. classrooms what could be described as "more Japanese" (emphasizing higher order thinking skills(Burton et al. 2002; Chappell 2006; Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999; Nichols 2007), emphasizing student interaction (Chappell 2006; Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999), professional development where teachers learned what difficulties students typically have and how to effectively respond (Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999), situating the content in the real world (Nichols 2007)) have been successful. At the same time, however, many other reform attempts that similarly appear "more Japanese" (focusing on underlying principles(Education 1975), having a more challenging curriculum at earlier grades (Education 1975), emphasizing higher-order thinking (Burton et al. 2002; Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999; Qin, Johnson, and Johnson 1995; Education 1975; J.W. Stigler and Hiebert 1998), emphasizing student interaction (Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999; Qin, Johnson, and Johnson 1995; Education 1975), giving teachers opportunities to meet with each other and discuss curriculum(Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999)) have ended unsuccessfully.

Stigler reports many unsuccessful examples of reforms that would result in a U.S. classroom looking more like a Japanese classroom (as described in <u>The Teaching Gap</u>, for example). Often the problem is in how the teacher goes about implementing the reform. Stigler and Hiebert showed that most U.S. teachers who reported on surveys that they implement educational reforms were attending only to the surface features of the reform, like having calculators present in the classroom, and not at the deeper intent of the reformers (i.e., how to use the calculators effectively for learning).(James W. Stigler and Hiebert 1999) "…Teachers who are asked to change features of their teaching often modify the features to fit within their pre-existing system instead of changing the system itself."(J.W. Stigler and Hiebert 1998)

In a lecture he gave at the Harvard Graduate School of Education, Stigler described several examples of this phenomenon. Stigler had observed how teachers responded to the Connected Math curriculum (1:05:11 in the video).(J. W. Stigler

2002) The curriculum has students cut, paste, and manipulate triangles with the intent of deriving the formula for the area of a triangle over the course of three or four lessons. Many teachers, however, saw in the instructor's manual that their students will be learning "the area of a triangle" and so they wrote "A = 1/2 b*h" on the board and puzzled over how the triangles students would be working with have no dotted line that would go into the "h" in the formula. Furthermore, since, in their minds, teachers had already taught the students how to find the area of a triangle, they struggled with how they are supposed to spend the remainder of the four days.

An additional example Stigler provided was from Claire Fernandez's work at Columbia on lesson study (41:50 of the video). Japanese teachers had been invited to work with American educators to instruct them in how to establish lesson study at their own school. Although the intent of the practice is to observe the teacher and the students as unobtrusively as possible so as to monitor what a typical classroom would look like, the American "observer" teachers went around the class tutoring students who were struggling. The American teachers had interpreted the task of "observe the class" in a way that made sense to them as teachers – see where students are struggling and help them.

Even if teachers do not resist reform, students often will. Stigler gave an example of an American teacher involved in analyzing videotapes of Japanese mathematics classrooms who tried to implement a reform in his own fourth grade classroom.

> *"Instead of asking short-answer questions, he began his next lesson by presenting a problem and asking students to spend ten minutes working on a solution. Although the teacher changed his behavior to correspond with the teacher in the videotape, the students, not having watched the video and not having thought about their own participation, failed to respond like the students on the tape. They played their traditional roles and waited to be shown how to solve the problem. The lesson did not succeed."(J.W. Stigler and Hiebert 1998)*

Chappell acknowledged that, although he and (eventually) his students considered a reformed geography class using the PBL curriculum to have been successful, many of his colleagues, in observing how torturous the experience was for students, did not have that perspective while it was taking place. He described what the students went through as a "grieving process" and wrote that critics "might also cite as evidence against PBL being worthwhile the tempestuous nature of the learning ('grieving') process."(p. 27 in (Chappell 2006))[18]

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[18] Chappell's description of how his students changed in their epistemology of how to learn geography is consistent with what cognitive scientists in the unitary epistemology camp (described in Part A above) describe. The students began with a stable attitude about how learning should take place, and, in Chappell's account they underwent a slow transformation into a new stable attitude.

(4) Stigler's "cultural scripts" (which treat students as having a unitary epistemology) explain why reforms don't always work

Stigler's explanation for many attempted and failed reforms is that too often a reformer or teacher will try to make localized changes, without recognizing the complexity of the interactions taking place in the classroom. Stigler and Hiebert discussed how cultural activities, like learning in the classroom,

> *"often have a 'routineness' about them that ensures a degree of consistency and predictability. Lessons are the daily routine of teaching and are usually organized according to a 'cultural script,' a commonly accepted and predictable way of structuring a classroom session and sequencing the instructional activities."(James W. Stigler and Hiebert 1997)*

In The Teaching Gap, a vivid anecdote from Albert Shanker was quoted as an example of how Yemeni immigrants assimilated the idea of using a table into their cultural script of eating a meal:

> *"As we were touring this housing project, we were told that most of these people had lived in tents or in very primitive housing and that most of them had not eaten on tables. There was this concerted effort to convince them to use tables. As we went through the development, our guides said, 'Let's visit one of these families...' … We walked in, and there was a family from Yemen, and they were eating from the table. But the table was upside down with the top on the floor and the legs standing up." (Shanker 1997)*

Although Stigler of course acknowledges that there are teachers and lessons that diverge from the script, it is the similarities across teachers and across classrooms within a country (when compared to counterparts in other countries) that are the most striking, and that is what serves as the focus of his discussions and analyses. The observations described above that were found in the TIMSS 1995 video study are part of the cultural script that Stigler claimed to be shared nationwide. For example, most of the work done by 8th graders in the U.S. math classroom is related to memorizing definitions of terms and following procedures for solving exercises. Japanese students, in contrast, create and share their own solutions. (James W. Stigler and Hiebert 1999) Patterns like these are part of the "commonly accepted and predictable way of structuring the classroom session."

The answer to the question of where these scripts come from can similarly be found in The Teaching Gap.

> *"As children move through twelve years and more of school, they form scripts for teaching. All of us could probably enter a classroom tomorrow and act like a teacher, because we all share this cultural script. In fact, one of the reasons classrooms run as smoothly as they do is that students and teachers have the same script in their heads: they*

know what to expect and what roles to play." (pg. 87 of (James W. Stigler and Hiebert 1999))

During his lecture at Harvard, Stigler at one point talked about how people often think that brilliant engineers, who were for example laid off from the aerospace industry, would make great math teachers, but that, looking at their classrooms, it turns out that even they teach using "the same standard American script."(J. W. Stigler 2002)

Teachers and students bring with them cultural scripts with which to manage their involvement in the classroom interaction, and a reformed curriculum that is incongruent with these scripts (like what Stigler's anecdotal teacher brought into the 4th grade classroom) will meet with failure. Thus, to change what happens in the classroom, it is necessary to change not just one component of the system (textbooks, for example, that focus on underlying concepts), but the entire system as a whole (consisting of textbooks, teachers, and students). And even then, as demonstrated by Chappell's students who went through the grieving process, it takes time and effort to change that script.

In "Teaching is a Cultural Activity", in contrast to the reforms of "new math" in elementary schools, Stigler credited Geoffrey Saxe with establishing a reform that was successful because it "addressed the system." This reform not only implemented new curriculum, but also included teacher professional development that helped the teachers learn how to teach the material, as well as how to motivate students. (Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999) Although Stigler described the national culture surrounding the classroom as being a huge contributor to the creation of cultural scripts, he did not provide examples of successful reforms that made changes to national culture. Presumably, the more pieces of the system (including the cultural background) you can change, the better your chances of success teaching a reformed class.

Stigler's emphasis on the system (instead of on the individual student, teacher, or curriculum) is not unique. For example, Biggs has called for the importance of looking at the overall system, warning against assuming that Western classrooms would have no losses in increasing class sizes (since CHC classes are so big), for example.(Biggs 1998) The first highlight of research findings of IAEP-II was that "Factors that impact academic performance interact in complex ways and operate differently in various cultural and educational systems. There is no single formula for success"(pg. 15 of (Lapointe and others 1992)). Anderson, Reder, and Simon expressed a similar idea of the overall system playing a crucial role in learning, albeit less positively. "Geary, 1995, argues, as have others (e.g., Bahrick & Hall, 1991; Stevenson & Stigler, 1992), that it is this difference in cultural support that accounts for the large difference in mathematics achievement between Asian and American children."(Anderson, Reder, and Simon 1996)

Cultural support can manifest in smaller ways, such as tacit agreements to not interrupt classrooms with public announcements, larger ways, such as the institution of lesson study, and insidiously pervasive ways, such as the general attitude citizens have about learning. It has been argued that the attitude Americans have towards elementary mathematics is that it is very simple and that it is just a bunch of rules that need to be memorized. (Ma 1999) Factors such as these can contribute to student (and teachers!) unwillingness to engage with curriculum in the way desired by education reformers. "Attitudes can be influenced by students' peers in the classroom, the culture of their school, their home and family culture, and more generally their national culture."(pg. 11 of (Schleicher 2012))

Thus, the idea of cultural scripts has provided an explanation for why reforms do not necessarily work. "You can't just plug Japanese curriculum into your own classroom, because your students have expectations about what learning should look like in the classroom, and those expectations play an important role in learning." This framework of cultural scripts has been vital in explaining to educators the dangers of thinking that students are blank slates that are indifferent to the pattern of how learning takes place in the classroom.

At the same time, however, this framework has treated these student expectations as being rigid, unitary things. Although these expectations interact with the other features of the classroom, they are not themselves affected by the context. Hence, in taking up the idea of cultural scripts to explain what reforms can and can't work in a classroom, cross-cultural education researchers have become more committed to (or at least, not questioned) a unitary epistemology framework.

e) The origin of cultural scripts

In the previous subsection, I explained how Stigler's concept of cultural scripts has been used to account for how often reforms aimed at making an American classroom more like a Japanese classroom don't work. I described the concept of cultural scripts to show how they treat students and teachers as having expectations about learning that are determined by the culture that the person grows up in, and that are unitary in nature. In this section, I will provide some of the theoretical background surrounding the concept of cultural scripts. I do this to show that much of the theoretical heritage that cultural scripts arise from is not, actually, unitary. In fact, the authors that Stigler references for his idea of studying the system utilize theoretical perspectives that are more manifold. This suggests that the idea of cultural scripts can either be modified to become a manifold construct, or that an alternative (manifold) theoretical framework can be applied to the field of cross-cultural education research. I will discuss this idea in section C of this literature review, and also in the Discussion of this dissertation.

(1) "Scripts" as described by Stigler mirror those described by Schank and Abelson

Stigler and Hiebert described a cultural script with the example of family dinner.

> *"Everyone comes to the table and begins eating at about the same time. There are no menus; the food is brought to the table in containers and everyone eats the same things. The food is then parceled out by passing the containers around the table, with everyone dishing up their own*

> *portions. Adults often help children with this task. Conversation usually is open, with no set agenda. Comments from everyone are welcome, and children and adults participate as conversational partners… Family dinner is a cultural activity. Cultural activities are represented in cultural scripts…"(J.W. Stigler and Hiebert 1998)*

Comparing this example with those of Schank and Abelson (for example, the routine that one follows when entering a restaurant) reveals strong similarities. (Schank and Abelson 1975) Furthermore, there is a strong resemblance to be found in comparing Stigler and Hiebert's definition of a script: "generalized knowledge about the event that resides in the heads of participants. These scripts not only guide behavior, they also tell participants what to expect."(J.W. Stigler and Hiebert 1998) with those of Schank and Abelson: "A script, as we use it, is a structure that describes an appropriate sequence of events in a particular context… They are not subject to much change… a script is a predetermined, stereotyped sequence of actions that define a well-known situation. A script is, in effect, a very boring little story." (pg. 151)(Schank and Abelson 1975) Although none of Stigler's writings cite this seminal work by Schank and Abelson, it is possible that his idea was in some way inspired by their own.

The important difference, however, in how Stigler uses the construct of scripts, is that he both implicitly and explicitly takes the "predetermined, stereotyped sequence" of "what to expect" as being the extent of the participant's expectations. Stigler and Hiebert note that "We'd be surprised at a family dinner, for example, to be offered a menu or presented with a check at the end of the meal."(J.W. Stigler and Hiebert 1998) This idea of being surprised when the script is violated is repeated with his anecdote of the fourth grade math class. In other words, the students had a fixed expectation of what to find in the classroom, and when that was not met, they were unable to productively deal with the reformed class.

Schank and Abelson, on the other hand, introduce scripts as a "specialization" of the idea of framing, and like other frame theorists emphasize the context-dependency of framing. They do acknowledge that there is a "classroom script", and the way that they would likely describe the script-violating that took place in Stigler's anecdotal fourth grade classroom would be in terms of an "obstacle", which is when "someone or something prevents a normal action from occurring or some usual enabling condition for the action is absent… the methods used to remove the obstacle… are stored with the script as what-ifs." In other words, an "obstacle" is not the end of the story for these authors. "Perhaps a new action not prescribed in the script will be generated in order to get things moving again. **This 'what-if' behavior… is an important component of scripts**" (emphasis added) Stigler and his colleagues do not discuss these "what-if"'s.

In summary, scripts for Schank and Abelson are pre-determined and stereotyped. However, the way that people interact with scripts is fluid. In Stigler's writing, when a script is violated, the participant seems unable to adapt. For Schank and

Abelson, such a situation is described as an "obstacle" and is overcome with built-in "what-if" behavior.

(2) The theorist Stigler and Hiebert *do* cite also uses a fluid theoretical framework

The idea of "cultural scripts" described by Stigler is strongly in line with perspectives such as situated cognition and the sociocultural framework. In "Teaching is a Cultural Activity", Stigler and Hiebert cited Gallimore, a socioculturalist, as reaching similar conclusions as Stigler and Hiebert did. Gallimore, in turn, cited Erickson, Rogoff, Moll, and others, for their perspectives of classrooms being about cultural activity (pg. 231 of (Gallimore 1996)).

Gallimore argued that because the context of the classroom is a "joint, social construction of two or more participants", the unit of analysis cannot be at the level of an individual component (pg. 233 of (Gallimore 1996)). Gallimore challenged the idea of Piagetian stages by citing variations of the conservation task.[19] If the task is interrupted and another adult takes over the task, or if it is interrupted by a "naughty puppet" pulling a screen in front of the beakers, or if the task is reframed to be a game about fairness, studies show that children are able to give the correct answer at a much younger age. The changing context affects how the child interprets the task, and hence what inferences they make. Gallimore used this as an argument that cultural norms affect how students respond to a task.

> *"A child brings to any encounter with an adult… some understanding of the meaning and purpose of an activity, a set of normative interaction rules or conduct scripts, and some capacity to construct an interpretation of the unexpected. The Piagetian experiments suggest that cultural norms are affecting some children's response to the conservation problem… Young children in the conservation experiments bring whatever pieces of that heritage they have thus far appropriated. The variability in results as a function of subtle changes in the testing context indicates that they use these appropriations to construct an understanding of what the task is and what the experimenter wants to know."(pg. 238 of (Gallimore 1996))*

This language is very similar to that of framing described in part A above. Indeed, compare Gallimore: "What's in the head of participants in a particular setting contributes to the "reality" that is perceived and responded to… Reading a text can be for fun, learning, a gateway to upward mobility, or a sacred path to heaven."(pg. 232) with Bateson's discussion about monkey biting.

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[19] In the traditional conservation task, children are shown two identical beakers with the same amount of water. Water is poured from one beaker into a third wider beaker and children are asked to compare the amount of water in the wider beaker to that in the other untouched beaker.

Despite these similarities, Gallimore does not use the word "framing" nor does he cite any of the frame theorists mentioned above. In fact, a citation search on Google Scholar revealed that nothing written by Gallimore cites Tannen's "What's in a frame?", Goffman's "Frame analysis", or Bateson's "Steps to an ecology of mind" with the exception of one article citing the work by Bateson. That one exception cited Bateson for a different reason and does not discuss framing.

Gallimore, citing Blumenfeld (1992), explained a reason for children to shy away from approaching difficult problems in the classroom. "…prior educational history, conventional classroom practices, or prevailing peer norms form the basis of student resistance. In other words, students may resist challenging tasks for sociocultural reasons." (pg. 239 of (Gallimore 1996)) This is very similar to Stigler's anecdote about the students in his colleague's 4th grade math class. Students bring with them personal experiences and expectations about what should happen in the classroom, and this plays a role in determining how they will respond to what is presented in instruction. Gallimore, however, provided room to make a more subtle argument when he cited page 4 of Grossen and Perret-Clermont : "The child's cognitive activity is… always an answer to the [local] staging [or activity setting] and what he interprets about its sense and aims." (pg. 240 of (Gallimore 1996))

The referenced Grossen and Perret-Clermont book chapter chiefly argues against saying that a "child's cognitive abilities are individual characteristics" and asserts instead that they "appear as being the fruit of a social co-construction whose result does not depend entirely on the subject…"(pg. 255 of (Grossen and Perret-Clermont 1994)) Again, looking at Piagetian conservation tasks, they found a correlation between student cognitive ability as determined by the task and how students were interpreting the activity (as determined by the instructions the students then in turn gave to classmates while impersonating the experimenter). Namely, all but one of the students who were categorized as "non-conserving", defined the task to their classmates as being one of evaluating how high the water level in each beaker was. All the "conserving" students, on the other hand, in turn explained the task as the experimenter had. Thus, it seems likely that the way students interpret the task has important implications for their "success" or "failure" in the eyes of the task administrator. In other words, if a child gives the wrong answer to a conservation task prompt, it does not imply that the student "lacks conservation"; rather, it could be just that the participant was interpreting the task in a different way. The researchers had the children explain the task to another participant as means of determining how the children were interpreting the task.

Critically, the authors discussed that this understanding of (and presumably attitude towards) the task is itself something that can change fluidly. To use language more accurate of their framework, they described the object of the interaction between the interviewer and child as one that is constructed in the interaction itself and that is a negotiation between the interviewer, the child, and the task at hand. This agreement is "not a constant state, but a series of states which are continually challenged by interruptions which provoke the interactants into recreating a new state…"(p. 256 of (Grossen and Perret-Clermont 1994)) Clearly, elements of this framework are very similar to that of framing described previously.

Despite these similarities to framing, like the Gallimore book chapter, the Grossen and Perret-Clermont chapter does not mention framing, nor does it cite frame theorists of renown. It is noteworthy that the work of socioculturalists like Gallimore and Grossen and Perret-Clermont has developed independently of the development of the framing framework. This point will be revisited below, and it will be suggested that the ongoing debate in cognitive science about the degree to which understanding and attitude are context-dependent is relevant to these and other researchers who look at emergent phenomena in interactions. From there, I will suggest that the arguments made in cognitive science in favor of a manifold framework over a unitary one can similarly apply.

Like Grossen and Perret-Clermont, many education researchers who look at the level of the system do not think of the student as bringing in a stable attitude towards the course material. For example, Brown, Collins, and Duguid described research showing that you cannot separate what is learned from how it is learned and used. Thus, the idea that schools have of transferring some substance of knowledge with the school setting being ancillary is unfounded. You cannot ignore the influence of school culture on what is learned.(Brown, Collins, and Duguid 1989) Herrenkohl (Herrenkohl et al. 1999; Kawasaki, Herrenkohl, and Yeary 2004) similarly acknowledged that student epistemology is dependent on context of what activity is being done and where it is taking place:

> *"this article would not claim that the results from this study would work for other content areas in science. Therefore, a possible limitation of this study is that the students' developing epistemology of science is done in one context (theory building and modeling in a sinking and floating unit) with one data source (student conversations during classroom instruction)." (Kawasaki, Herrenkohl, and Yeary 2004)*

Stigler's notion of cultural scripts, on the other hand, does not allow for such pliancy in a student's notion of what constitutes a "classroom". In "Teaching is a Cultural Activity", Stigler does not explicitly say that the 8th grade students attitude about what constitutes appropriate mathematics instruction is context-independent. However, looking at the methods and analysis Stigler uses to make his claims about what constitutes a "cultural script", we see that the theoretical construct as he defines it is unitary in nature. He looks at a coarse grain size (i.e., Japanese students share experiences surrounding and within school that could feasibly lead to observed differences) and utilizes poignant examples that, while demonstrating that students are part of the system, do not speak to variability of students from moment to moment. Most importantly, his means for determining what he refers to as students and teacher "beliefs" that Japanese and Americans "have", especially as described in <u>The Teaching Gap</u> and <u>The Learning Gap</u>, are primarily surveys where participants answer how strongly they agree with a given statement (as described above).

In this section, I have described the intellectual roots of cultural scripts. Although the construct as used by Stigler is unitary in nature, this comes as the result of removing or ignoring context-dependency prevalent in those roots. Since the theoretical heritage would allow (and even expect) variability in the participants' behaviors, however, I will argue for either a modified (context-dependent) version of cultural scripts or for some alternative concept (that maintains this fluidity) to be taken up and utilized by the cross-cultural education research community.

f) What has happened to Stigler's scripts since then

The students that Stigler's research has looked at are exclusively children up to 8th grade. However, he clearly does not restrict his framework to only be applicable to children, as he has written much about cultural scripts that teachers and parents have. Furthermore, cultural scripts have been adopted as tools for looking at students struggling at the college level as well, and I will discuss some of these studies in this section. I will show that all who have taken up the concept have maintained the unitarity of Stigler's scripts.

A search on Google scholar for scholarly works citing "Teaching is a Cultural Activity" turned up about 80 sources (which pales in comparison to the 2257 hits on The Teaching Gap but is significant nevertheless). These sources were first opened and searched for where "Teaching is a Cultural Activity" is cited to see whether or not they cited the article for the purpose of talking about cultural scripts. Consistently, the script that a student has is treated as an individual collection of beliefs that are developed as the result of past group experiences. Also consistently, none of the articles that talked about these scripts preserved the context-dependency of student reasoning found in many sociocultural works. Rather, student attitude towards an academic subject was often perceived as something that can be gleaned from a survey and that then interacts as a stable entity with the other elements of teacher attitudes (also often discernible from a survey) and curriculum.

Holland, for example, wrote about international teaching assistants adjusting to being a TA in America. (Holland 2008) Paula (one of the TA's) said she was having trouble accepting the ethos of making students compete with each other instead of collaborating, and the author explained this with the following:

> *"Paula's perplexity stemmed from a belief system about students and the classroom environment acquired from years of cultural orientation that dictated attitudes and behaviors. Behaviors, then, were the result of what Stigler and Hiebert (1998) referred to as a 'cultural script, generalized knowledge about the event that resides in the heads of the participants'…The participants brought their originary cultures of learning with them to the site institution." (pg. 182 of (Holland 2008)).*

In Holland's framework of analysis, the TA's attitudes towards learning were "dictated" by her cultural background. She had a system of "beliefs" about what a classroom should look like that were carried with her wherever she went. Implicit in this description is a unitary characterization of the attitudes carried by Paula.

Contrast especially Holland's last sentence of the quote above with the quote by Grossen and Perret-Clermont above: "The child's cognitive activity is… always an answer to the [local] staging [or activity setting] and what he interprets about its sense and aims." Although Stigler and Hiebert's language of a script being "generalized knowledge about the event" does not rule out the possibility that the espoused attitude of the individual may be in response to the contextual setting, Holland and many others have interpreted it as doing such.

Chappell suggested that the difficulties his students had in accepting PBL (Problem-Based Learning) were evidence that students are bringing in scripts about learning that conflict with the curriculum and that are negotiated as they manage change. (Chappell 2006)

Isabelle, reflecting on preservice elementary teacher training programs, wrote about how teachers acquired cultural scripts (about what learning should look like) in their early years of schooling that tenaciously resist change. "Although we have attempted to provide dominant and powerful constructs to compete with alternate conceptions, we are faced with the task of assisting teachers to resist their own cultural scripts."(Isabelle and de Groot 2008)

To be clear, the argument is not that other researchers are using Stigler's writings on "cultural scripts" to suggest that people cannot change their attitudes towards learning. Rather, it is in part the nature of what this change looks like that is being contested. Isabelle's description of a "cultural script" suggests that teachers bring with them a unitary and stable initial belief system (which may or may not include epistemological beliefs), and that in order to get the preservice teachers into the desired end state, that unitary epistemology must undergo a transformation, or be removed and replaced by an "alternate conception." Holland described a similar process, and a prediction consistent with this idea is that, once this transformation has been completed, teachers will bring this new epistemology with them to the schools where they will teach. Common experience, however, suggests that it is more realistic for a teacher, when thrown into a classroom where there are actually little kids running around, to adopt a new attitude towards learning that may be quite different than what was "learned" in the preservice teacher training (and that is likely also different than what the preservice teachers would have written as their "philosophy of teaching" prior to the training.)

Researchers taking up Stigler's construct of cultural scripts as unitary have included not only education reformers in America, but cross-cultural education researchers as well. Perhaps most notably, the Learners' Perspective Study (LPS), which was initiated in reaction to complaints about the TIMSS video study "ignoring the important role students have in the learning process"(Amit and Fried 2005) and currently consists of researchers in fifteen countries benefiting from funding sources worldwide including the World Bank and the Spencer Foundation, is intended to make conclusions about stable attitudes that students carry in their heads. Clarke, first editor of both volumes in the LPS Book Series, cited Stigler and explained

"Culturally-specific teacher 'scripts' were identified by which the practices of teachers in the USA, Japan and Germany might be differentiated and studied. However, this research into mathematics classrooms collected only single lessons from each teacher and did not address learner practices. In the same way that coherent sets of actions, and associated attitudes, beliefs and knowledge, appear to constitute culturally-specific teacher practices, it is hypothesized for the purposes of this study that the actions and associated attitudes, beliefs, and knowledge of students constitute a culturally-specific coherent body of learner practices."(D. Clarke, Keitel, and Shimizu 2006)

Clarke explained that the act of a student solving a problem publicly in front of the class is openly accepted in some countries but a rare occurrence in others and that "such time-honored practices and the values and beliefs which they embody are deeply 'cultural' in character." Researchers determined these beliefs by giving teachers and students questionnaires. (D. Clarke, Keitel, and Shimizu 2006)

Contrast again this approach with the words of those operating under a sociocultural perspective:

"At first sight, terms such as… 'cognitive development' could therefore be interpreted as the development of the child's internal competence (possibly influenced by some social factors). Nevertheless, the studies reported showed that the problem is more complex since the social context is far more than a set of external factors which influence development: it plays an integral part in cognitive activity. This means therefore that, in order to understand and interpret children's cognitive activity, it is not sufficient to observe the child as an isolated unit of analysis; on the contrary it is necessary to consider the interaction between the individual child and the social actors he interacts with…" (p. 256-257 of (Grossen and Perret-Clermont 1994))

Two notes are in order at this point. First, not all cross-cultural education research revolves around surveys and making broad claims about beliefs of the students in a country. The work that, for example, Amit and Fried have done with the LPS project has implemented video recordings of classrooms and semi-structured interviews (Amit and Fried 2005; Fried and Amit 2003) for the purpose of case studies, like those called for by Gallimore (pg. 245 of (Gallimore 1996)) and other socioculturalists. They have thus kept their claims about relationships of authority (Amit and Fried 2005) and the role of the student notebook (Fried and Amit 2003) to the confines of the math classes they studied. Although the grander scope of the LPS project is "to identify and explore the ways students conceive mathematics classroom practice and mathematics learning", it is not necessarily the case that Amit and Fried personally agree with the hypothesis set forth by Clarke (above).

Since Amit and Fried did not lay out a conceptual framework in which to situate their research, no claim can be made. I will hence make an argument in the Discussion section of this dissertation that, rather than having their results be used as evidence of student beliefs about authority in a given country, it is worth considering a framework in which it is *not* assumed that just because students act a certain way in one context that they will always act that way.

Second, Stigler and those inspired by his idea of cultural scripts are not the only ones in the field to treat students as having rigid beliefs about learning that come from their culture. Biggs, in writing about why CHC students encounter difficulties when studying in Western countries, explained "CHC students will be moving from an academic culture based on a set of values and expectations that are congruent with their general socialization to an environment lacking familiar support structures." (pg. 56) As Holland explained, these students "bring their cultural frameworks with them to study in Western institutions." (pg. 60) (Biggs 1994)

In summary, the notion of cultural scripts as taken up and passed on by Stigler aligns poorly with the sociocultural roots from which he claims the idea originated. The idea of learners continuously reevaluating the interaction between themselves and their surroundings has been lost, and instead, the learner's "script" (or, using Biggs's verbiage, her "cultural framework") is being discussed as "an isolated unit of analysis".

C. Gaining perspective on cultural scripts and proposal for a manifold epistemology alternative

1. The notion of cultural scripts has already been challenged, but not for their fluidity

Although many researchers have challenged the idea of cultural scripts, none of these challenges have been about the unitarity of the construct: none of the sources on Google Scholar citing "Teaching is a Cultural Activity" considered the fluidity of so-called "beliefs".

Although Clarke has made arguments against Stigler's notion of scripts (and has noticed that Stigler and Hiebert themselves have changed the phrasing of the concept as time has passed from "lesson scripts "in 1998 to "lesson patterns" in 1999, the arguments have been at the level of diversity between what happens from lesson to lesson and from teacher to teacher. (D. Clarke 2003; David Clarke et al. 2007) Although he has challenged Stigler and Hiebert at the cultural level, he has not done so at the cognitive level.

Zaman similarly criticized Stigler's claims of how widespread scripts are across a country. Looking at questionnaires from the IEA (which used a Likert scale), most teachers in the three countries Zaman looked at had similar responses for most of the statements in the three categories he analyzed. (Zaman 2006) Specifically, he found that the degree to which teacher responses differed *across* countries was not significantly larger than the degree that they differed *within* a given country. At the same time, however, Zaman upheld that the study did "show that differences among the countries exist that can be correlated with some national factors and conditions." From the survey analysis, he concluded that "English teachers did not agree that serving in the military or being loyal and patriotic to one's government were signs of good citizenship" and this is consistent with the fact that "schools in England have long been viewed as institutions responsible for developing critical reasoning rather than shaping nationalistic goals."

LeTendre challenged cultural scripts from a different angle. He summarized the idea of national scripts (citing Stigler and Hiebert, 1998) as extensions of the national cultures model, which assumes "hard wiring" between culture and teaching. (LeTendre et al. 2001) LeTendre challenged the idea that "cross-national differences in beliefs or values held by teachers are the root of major cross-national differences in instructional approaches." This disagreement too was not provoked because of disagreement about whether or not teachers "have beliefs", but rather because "much of the 'culture' of nations like Japan, the U.S., and Germany is embedded in shared common institutional forms establishing similar organizational patterns based on a single overarching model, e.g., the hospital, the school, the legislature, and the corporation."

To summarize, some (D. Clarke 2003; David Clarke et al. 2007; Zaman 2006) of the researchers discovered in this way argued that their research findings suggest a comparable degree of diversity in beliefs within countries as between countries. Others (LeTendre et al. 2001) argued that those differences in beliefs don't correspond to differences in instruction. However, no researcher citing "Teaching is a Cultural Activity" has contended with the idea that the beliefs captured by cultural scripts are stable across contexts, and I am not aware of any cross-cultural education researchers who have addressed the fluidity of beliefs.

2. Although complicated cross-cultural data exists, students are still treated as having unitary beliefs

The dispositions and interests that foreign students supposedly bring with them into the classroom are being discovered to be rather complex. For example, the LPS study on authority (Amit and Fried 2005) found that student deference to authority is hierarchical, both in terms of who is closest spatially to the students, and the degree to which a person's statements are to be taken unchallenged. Similarly, the ROSE (Relevance of Science Education) project found that, despite not being interested in science and technology in general, surveyed girls were nevertheless very interested in learning the physics of cell phones and whether they can hurt the human body. (Ogawa and Shimode 2004) However, researchers continue to analyze this learner-centered data with a lens that sees a student as having ONE attitude/ set of interests or beliefs (however complex it may be) that interacts with the context of the classroom, curriculum, and educator.

3. Conclusions on cultural scripts

Cultural scripts and other frameworks that compare beliefs of peoples raised in different cultures have been of tremendous benefit. Cross-cultural researchers using such frameworks have contributed to educators and cross-cultural education researchers in much the same way that cognitive scientists using unitary epistemology frameworks have contributed to teachers and education researchers. Perhaps the greatest benefit is that the argument "you can't teach your American students the way that Japanese teachers teach their students because your students have different beliefs about learning" prevents teachers from trying to haphazardly implement reforms that will make their classes "look Japanese" and end up causing more harm than good (see Discussion Part 1 for more on this).

Just as there was an alternative to unitary epistemology frameworks in cognitive science, however, so too there is one for the field of cross-cultural research. The data that I will present will make the argument for manifold epistemologies more promising, both in terms of elegance (D. M. Hammer and Elby 2002) and explanatory power.

To be fair, it is not being argued that, if asked, Stigler would staunchly defend that students in a classroom have a rigid cultural script that dictates how they will respond to instruction and that that script must be changed for them to proceed productively in an unusual classroom. Indeed, in his lecture to the Harvard Graduate School of Education(J. W. Stigler 2002), he provided an anecdote similar to that provided in "Teaching is a Cultural Activity", about a 2nd grade teacher in Los Angeles who had read some papers by Stigler and colleagues and had wanted to try to teach a lesson that had been successful in Japan. She had the videotapes and text materials translated, and after all her hard work, found the lesson to utterly fail. Stigler asserted that the problem was that her students were not Japanese: "The same presentation and material that Japanese students respond to leave American students flat." He went on to add the following as an interesting aside:

> *"Her solution to this problem was to actually get the video, go in and show it to her second-grade students saying 'Now let me explain what we're trying to do here.'" (laughter from the audience) "'I'm trying to act like that teacher, so you're supposed to act like those students.'" (more laughter). "And actually, they had a really good time with that, once they realized that they were putting on a play and not" (more laughter) "you know, just taking a regular old math lesson." (J. W. Stigler 2002)*

This anecdote, actually, is supporting evidence that students have multiple "scripts" that can be utilized in the classroom. This is supporting evidence that Stigler recognizes that students *are* variable in their perceptions of what kind of behavior is appropriate for learning in a classroom. But the *framework itself* of cultural scripts, as described in Stigler's writings, lacks this nuance. Particularly in The Teaching Gap and The Learning Gap, claims about the cultural scripts that students, teachers, and parents have are warranted by surveys that participants fill out, surveys that determine their "beliefs" about learning and the nature of mathematics, effort, etc. This is exactly how the construct has been taken up by education researchers in America as well as by cross-cultural education researchers like those mentioned above – students have a cultural script consisting of unitary attitudes towards what appropriate learning should look like.

a) Scripts could reasonably be reconceptualized as manifold, given the similarity to framing

As discussed above, it appears that a similar theoretical construct has developed in seemingly separate intellectual traditions. Although Tannen and other frame theorists tend to be more sociocultural, linguistic, etc., their argument is that frames are something in the minds of the interactee. Goffman's frame resides in one's head. Gallimore and other socioculturalists, on the other hand, focus on emergent phenomena at the level of the system. In personal correspondence, Redish described framing as "the interface between the individual and the socio-cultural. It's where the individual keeps and applies her knowledge about what to expect and how to behave in social situations." It is not difficult to describe cultural scripts with consideration of such a description: a cultural script for school is a framing with epistemological and behavioral components. To answer the question "what is going on here?", the interactee brings to bear an epistemological stance, a set of associated expectations, and from there, associated ways of acting.

With this in mind, we see that the same kind of debate that takes place in cognitive science between unitary and manifold epistemological frameworks is applicable to the notion of cultural scripts as well. The nuanced work that has been done arguing for a manifold epistemology framework over a unitary one can be productive in explicitly considering the ontology of just what it is that students in America bring with them into a classroom that makes it difficult for them to adapt to a curriculum that works in Japan. In the next chapter, I will present some data that will give us further cause to question the idea of cultural scripts as a unitary construct, and it will be suggested that cross-cultural education researchers instead consider the context-dependency of student epistemology.

IV. Students Adapted Quickly to the Unfamiliar Physics Curriculum

A. Introduction

In "Teaching is a Cultural Acitivity", Stigler and Hiebert provided the example of an American fourth grade math teacher, who tried to implement a Japanese-style lesson in his classroom. (J.W. Stigler and Hiebert 1998) Although the teacher typically taught by giving the students short-answer questions, he changed his approach one day and instructed the students to spend ten minutes working on a difficult problem that he posed. The students, however, responded with silent anticipation of the teacher giving them the answer, and they remained idle.

Stigler explained that the students had a cultural script about what learning in a mathematics classroom should look like, and the teacher was violating that script with the problem he had posed and his request that they think about it on their own for such a long time.

Chappell told a similar story of his undergraduate students in a geography class that had been reformed to feature Problem-Based Learning (PBL). The students wrote in their journals how they found the style of instruction to be "useless and boring" and that that style of teaching "is not suited" to the group of students. Chappell described this resistance as a "grieving process."

The implementation of Tutorials at Gakugei was in many regards the flip of what Stigler's anecdotal teacher performed. Rather than trying to put a Japanese class into an American school, a course designed at and for an American university was implemented in a Japanese school. The concept of students coming to the class with expectations of what would happen, and having those expectations absolutely violated, however, was a constant. In the case of the fourth graders, they had gone to many math classes previously where the implicit message had been that if they are not able to solve a problem on their own in a few minutes, then they have not yet learned the needed material, and they should wait to be taught it by the teacher. (H. Stevenson and Stigler 1992) In the case of the Gakugei students, they were coming from experiences of high school and college physics of sitting and listening to the teacher lecture, memorizing equations, and using the canonical knowledge to solve problems.

Although Tutorials absolutely violated expectations brought about by the Japanese university student "culture" of what a college physics class should look like, the students by and large DID NOT respond the way Stigler's anecdotal fourth graders did.

In this chapter, I will draw upon video and field notes from early Tutorials, TA's reports, student interviews, and the 2012 survey to show that there was no widespread "grieving process" or other form of resistance that made the class fail.

Rather, students in interviews reported that although they had had a reaction of surprise, it had been easy for them to accept this new style of class.

What could account for this difference in how students react to their expectations about learning being violated? That question will be addressed in later sections. In this chapter, however, I set out only to demonstrate that there was no widespread resistance: the class proceeded smoothly.

First, I will discuss what evidence is available that students did not enter Physics Exercises already predisposed to apply their own ideas to actively learn physics. Then I will present data that exists from the first two weeks of Physics Exercises to show that students eagerly took up the new style of physics learning. Then I will begin to develop a hypothesis from my data as to why this took place. This hypothesis will be built more fully in later chapters of this dissertation.

B. Students entered expecting to learn physics as they had in traditional classrooms: without making sense of it

1. Traditional physics instruction (like that in Japan) leads American students to the expectation that physics doesn't make sense

The scholar commonly cited for depictions of Japanese high schools is Thomas Rohlen, who wrote the seminal book Japan's High Schools in 1983. Twenty-nine years after his publication, many Japanese colleagues of mine still feel that the descriptions of students sitting and passively absorbing knowledge from the instructor to later regurgitate on college entrance exams is an accurate one.

Research done on physics classes taught in this kind of didactic style reliably shows that students leave such classes with unsophisticated attitudes about the nature of knowledge and learning in physics. (Edward F. Redish, Saul, and Steinberg 1998)

2. But would it have that effect with Japanese students?

The research done by Redish, Saul, and Steinberg, however, looked only at physics classes in America, and extending the results to didactic physics classes in Japan must be done with caution. Stigler (J. W Stigler, Fernandez, and Yoshida 1996), in discussing why high schools in Japan are so different from primary school, wrote:

> *"Perhaps elementary lessons are the way they are in order to explicitly teach young Japanese students how to think, analyze problems, and invent solutions. Once they have learned these skills, however, it is no longer necessary to display them publicly, hence the shift in high school."(247)*

One can interpret this speculation as implying that the tendency of students to analyze problems and invent solutions is one that persists into high school. Hence, although high school students are being bombarded by knowledge from their physics teacher, they remember the value of making sense of school knowledge themselves, and they do so. Biggs similarly argued that repetitive drills in CHC classrooms does not necessarily imply rote learning is going on. (Biggs 1998; Biggs 1994)

3. There is evidence that the traditional physics classrooms did affect Gakugei students' expectation that physics doesn't make sense.

The most compelling data that the Gakugei students did not think that the physics knowledge they were being bombarded with was material that they could and should personally make sense of would come from interviewing and observing the students in their physics classes prior to entering Physics Exercises. Although this is of course impossible, a candidate for future research would be to follow students along their trajectory from traditional physics classes into Open Source Tutorials.

With the data that is available, however, there is still good reason to doubt that many of the Gakugei students had had positive expectations about physics and physics learning in their prior physics courses. Students consistently said in interviews not only that, prior to Physics Exercises, their experiences in physics classes had been very similar to Rohlen's depictions, but also that they had accordingly thought of physics as being a body of formal knowledge passed on by authority that one should memorize whether or not it makes personal sense. This attitude is similar to what Redish, Saul, and Steinberg found to be common as a result of traditionally-taught American physics classes. (Edward F. Redish, Saul, and Steinberg 1998)

A table of students and what previous physics classes they had taken, what style the classes were, and what they claimed to have previously thought about physics is provided in Appendix G. Note that, out of 28 students, 21 students described pre-Physics Exercises physics as being lecture-based and 20 students described pre-Physics Exercises physics as emphasizing memorization. Most of the remaining interviews do not have evidence to confirm or disconfirm whether pre-Physics Exercises physics was lecture-based or focused on memorization. Note also that only 3 of the 28 students NEITHER described pre-Physics Exercises physics as being lecture-based OR emphasizing memorization.

4. Students probably didn't change their beliefs about physics in between those traditional classes and Physics Exercises.

It is unlikely that students would have changed these views prior to entering Physics Exercises. The class was not advertised ahead of time as "an opportunity to relearn canonical knowledge in a way that makes personal sense." Rather, students expected it to be like other "Physics Exercises" classes, which, according to Professor Nitta at Gakugei, are commonly known to be times for students to do practice problems with material that they learn in lecture. At other universities, in fact, "Exercises" exists side-by-side with a lecture class, much as recitations do with lectures in American physics classes.

To be sure, it is not the case that students were plunged into the shock of Tutorials utterly without preparation. On the first day of class, Professor Uematsu introduced the TA's and me, and she explained the motivation for using Tutorials in a short lecture. The portion of the lecture that motivated Tutorials consisted of two slides. The first slide was titled (translated into English by me) "Why do we learn physics? The case of the Fukushima #1 nuclear power plant accident)" and had the following bullet points on it: "Understanding of the nuclear power plant? ; If you think carefully about the data, can you judge whether or not it's safe? ; Can you deal with unexpected events? ; The need for logical thinking ; The role of teachers". The second slide was titled "About this class" and consisted of the following bullets: "Not 'memorize answers', but rather 'think'; Contents---Mechanics and a little of circuits ; Lecture or quiz---30 min ; 'Tutorial'(group learning)---60 min ; Based on physics education research in America ; Examples used at the University of Maryland".

After this lecture, the students were given the FCI to take as a pre-test. The following week before the students did Tutorial 1, Professor Uematsu announced to one of the two classrooms that she would give a lecture at the end and briefly instructed them in how to do Tutorials (she asked them not to speak too loudly to each other because of how crowded the room was, for example). The other half of the students received an additional 20-minute lecture prior to doing Tutorial 1, but this lecture did not discuss motivation for learning physics in such a radically different style as what students were expecting. The first slide of the lecture began a discussion about measurement and units and the last slide was about an acceleration graph for a bicycle given its position at various points of time. Then, without further ado, students began their first Tutorial.

One could ask "In between the time that students learned that the class would be about 'thinking' instead of 'memorizing answers' and the time that the cameras first captured them in Tutorial 1, is it possible that they underwent a grieving process?" If the "grieving process" consists of nothing more than passively listening to two slides of a presentation explaining that this class will be different, then yes - there was enough time for such a transition to occur. However, this is not the grieving process that Chapell described, and this is not what one would expect to be sufficient to change rigidly held beliefs about how learning should take place.

In this section, I have set the stage leading up to student engagement with the first Tutorial. Next, I will discuss what Physics Exercises looked like on the first days of class to show that there were not obvious signs of widespread resistance; rather, class ran very smoothly.

C. My field notes from the first day and what I said to the TA's subsequently in training

Prior to this research endeavor, our research group at the University of Maryland had hosted several physics educators from Japan who observed our classrooms for several days. One visitor to one of our interactive physics lectures admired how actively students engaged in discussion with each other and remarked with regret that he could never implement something like that in his own school. He confidently predicted that the students would just sit there, waiting for the correct answer, refusing to talk to each other. Indeed, many Japanese college professors have relayed to me that they perceive the high school approach to learning to become comfortable to students, that students come to perceive passively taking the teacher's knowledge as being what "learning" is all about, and that this attitude persists into college. In part from this anecdotal evidence, the original hypotheses we had at the embarkation of this research enterprise (as written in the grant proposal to NSF which was denied) were:

> *"when Japanese students enter the physics classroom at Gakugei, they will enter thinking that physics class is a place to sit and quietly pay attention and take notes, much like many of our own American students do. … when asked to work in small groups, many Japanese students will … feel less urgency to express their attitudes and will think that it is appropriate to listen carefully to what others say more than our own students. … If sufficiently cued into remembering their elementary school experiences, however, many Japanese students, we hypothesize, would show a rather dramatic change of behavior".*

In other words, when I arrived at Gakugei and observed the first day of class, I was expecting and hoping to find signs of students shifting away from discomfort at the idea of working together in groups and drawing upon their own ideas, to a state of readily engaging with their group members and with the Tutorial. I expected to see both a gradual shift as the semester progressed, and also sudden and sporadic shifts as educators or myself (in interviews) provided certain cues about elementary school.

I approached the first day of class with a feeling of interest as a researcher but dread as an assistant in implementing the class (what if what our visitor had predicted turned out to be true and students absolutely refused to talk with each other!) However, I eventually never did observe either type of shifting. This is because I did not observe the initial resistance level to be anywhere close to what I had been hypothesizing. I walked around the room, observing groups and taking field notes, while my camera recorded the classroom. My field notes read "happy & focused" and "too easy?"

Shortly after the class, during the TA training for the following week's Tutorial, I read these field notes and reconstructed a memory of what had happened as I told the TA's my impressions about that first class. The following is transcription from a video of that TA training, translated into English by me:

> *"Honestly, it was better than I was expecting. I was really grateful. I thought "Alright!" When I looked at the students, not everyone, but for the most part, students weren't talking about their plans for the weekend or basketball games, but rather debating about physics. They were talking to each other, not just alone, and I saw a lot of smiles. Like, it looked like fun. Sometimes I could hear laughter, for example. But they were talking about physics. I was expecting it to be much more difficult, but I think it went surprisingly well."*

Again, at the time I wrote those field notes, my research hypothesis was NOT that students would quickly react favorably to Tutorials. There was thus little research bias for me to see the students' reactions as positive. Arguably, there would have been bias in the opposite direction, because the observations that I made complicated my research agenda. Nevertheless, the impression that students were responding well to the curriculum was unavoidable at the time.

In addition to these field notes and my own impression, there is also video and written data to support the claim that there was minimal resistance from the class, and that data is presented next, beginning with video data of TA debriefing and training.

D. Descriptions from the educators of how the first two weeks went

From my perspective as a researcher and as a classroom observer, the first class of Physics Exercises went very well; there was not widespread resistance that stopped the class from smoothly progressing. More significantly, this was the perspective of the class educators as well. During the same training session in which I reported my field notes and my own impressions to the TA's (training session for Tutorial 2, which took place several hours after Tutorial 1 had ended), I asked the TA's what their perceptions of the class had been. Although I did not know it at the time that I asked, the TA's had already relayed their experiences to Professor Uematsu earlier, immediately after the class had ended. Hence, their comments recorded had gone through a process of percolation for a few hours after their original reporting.

1. The TA's felt the students responded very well

The TA's reported largely good things about the class. They reported that although students initially were thinking individually, they warmed up to the idea of thinking in a group very quickly, and some students in fact were reluctant to stop doing the activity even when the lecture began. I asked if the students complained about anything, and the TA's reported that there had been no complaints (although there would be a small amount of complaining in some of the future classes).

2. There were also concerns, including that a small number of students were having trouble adapting to the new style

The TA's also had concerns, however. For example, they mentioned that some groups would reach a consensus (i.e., about the interpretation of speed), but they'd have the wrong answer, and the TA's didn't know whether to have them proceed or not. Perhaps most telling, however, was this comment mentioned by Shuji-TA:

[00:13:21.24] Shuji-TA: There were some students who said nothing, just waiting for the answer.

Note the striking similarity of this issue with what Stigler's anecdotal math teacher faced with his fourth grade students. Unlike that teacher, however, for the Physics Exercises educators, this was not a prominent characteristic of the class. Rather, this was one thing that happened to a few students. It was mentioned briefly, with no follow-ups from the other educators, and it was mentioned in a list of other positive and negative observations.

The following week, immediately after Tutorial 2 had completed, I met with the TA's for their debriefing. Unlike TA training, which met in a classroom, the debriefing took place in the professor's office and had a much more relaxed and informal atmosphere. There would usually be tea and snacks for the instructors to enjoy together. Out of consideration and hesitancy to intrude on these sessions, I did not videotape this first session. I did, however, take notes of what was being said.

Whereas my data of TA perceptions from the first Tutorial was very limited, since the TA's had just previously exhausted the bulk of what they had to say at their own debriefing session with Professor Uematsu, that second week, I was able to hear the first and undiminished blast of it. Although my notes do not mention the particular problem of students shutting down and waiting for the teacher to give them the answer, they do mention other similar problems.

Akiko-TA was particularly eloquent and vocal about reporting several things that she had seen to be problematic. She reported that students who don't already know each from before Physics Exercises aren't talking with each other at some points of the worksheets. She reported that there were some students who just nodded their heads saying little more than "uh huh". When she asked them for their own opinions, they would just tip their heads to the side and there would be uncomfortable silence. She said that some students were writing down whatever she said, even without thinking about it.

This is similar to what Shuji-TA reported the first week, about how some students just sat, waiting for the answers. This is evidence of grieving. However, both TA's described this as being a characteristic of a minority of students. Notably, Akiko-TA did not have a reaction of "Tutorials are crazy and absolutely doesn't work – the students weren't willing to say their own opinions and just wrote down whatever I said!" Although she did say something along the lines of "I've told students so many times that the point of Tutorial is to tell your opinion and hear other opinions and discuss, but they don't really get it", she followed this up with an explanation of "they're having fun talking at some places. But they also feel that some places are a pain – to wait, for example."

3. The biggest concern was not about student resistance, but rather differing abilities in a group

This point of having to wait for slower students seemed to occupy the center of Akiko-TA's concern, and she discussed it more extensively than any other concern. Particularly the first page of Tutorial 2 involves a lot of calculations (which is rare for the OSTs), and, according to Akiko-TA, students who know how to do the calculations quickly completed them and waited for the other students. She said that students who finished early seemed to be feeling "Why do I have to wait? It's a pain." She clarified that the situation is not that the slower people can't do it – it's not that they don't understand. It's just that the pace is different. The slower people want to think a lot more, but they don't want to keep their group mates waiting, so they just adopt the answer of the faster person. She struggled with finding something productive for the faster students to do, while at the same time not wanting to tell the more thoughtful students not to think so much, as that would make them less motivated to think at all.

4. Additional TA reports: students attempt to use pre-memorized facts, think too long at certain points, and have lively and deep conversations.

On the first page of the second Tutorial, students are given the graph of a car's velocity as a function of time as shown in figure 4. Students are asked to think of an interpretation for constant acceleration (for example, "the amount that the speed increases every second") to complement their interpretation for constant velocity that they developed the previous week ("the number of meters you travel every second") and to then find the distance traveled by the car.

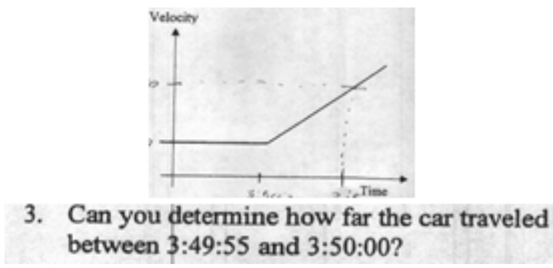


Figure 4. Diagram of the car's speed as a function of time

TA's reported that students used a previously memorized equation to answer the question, and that when TA's asked if students could do it without the equation, students answered that they can find the area under the curve. When the TA's asked why that area is the distance traveled, students were content to answer that "area is time times velocity".

At another part of the Tutorial, students are given motion graphs and asked to come up with a physical ramp that could create such motion. The third of these graphs is a (perhaps unnecessarily) complicated one that students, if unattended, can spend a long time thinking about (see figure 5).

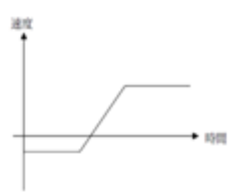


Figure 5. A perhaps unnecessarily challenging graph of velocity vs time

During TA training, we discussed how this is not a crucial point of the Tutorial, and that TA's should consider asking students to move on and not take too long thinking about the problem, especially since time was limited (students had not had time to complete the Tutorial the previous week). Although TA's told students that they didn't need to think so much here, students doggedly kept working at the problem, enjoying their discussions about it.

TA's reported that students enjoyed lively or deep discussions at other points of the Tutorial as well, such as when they were thinking of their interpretation for constant acceleration or when the Tutorial had them use their fingers to show the motion of an object following a motion graph.

5. These kinds of observations were characteristic of the course

Reports of this kind were not idiosyncratic; they were reported again and again. Throughout the semester, there would be students solving some parts of the tutorials formulaically until TA's talked with them about it. There would always be some parts that students would want to keep thinking about even though they weren't crucial to the Tutorial. There would always be some students who would not participate much. Students going at different paces was not a problem that went away. Some places had more discussion than at other points. And some students would continue to look to authority as the semester went on. But the fact that some sections did engage students in discussion (without the need of authority-sanctioned knowledge) was also present as early as this Tutorial.

E. Description of videos from the class

1. Video data from the first week is scarce

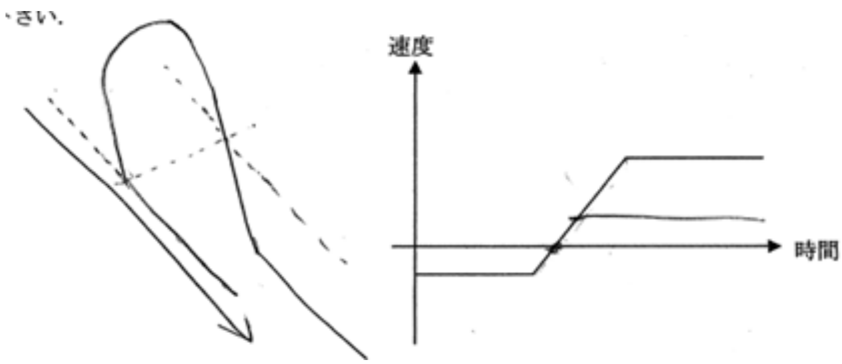
Immediately before the first Tutorial, Professor Uematsu introduced me to the class and briefly explained that I would be videotaping so as to make the class better for future generations of students, and that she would not see the videos while the class was taking place. I was not sure how the students would react to the presence of a camera (colleagues had warned me that it might make the students even more shy) and I did not want to disrupt what I anticipated could be a challenging class for them already. Thus, I did not aim the cameras at a particular group nor did I use a microphone.

What's more so, the logistics on that first day were unusually haphazard. Physics Exercises took place simultaneously in two very cramped rooms (S301 and S302), and during that first day, the desks had not been pushed together, and so a student had as his group mates the student beside him, the student behind him, and the student beside her. Thus, students were often contorted in a strange twisted formation and frequently gyrated back and forth to discuss with their group mates and to write on their worksheets.

To make matters even worse, for more than half of the class, a TA was standing in front of one of the cameras (the camera in S301), demonstrating equipment that corresponds to the second part of the Tutorial.

For these reasons, usable data from the first day of class is very sparse. However, the useful data that was available will be presented here. Tutorial 2 conversation in S302

The most engaged conversation that was captured by the cameras in the first two Tutorials took place when the group of students captured on film in S302 were asked to design the track that could create the speed vs. time graph shown above and again here. Eventually, after much deliberation, the students decided on a three-dimensional design. Their sketch is to the left of the graph.



1. [00:00:04.19] S2: Speed is at first negative

2. S1: It's negative, it's coming back, right

3. S2: It's coming back and bit by bit the speed is increasing, eventually

4. S1: That's right, isn't it

5. S2: Perhaps this point is the summit, if you will, it stops and goes to fall

6. S1: It is, isn't it

7. S2: Just that, I can't draw it nicely

8. S1: (realizing something) Is that right?

9. S2: Is it not?

10. S1: Ah, but that's so you know, right. The beginning having a constant speed means it must be a level surface. I can't draw anything but that.

11. S2: Ah, but, huh?

12. S1: Like, it's becoming REALLY fast

13. S2: That's right, isn't it. If it's like this, I understand. Huh? Huh?

14. S1: Therefore, since it's accelerating, is this correct? A rollercoaster's... I don't know where this energy comes from.

15. S2: It rotates three-dimensionally... downward (S3 laughs, see photo)

16. S1: If from the start, it's some kind of wrong feeling like this, what if you start from a hill and are becoming faster like this...

17. S2: Ah? A hill's... huh?

18. S1: The start is horizontal you know

19. S2: That's right, isn't it

20. S1: It has to be a flat surface

21. S2: The start is like that you know, right

22. S1: If it's not flat from the start, start from a hill and upward...

23. S2: three-dimensionally, it's like this...

24. S2?: Not good… let's skip this.

Although it's difficult to understand the specifics of what the students were talking about, it is clear that they were going back and forth between this formal representation and what actual motion in the real world could create it. In line 10, for example, S1 was seamlessly connecting the graphical representation of a straight line with what could cause such motion in the real world – a flat surface. It is also clear that they were checking their solution to see if it matches their expectations of how things work. Around line 14, for example, both S1 and S2 are obviously perturbed by the inconsistency of the ramp they are envisioning with the motion graph. S1 makes the concern explicit in line 14: "I don't know where this energy comes from." S3's laugh in line 15 suggests that, even if she was not speaking in the conversation, she was nonetheless participating enough to recognize a solution that would make things unexpectedly complex. The nature of her laugh seems not in the spirit of "Oh, jeez, what is this?" but rather "Ha, that's kind of an absurd but creative and therefore fun idea!"

F. Notes that Professor Uematsu took from TA debriefings

Since I did not get feedback from the TA's until several hours after the class had ended (and after they had already debriefed to Professor Uematsu), one could argue that the story I heard from the first week was skewed. Or, perhaps the TA's were selective in what they chose to report while they were around me. Lastly, perhaps my camera failed to capture something in the TA training that took place later that day.

Notes that Professor Uematsu herself took can help answer all of these challenges. She took notes of her own immediately after the first Tutorial while meeting with her TA's, and she also took notes from the later TA training. In appendix H, I present both of these sets of notes, which capture her own impressions and those of her TA's.

She, like I, noted Shuji-TA's observation about students just waiting for the answer as being important. However, she mentioned a lot of other things as well. Prior to the TA debriefing, she wrote that the conversations were lively, and her biggest concerns seem to have been logistical.

This serves as a good check with my own impression that the educators did not perceive the class to have malfunctioned because of student inability to adapt to the new learning style smoothly.

G. Conclusion

1. Students *adapted* readily to Tutorials

Perhaps the most compelling evidence available that supports the argument that students adapted readily to Tutorials is, actually, Shuji-TA discussing how there were students that just sat there waiting for the answer, like what Stigler's anecdotal fourth graders did. The fact that this occurred rules out the explanation that the Japanese students just don't grieve in the same way as those fourth graders, and so of course we wouldn't expect to see that. Some students did in fact do that, but the point is that most did not. This concern by Shuji-TA was one of many in a list of good and bad things that occurred. It did not make the class a failure. Rather, it was just a note that for some students, this was indeed a strange experience. Hence we can say that, even if some students may have gone through a grieving process, the majority did not, and, unlike the classroom of Stigler's anecdotal teacher, the class could progress smoothly. Unlike Chappell's colleagues, other teachers who would pass by and observe students engaging in Open Source Tutorials at Gakugei would not feel sorry for the class and their high amount of discomfort.

2. Survey data from 2012: the students themselves say it was easy to adapt

Data from the 2012 survey shows that this ease of adaptation was not only my impression and the impression of the educators, but was the impression of the students as well.

On the survey, students were asked "Physics Exercises was different from previously taken physics classes (including college and high school)" and students were asked to select an option ranging from "Applies well" to "Does not apply". 26 students said that it applies well and 16 said that it more or less applies. Only 2 students replied "Can't say either way" and only one student said "Doesn't really apply". No students said "Does not apply".

The following prompt was "Physics Exercises was different than my expectations before entering the class, and I was surprised." Here again, the majority said that it either applies well (16 students) or that it more or less applies (22 students). A very small number said that it does not apply (1 student) or doesn't really apply (2 students) or that they can't say either way (4 students).

Students were given the following prompt:

> *Two years ago, a Japanese physics teacher came to observe a class using Tutorials at the UMD. Although he had an interest in that class, he decided that it would be problematic to try implementing that kind of teaching style in his own class in Japan. The reason is that, since Japanese students are not trained to think about their own ideas and make people around them listen to those ideas during class, even if the worksheet would say "think about this question and please discuss with those around you", he predicted that it would become nothing more than the students just quietly waiting for the answer from the teacher. In Physics Exercises, do you think up your own ideas and opinions and tell that thinking to the students near you? If so, to what degree was it easy to adapt to that way of learning?*

Again, the vast majority replied favorably. 26 students said that it was "Easy to adapt", 16 said "More or less easy to adapt", 2 students said "can't say either way", and one student who selected "Other" with the explanation:

> *"I always had my own opinions, and since I have no resistance to communication, I could take it in with a sense of the degree 'I am extending daily conversation' ".*

In summary, students were surprised by the new style of learning, but they found it easy to adapt. We are still left with the question of why this was so for the Gakugei students.

3. Possible explanations of why students could change

a) Maybe Japanese students just do whatever the teacher asks them to?

One possible explanation is that students in Japan want to do as is expected of them and respect what the teacher asks them to do. Indeed, this is the reason that some students in interviews provided when asked why it was easy to adapt to the new class style. This does not seem to fully capture what took place, however. The evidence shown here suggests that students did not perceive Tutorials as being an unpleasant experience. Rather, from the sounds of student excitement, laughter, and general engagement, it seems that they by and large were experiencing Tutorials as being positive.

If students were swallowing unpleasant medicine just because the teacher told them to, there would be traces of this negative emotion in their body language and faces. Colleagues at UMD and I did not detect such traces, despite explicitly looking for them. More relevantly, the educators of the class, who were actually engaging with the students and would have been much more attune to noticing such traces, did not perceive the experience to be unpleasant for students.

Further support that students were not forcing themselves to do something disagreeable is found in interviews when students describe Tutorials as being “fresh” or “fun”, and that they prefer it to their previous traditionally-taught physics courses. Although this interview data itself might not be sufficient to argue that students enjoyed Physics Exercises, triangulating the interview data with the classroom observations described above of students actually *doing* the kind of reasoning they described creates a compelling argument.

b) This dissertation will explore reasons given by students in interviews and look at how deep this change was

There are other arguments that students make in interviews for why there was not a grieving process for the Gakugei students, and this dissertation will explore some of these explanations.

First, however, although it’s not absolutely central to the dissertation, I’m going to show some case studies of what students got out of the course. From this current chapter alone, it seems possible that students easily adapted because they’re having a good time but when the class is over they’ll get back to “business as usual”. I will show that they were opened to a deeper epistemological change than that. Students adapted not just superficially, but in a way that let them genuinely change. This is important because it counters a potential argument of advocates of unitary cultural scripts. Proponents of unitary frameworks might not have difficulty conceding that students could flexibly go along with a new type of lesson on a superficial, without their core cultural script becoming influenced. These case studies, however, will show that some students tried on a whole new way of learning, making my challenge to unitary cultural scripts “deeper” than it would have been without this data.

V. Success of Open Source Tutorials at Gakugei

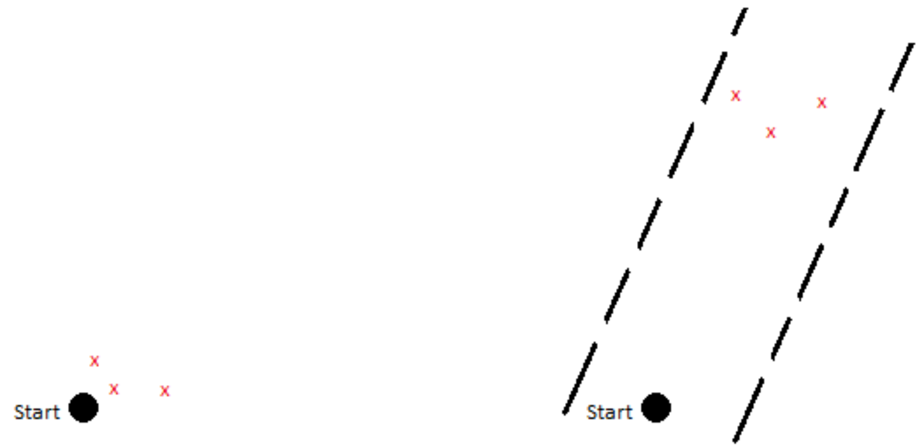
A. Introduction

This section consists of case studies of students who were transformed in their epistemology of physics. I begin this section with several case studies of interviewees who explicitly described how Physics Exercises left them with a more sophisticated epistemology about physics and physics learning, and who solved a physics problem during the interview in a way consistent with this. The most detailed case study is that of Tadao, about which I have written two publications.(Hull and Elby 2012; Hull 2012) His story demonstrates his willingness to engage with the epistemologically transformative aspects of the class. It also motivates my analysis of one of the learning mechanisms pervasive in the classroom - students like Tadao found Physics Exercises to be an epistemologically familiar experience.

The original interview protocol did not include prompts asking directly whether or not the interviewee's image of what constitutes physics changed as a result of Tutorial. It was the 14th interviewee (Maeda) who freely offered that Physics Exercises had made him change the way he thinks about physics. Every interview after that had a revised protocol to include prompts along the lines of "Is your image of what physics is now different than what it was before Tutorial?"

Of the 14 students given this kind of prompt, 11 of them indicated that, indeed, they now had a new impression about the field, and most of them reported things like "Physics Exercises has shown me that physics is actually very closely connected to the everyday world around us." From the 2012 cohort of Physics Exercises students, 42 students answered survey prompts designed to get at whether or not their image of physics knowledge and learning had changed, and 24 of those students gave evidence that, indeed, they had changed.

It is reasonable to imagine that, despite sharing a message of being changed by Physics Exercises, the degree to which Physics Exercises affected these eleven students varied, and this notion is supported by the interview data itself. Of the eleven, there were some students who showed relatively weak indications of having been changed. For example, some students answered the prompts about their attitude changing rather vaguely and did not reference that change again in the interview. Other students, however, persistently demonstrated a self-consistent post-Physics Exercises view of physics. In this section, we look at four examples taken from these more extreme cases, Rina, Madoka, Miu, and Tadao. The argument is not that these four are representative of the eleven; rather, these four provide a visualization of the general direction that the flow of Physics Exercises was taking these eleven students (see Fig. 6 for analogy). In other words, the other seven students were epistemologically nudged in the same direction, but not as far.



Studying students who do not provide much evidence of having changed (and, indeed, who have perhaps not changed much) make it difficult to determine the general flow that the course takes students

In contrast, studying students who provide more evidence and detail for how the class affected them can illustrate the direction of the influence exerted by the class. The dashed lines represent the "pipe" that students are sent down by the class. Note that the other three students on the left also fit within this pipe.

Figure 6. Analogy of the benefit of studying the students who changed by the greatest amount

1. Validity of the translations of Japanese data

As I stated in Methodology (Chapter 3), the data I present below and throughout the dissertation was informed by transcripts available in the appendix (which I transcribed and translated independently). Transcriptions that appear in the body of the dissertation (as opposed to the appendix) as quotes were either changed or confirmed by Dr. Maki Kishida. The reader is encouraged to judge the adequacy of the appendix transcript (and hence of the narratives below) by comparing the quotations in the dissertation body with what is in the appendix as examples.

B. Rina: Physics isn't supposed to make sense, so just memorize it → It can make sense, and formalism should be compared with intuition

1. Thanks to Tutorials, Rina came to believe that she can personally understand physics.

Rina's experience with taking physics was limited to a chemistry/physics class in middle school and Physics Exercises at Gakugei. Physics Exercises was a requirement for her to get her teacher's license, and since she had attempted but dropped it spring 2010, she was once again enrolled the semester that Physics Exercises featured Tutorials.

She reported that her middle school teacher had been a "really awful teacher" and that she hadn't followed his lectures well. It was this preliminary experience that left an impression of physics being difficult. When, in high school, students needed to choose whether to take physics or other science classes, she, remembering middle school, felt that physics would be "impossible" for her, and so she postponed her next physics exposure until college. Her first attempt at Physics Exercises only confirmed what she had thought – physics is difficult. Both from her own experiences in the class and from talking with her classmates, she developed an epistemology about physics.

> *[36:26]It's abstract, and really... like electricity or forces, it's things that you can't see with your eye, right? I didn't really understand…*

Rina talked about how the professor last year would give lectures to explain "basic" related information, but, once again, it just didn't make sense, or "seep in" as she put it. Lectures would be full of equations and go too quickly with too little time for asking questions about why something is the way it is. Rina would ask for help understanding something from classmates who had taken physics before, but they would dismiss her, telling her that that is just the way it's done in the world of physics, and that she shouldn't think too much about the real world.

> *[00:27:40.19] Perhaps many Japanese students learning physics don't think deeply about concepts or why something is interpreted in such a way; rather, I think they are taught the way to solve problems, so with things like why in certain situations you do a certain calculation, they don't really... it doesn't mean that they really understand. They are taught solutions, ways of solving problems. You just apply the equation; you decipher the context, you interpret the problem wording... I think it's common to solve by thinking "in times of this type of problem, you use that way of solving", so it doesn't really mean that you understand the world of physics, you know what I mean?*

At last Rina too would relent and, even without an understanding of why she was doing it, would try to apply some equation to the problem. When she took Physics Exercises again spring 2011, she was in for a drastic change. In the interview, she consistently praised the class, saying how the class provides students with ample opportunities to take their own ideas about physics, think about why those ideas don't match up with physics, and "fix" those everyday ideas, and that she appreciated that. As a result of Physics Exercises, she said, she had come to believe that she can understand physics.

To be fair, she recognized that there are still many places that can't connect to daily experiences (she gave examples of magnetism and E-M waves) where it is necessary to just trust the teacher when he tells you something even if it doesn't make sense. She still thought physics is difficult. But at the same time, because of (at least one) positive anecdotal experience in Physics Exercises that she described in the interview, she now espoused the belief that, at least with some areas, if she goes step by step, piece by piece, she can reach an understanding of what is going on.

> *[00:41:17.21] … there was a place that really made sense where we showed that definitely if you go from the assumption that that kind of force is acting, everything that follows fits. Even if it's about how complicated forces relate, if I go step by step, I think I can understand it.*

2. Rina strove for such understanding when solving a traditional physics problem.

Rina's new attitude of "physics is something I can understand" is visible not only when comparing Physics Exercises to the prior year's Physics Exercises, however. Evidence for this new stance is visible in how she solved a traditional physics problem in the interview as well.

As described in the methodology section, I told students to think about the situation of throwing a rock down with a speed of 2 m/s and letting go of another rock at the same moment and asked them how the speeds would compare after five seconds. Rina began her assault on this Two Rocks Problem purely conceptually (56:05). She threw an imaginary rock while thinking silently. She thought about how gravity will make the two rocks get significantly faster and faster as they fall and how that effect will dwarf the effect of the initial difference of 2 m/s. She concluded that the 2 m/s difference will get smaller.

When I attempted to repeat her argument for clarification, saying "And that's because they are accelerating? With this large acceleration?" she seemed dissatisfied with her answer. Two minutes into working on the problem, Rina began to think numerically. Perhaps to get a grasp on how big of an effect gravity would have, she considered the ball that you just let go. She said to herself that after one second, that ball would reach a speed of 10 m/s, but she then trailed off and returned to a more conceptual angle.

She again threw an imaginary rock and reasoned that that force given to the thrown rock would be in the downward direction before trailing off again. Perhaps because she was unsure if five seconds would be a sufficient amount of time for the 2m/s difference to become dwarfed, she then solved the problem numerically, and arrived at an answer of 2 m/s.

When I asked if the answer surprised her, Rina said that she had already started thinking about why her intuitive answer had not aligned with the answer derived from the physics formalism. She elaborated on what she had been expecting to happen conceptually. Her image was connected to the "power" of the two rocks, which perhaps can be thought of in terms of damage caused upon impact. If you have one rock traveling at 2 m/s and another rock not moving, there is a noticeable difference in how much it would hurt to be hit by the rocks. However, after gravity has made both rocks become considerably faster, there wouldn't really be a noticeable difference between getting hit by either rock.

Unprompted, she then launched a three minute monologue about why formal physics solutions often don't match up with what would happen in the real world. She explained that one effect that might be giving her an intuition that differs from the results of the velocity equation is that her intuition is from a world with air in it, which will have an effect on the motion of the rocks. However, she maintained that

> *[01:02:17.07] The stuff you learn in class is correct and our daily experiences are correct, so I think there is absolutely a way to get them*

to be consistent and I want to think that if we are made to align the content in class with daily experiences, that we can understand.

She reasoned that there should be some physics equation that takes into account air resistance.

Rina's natural common-sensy attempts at solving the problem and her consistency in explicitly saying that physics can make sense is additional support to the argument that, at the time of the interview, Rina had a view that physics can be personally understood; it's not just a body of incoherent stuff to memorize.

At the same time, however, this data gives a fuller image of what her new epistemological state looks like. *Rina still placed high value on physics formalism*, in this case, the velocity equation being an example of the "stuff you learn in class." When she first arrived at the result of 2 m/s, the confidence of her answer and the laughter with which she delivered it seems to suggest an attitude of "If that's what the equations tell you, then that's got to be right." At 1:01:23, she even said that sometimes you just need to go and actually solve the problem.

At the end of the interview, I asked Rina if she had any questions. She wanted to know if her answer was correct or not. She had previously not been able to reconcile her own reasoning with the formal solution to the problem, and seemed to still be ill at ease about it. When I explained a conceptual way to solve the problem, however, either Rina did not understand, or she was simply not interested. When I asked if that answer satisfied her, her response was akin to "Yeah, I guess… and anyway, I think I've figured out where my own thinking was going astray." It seems that what really interested Rina was not the correct answer to this problem, but rather how to get her own ideas to match up with physics, which is exactly what she had liked so much about Tutorials.

The interview concluded with me asking Rina whether she prefers the conceptual solution given by me or the numerical algebraic solution she had reached herself. She gave a message consistent with what she had been saying throughout the interview: It is important to try and make sense of the problem, to connect it with everyday thinking. At the same time, however, the answer derived with formal physics remains very important, and the goal is to align everyday experiences with that.

[01:13:24.21] So, once, as expected, just memorize it, solve the problem, and compare with the initial speed, if it's faster or slower. But it's not get out that answer, just write it and be done. Rather, look to see if it's different than what you were thinking initially and if so, think why - that will make it easier to understand.

C. Madoka: Physics is calculations and connections to the real world are unclear → Drawing upon everyday experiences can lead to a deeper understanding

1. Physics Exercises was very different from previous physics classes, and that made it difficult.

Rina described former classmates who had "taken physics" telling her not to think too deeply about the real world when doing physics, because in the world of physics, "that's just the way it's done". Madoka took not only Physics I in high school that most Japanese students take, but Physics II as well. He is the kind of student whom Rina might have dubbed a "physics taker", and looking at his interview, it is easy to imagine him telling her to just accept what the teacher is telling her and not try to reason too much about it.

Madoka described how in previous physics classes, students were never really put into a situation where one needed to resolve contradictions between common sense and results of physics. It seems like it just hadn't occurred to him to be a reasonable thing to do (15:14). It wasn't the case that explanations about how physics laws and phenomena connect to reality were utterly absent, but when explanations were given, they didn't leave a satisfying level of clarity (22:24). Although he was always vaguely aware that what they were studying did connect to reality, those connections were never an important point of focus and they remained fuzzy (28:36).

Classes were lecture-based, and students would take notes from the teacher silently. Madoka agreed that the teacher was the source of knowledge in those classrooms (23:55 – 24:41). He talked about previous physics classes focusing on memorization and he talked about how the mechanics course he was taking concurrently with Physics Exercises was stressing calculations with the goal of getting answers (19:45, 21:01, and 22:18). He described his first solution (36:26 and Fig. 7) to the Two Rocks Problem as being an example of that style (47:52).

$$u = 10 \times 5 = 50$$

$$u = 10 \times 5 + 2 = 52$$

Figure 7. Madoka's written work during his first, "plug and chug", solution, used a way of thinking similar to his previous view of physics classes.

When asked what he used to think physics is, Madoka reported (see also 14:54 for support):

> *[27:00] it's nothing but calculations and that makes it a difficult thing*

Like Rina, Madoka was pleasantly surprised by Tutorial. Although some students who had found previous calculation-intensive physics classes to be difficult might enjoy Physics Exercises because it is easier, this was not the case with Madoka. Madoka's first description of Physics Exercises was that it is difficult, but for a different reason. Whereas previous physics classes were difficult because of all the calculations, Physics Exercises was a challenge because it was so unlike other physics classes (14:30-15:30). Physics Exercises puts together student intuition, previous experiences, and prior physics knowledge(14:54 – 15:14 and 24:56) to interpret phenomena (16:23) and it spends time showing situations where those things do not align (15:14 and 16:30) and guiding students into a state where they do align (17:27), so that students can understand physics more clearly and see more easily how physics relates to daily life (below and also 22:15).

> *[00:17:17.19] If you solve your contradictions [between physics and what seems natural], your understanding of physics becomes more expert [if you can see that] the connection of phenomena occurring in everyday life with physics*

2. Physics Exercises changed the way Madoka thinks about physics.

Physics Exercises changed the way Madoka was thinking about physics in multiple ways. First, he was surprised to learn one can learn physics also by talking with your classmates (24:56 and 25:48): communication can also be a source of physics knowledge, or, as he succinctly put it, "there is this way of doing it too". Furthermore, he came to see everyday experiences as being potential sources of physics knowledge (24:56). At the time of the interview, he felt that physics is something that can be personally understood (22:07), and that it is clearer than he had thought originally.

> *[28:16] It is difficult, but it's connected hand-in-hand with the everyday. It is familiar.*

Towards the end of the interview, I attempted to recall what Madoka had said about how his attitude towards physics had changed, saying that he used to think of physics as equations and calculations, but now he thinks of physics as being connected to daily experiences (28:16). I drew two circles, one with the word "calculations" and the other with the word "everyday", and Madoka agreed with my summary. In doing so, he confirmed what he said earlier in the interview – although he previously did not think that everyday experiences are importantly connected to physics, he does now.

Madoka also provided an example of how his epistemology of physics had changed when he declared that his alternative, conceptual, solution (38:11) is pretty close to the Tutorial way of thinking. He said that if he had actually had the rock-throwing experience to draw upon, then it would be the after way of thinking about physics.

> *[00:48:16.25] This [conceptual solution given at 38:11], if I actually did it, might fit in "everyday", but I perhaps have not done it.*

Madoka's agreement, however, came with a strong caveat.

> *[00:46:44.00] [My current image is] not just calculations [but also everyday experiences], but calculations are also important*

This statement reveals the nuance of Madoka's new epistemological stance. *Madoka made it clear to the interviewer that he still thinks calculations are important in physics*. Like Rina, conceptual understanding had not taken the place of calculations. Rather, it was an additional piece of the whole that constitutes physics, a piece that was previously only dimly apparent.

Unlike Rina (and Miu in the next section), who had had marginal former physics experience, Madoka had taken both Physics 1 and Physics 2 in high school, and had been more fully immersed in the rote memorization physics culture. It is a testimony to the Physics Exercises experience at TGU that, despite this inertia, Madoka was willing and able to make this transition. More relevantly, considering how well versed Madoka was in the high school physics script, the ease with which Madoka changed scripts is a challenge to the notion of unitary cultural scripts.

D. Miu: Physics knowledge comes from equations → Physics permeates the real world so reality should be thought about when doing physics

1. Physics had been disgusting.

Miu, like Rina, had not taken many physics classes, and she seemed to have an attitude that the physics classes that she had taken hadn't really counted, because she hadn't really been there (17:39-17:59). She recounted how she had disliked physics so much that she would distance herself from it, even while in the classroom. As she spoke, she made a gesture of throwing something off to the side, as though turning down an offer for a disgusting-looking plate of food. She explained that as soon as she learned physics is about calculations, she knew it wasn't for her (18:21).

The former physics classes she described seemed pretty typical of what interviewees recalled. Students would quietly write in class, and if they had questions, they could ask the teacher after class (35:05). Like with Madoka, she agreed with the image of the teacher being the source of knowledge (35:57). And, solidifying her image of physics, there were lots of calculations, which she did not enjoy (28:18). She felt the classes were about memorizing equations to then apply to a problem to get out an answer (29:13 and 31:48). The enjoyable part of the class had been watching the teacher doing the calculations on the board and, as though by magic, arriving at the answer (28:55).

Prior to Physics Exercises, she had thought that the essence of physics is using equations not only to solve problems, but to generate the laws of physics as well.

> *[00:32:29.02] Answers [to physics questions] or [physics] laws, everything comes from mathematical equations, they are things derived,*

so, well, you have to understand equations, and you have to memorize them

It is not clear how much physical meaning that she previously placed in the equations and laws of physics. It is possible that she thought of them as being confined to the physics classroom with little relevance to the outside world. However, it is also possible that, at least to a superficial degree, she recognized that the equations carry some kind of meaning that dictate how the world around them functions. Either way, "doing physics" for her meant beginning with formal (mathematical) equations and, in physics class, she was not actively thinking about what meaning the formalism contains.

2. Tutorials showed that physics is something you experience

Physics Exercises was absolutely delightful for Miu, or so she excitedly explained. She never could have imagined that physics could be so *fun* (19:09). In Physics Exercises, physics came alive with hands-on experiments involving water beakers and a collision with a truck (19:09). Miu realized that physics is something that you experience, that it is visible in daily experiences.

[00:34:03] in the norm, this kind of movement you do yourself, if you will, even this kind of action (puts pen down in a different place), if you look at that for example, if you move for example, even just doing that, "that's physics too!" kind of thing.

She said energetically that even moving an object around is physics (34:03), and because of that, one's own common sense is the source of physics knowledge (30:47), not equations and calculations (33:29 - 34:03). Not only can knowledge relevant to learning physics come from your own experiences and from those experiences of your group members (30:47 and 36:00-36:33), but you can have revelations in the physics classroom that personally and deeply make sense to the extent that they make you want to always keep that feeling (24:36), and you can take this new perspective with you into the real world, to think how mechanical energy changes as you climb up the stairs, for example (25:02).

3. How she solved the traditional physics problem

Like with Rina and Madoka, we can find evidence for Miu's epistemological change by looking at her behavior when solving a traditional physics problem. If we see behavior that supports her prior statements about how physics is something apparent in everyday experiences, then that would strengthen the argument that that new attitude really has taken a hold on her.

Although the majority of Miu's transcript (and the other transcripts as well) does not include hand gestures, this section of the transcript in the appendix includes all relevant hand gestures, since those motions are referred to here. Miu was an extremely animated interviewee, and the interview was full of gestures. Not included even in this portion of transcript are the countless times that she raised and lowered her head, touched things on the paper, touched or scratched her head, and picked up and put down her pen.

Miu's first move in solving the problem was to verify that the rocks did not hit the ground (48:58). A "ground" was not referenced in the problem and one could argue that her thinking of this was a sign of her thinking about her own experiences of how things hit the ground after they've been falling for some time. On the other hand, her concern for the height that the two rocks start at could simply come from having solved projectile problems in physics classes where, although a ground is not explicitly described in the problem statement itself, projectiles nevertheless do hit the ground after they have fallen the specified height. Thus, it's possible that this question does not reflect an attitude that physics is pervasive in the everyday world, but rather just a familiarity with physics projectile problems.

After she had given her answer, Miu began her explanation by ensuring that it was OK to think of the rocks as identical, having the same mass. Although this was eventually not necessary for her solution, one could argue that this verification was perhaps important for her because it gave confirmation to the image that she had in her mind of the two rocks falling. On the other hand, as FCI results show, many students think that if masses of two objects are different that gravity will accelerate them differently, and so her question perhaps really was just to ensure that she could treat the acceleration as being the same for both rocks. Hence, this data too might not reinforce the idea that physics is connected to reality, or more precisely, her imagination of this situation taking place. It could again just be familiarity with the physics formalism of "gravity" being larger on heavier objects.

Although Miu made a gesture of throwing rocks a total of seven times in the four minutes it took her to explain the solution, one could argue that that shows merely a superficial connection of the context of the problem to reality. What is clear at this point, however, is that Miu was doing more than just taking an equation and plugging numbers into it. When students solve problems in this manner, they generally keep their eyes on the paper and cease to make hand gestures.

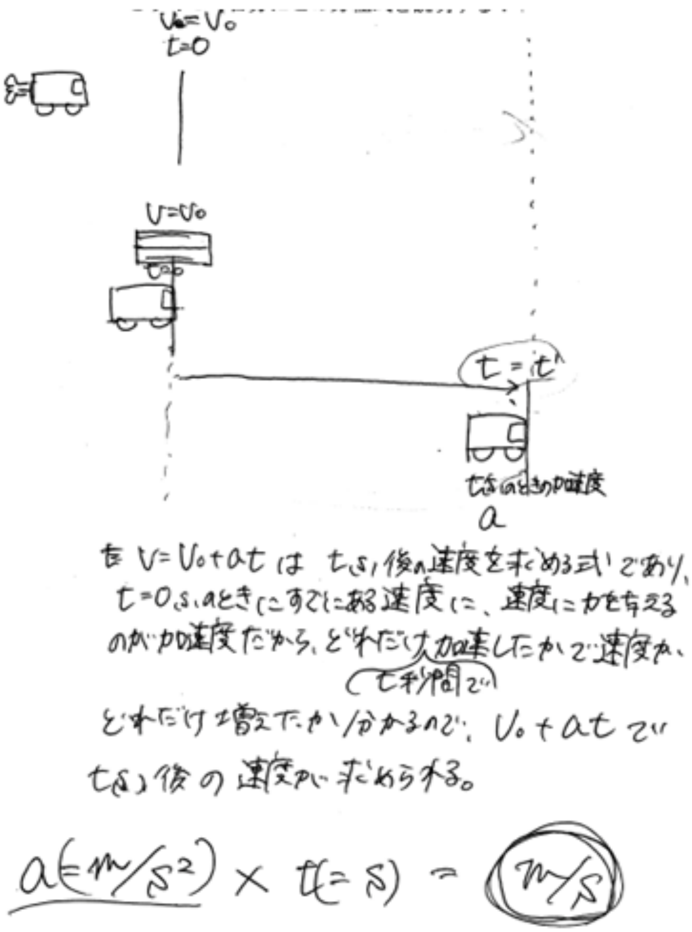
The best evidence supporting that Miu was thinking of something actually happening is thus not her questions about what the rocks look like, whether or not they hit the ground, or her hand gestures in themselves. The most compelling evidence is the following bit of transcript, where she gives a conceptual explanation to her previous answer that the speed remains 2 m/s:

> *[00:51:33.21] If you just dropped them both, they would gradually fall (holds two balls in her hands and lowers them and then repeats), but... they would fall the same (makes palms face her and then lowers the edges of her hands to the table), but it already has 2 m/s (half-heartedly throws a rock), because of that part, (puts hands parallel in front, like brackets), that it will fall faster (throws two rocks), I think*

She imagined dropping two balls and how they would fall together. If, to that situation, you would instead throw one of the rocks, you are giving it a little something extra, a difference that almost tangibly fits between her parallel hands and that is preserved for the entirety of the fall. In the interview, Miu practiced what she charismatically preached: her solution to a problem that could have easily been solved with plug and chug instead was firmly grounded in an image of phenomena actually taking place.

4. How she classified the explanations of the equation and solutions to the problem

There is evidence to be found in a third context as well, when Miu was retroactively considering whether her explanation of the velocity equation is closer to her "before" way of thinking about physics or her "after" way of thinking about physics, and when she then did the same task with various problem solutions. The part of her explanation (37:37 and Fig. 8) that involved a moving object was, she reported, close to her new way of thinking about physics (1:01:09), but the part where she showed that the equation is true because the units work out resembled the old way of thinking about physics [01:01:04.03].



- V=v0+at is an equation to find velocity after t seconds. At point "a", to the velocity that you already have, the force acting on the speed is the acceleration, so you know that however **much it accelerated in t seconds is how much the speed increased**, so you can find it after t seconds with v0+at.

Figure 8. Miu's second (top picture and paragraph) and third (bottom equation) explanations to the velocity equation. Translation is on the right of the written work (emphasis is mine).

This in itself is consistent with what she had said before. Her new view about physics was not one grounded in formal rules about how units cancel out when you multiply and how different terms have different units assigned to them. Rather, her new view about physics was that it is things actually moving in the everyday world.

In addition, a small piece of evidence that indicates perhaps a sense of pride and thus ownership of the new way of thinking about physics is the slight regret with which she said that part of her explanation was, in fact, the old way of thinking about physics. Although she did not change her tone of voice, her choice of the –teshimau verb form here is used to express regret. It is similar to adding "unfortunately" to the sentence. However, this could be entirely interview dynamics. It could be that her regret was not genuine, but rather that she felt expressing regret would help present a coherent picture of herself (Linde 1993). If her regret was genuine, it suggests that her new way of thinking about physics is something that she values, wants to have, and feels a sense of ownership over. If her expressed regret was the result of nothing more than a desire to be consistent, it shows that she thinks of her identity as containing this self-consistent story of how she now thinks about physics. In either case, she feels a sense of ownership over the new way of thinking.

Since Miu solved the problem conceptually, I gave her the plug and chug solution to evaluate. At first, she condemned the solution by contrasting it with her own first and second solutions:

> *[00:56:40.16] I have a feeling that it's not good to think of just substituting. In my case, first, like this (moves a bottle), an image if you will, actually [doing it], something like this, to some degree you have an image, and, and then something like, in a spirit of "let's look for the difference", I wrote [the equation and substitutions], but, if you just substitute like that… "since there is this equation, substitute, the answer comes out, the difference comes out, so, wow, it's always two meters/second faster", in that kind of spirit, to say that… it is somehow not very good - that is the feeling I get.*

This supports the argument that Miu made previously, that physics is about actual experiences and should make sense. When I asked her to describe whether this solution fit her prior or after view of physics, she immediately chose "before" (59:13). This gives an example of what the old view of physics was (which she had described verbally earlier). Moreover, Miu was so fast at making this association that she cut the interviewer off mid-sentence and laughed at her own impulsiveness a moment later. This suggests that in addition to her prior view of physics being consistent with plug and chug, her new view of physics was *certainly* not. She elaborated here that it is the "before" her who would just take equations, substitute in the knowns, and produce the unknown (59:50).

At the same time, Miu's comment above reveals depth to her new epistemology. Although she had previously asserted that physics knowledge comes from daily experiences *and not* equations and calculations, here, like what Rina and Madoka said, she gave credence to physics formalism as well. In fact, her own solutions to the problem very much followed the procedure that she laid out in the above excerpt – first, as illustrated above with her first solution, have a picture of what's actually going on in your mind. Then, as with her second solution, use equations that reflect that image (52:42 and Fig. 9).

Miu's description of the "now" her further supports this idea that equations can reflect an image of what's actually going on (01:00:02 - 01:00:20), saying that even if she would now solve the problem in the way I had demonstrated, it might be "after", because she would have an understanding of what the equation means and of the situation that it represents. The equation that she would "put out" would not be a mysterious black box. Rather, it would be something with meaning that fits the image of what is taking place in the situation. Hence, equations were not taboo for Miu - so long as the equation is used with an understanding of what it means and of the motion that it represents, then that's fine.

In conclusion, evidence suggests that Physics Exercises changed Miu's view about physics from thinking that physics knowledge comes from equations and calculations to thinking that, since physics is about actual occurrences in the real world, even the formalism of physics needs to be connected to a physical understanding.

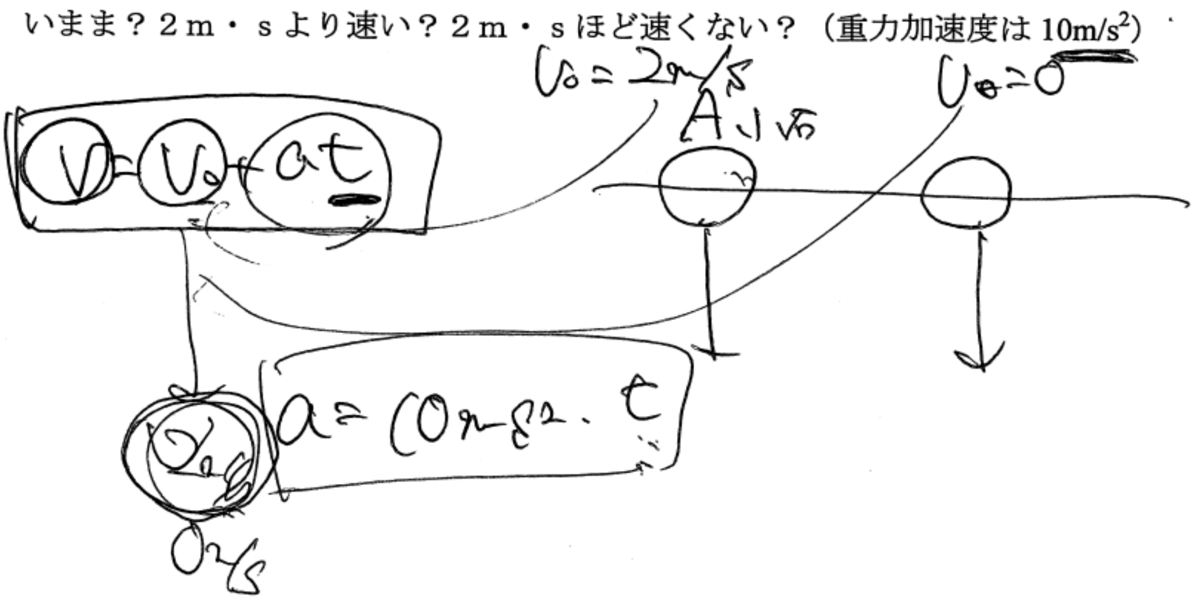


Figure 9. Miu's second solution to the Two Rocks Problem

E. Tadao case study

[00:16:00.06] Tadao: Uh, the calculations of physics, for example, that kind of thing, I thought it was a real pain. Physics really was not a class where I was thinking "I like this and want to do it!"; however, the Physics Exercises class is pretty much the thing that I like, since it feels

like elementary school classes... because it's the kind of class where you think in a group, where you organize your own thoughts.

[00:16:37.24] Interviewer: Sorry, say that again, how is Physics Exercises like elementary school classes... ?

[00:16:40.07] Tadao: Um, you think in a group and uh, the things that you yourself are thinking, just as they are you can write them down and organize them. So I'm thinking that it's pretty much a class that makes you like physics.

1. Tadao's espoused epistemology of physics

Tadao was one of five interviewees who also participated in survey validation interviews (which immediately followed the standard protocol-based hour-long interview). Hence, prior to the interview, Tadao had already completed a brief survey asking him how much he agrees or disagrees with several statements, for example: *generally speaking, there was a lot of group work in elementary school.*

On this survey, Tadao had said that his major at Gakugei is science, and that he had not taken physics in high school. He agreed that his elementary school did emphasize students thinking about their own knowledge and opinions more than getting knowledge from the teacher, explaining that "there were a lot of teachers who made children say things." He also agreed that there was a lot of group work in elementary school: "In order to force into us the ability to make those around us understand our own opinions, this happened a lot." In high school, on the other hand, this was not the case. Tadao wrote that "there were few teachers who strove to make students say things" and that "[the students] didn't do group work".

From his one-sentence explanations it is unknown how "teachers forcing students to talk" connects to there being an emphasis on knowledge coming from the student. From this data alone we might question if Tadao perhaps interpreted the survey prompt as "We talked a lot in elementary school." Fortunately, Tadao expanded on his answers during the interview that took place within a week of completing the survey.

a) Tadao's elementary school emphasized student reasoning

At the beginning of all 28 interviews, I asked the student about her experiences in elementary, middle, and, high school. I then asked the student to say if one of those three schools stood out as being the most different or not. With some students, I then asked what the biggest difference between primary and secondary school was, and whether or not the style of teaching changed. When I asked Tadao this last question, he explained that he was going to be repeating what he had said in the survey, but he continued nonetheless.

[00:09:45.02] Tadao: … elementary school was like, we would pretty much talk together in a group, um, students would meet together (…) but in high school, it felt like that was absolutely not there

Interviewer: At that time, did you prefer the elementary school style or the high school style?

Tadao: I preferred the elementary school style. It was pretty much thinking yourself... we got a lot of time to do that - just thinking ourselves.

This reinforces what Tadao wrote on the survey: in elementary school, students worked in groups with the emphasis on student's own ideas, and teachers would often elicit those ideas. We might expect a student who found elementary school to be like this to find similarities in Tutorial. The quote at the beginning of this chapter suggests that, indeed, that was the case. In addition to making the connection to elementary school, that quote gives some specifics about how Physics Exercises was different than other physics classes: whereas previous physics classes had been about calculations, Physics Exercises was about making sense of your own ideas, while working in a group. Whether your own ideas are correct or not isn't really the point; whatever they are, you write them down, and then you "organize" them. Although Tadao liked Physics Exercises, previous physics classes had been a "pain".

The TGU students were well aware that the interviewer was also the one largely responsible for bringing Tutorials from America to Japan. Hence, although Tadao praised Tutorials during the interview, one must exercise some degree of skepticism at these words. It is possible that he said this just because he wanted to say what he thought the interviewer wanted to hear. The social situation is perhaps similar to being a dinner guest in someone's home. If the host would ask the guest how the food was (as I had asked Tadao to tell me about Tutorial), the guest would likely feel socially obligated to say that he had enjoyed the food. He would, however, less likely feel social obligation to say that he had hated other food that he had previously eaten (as Tadao did in regards to other physics classes). He would also not likely feel obligated to explain in detail *how* the host's cooking was superior to that of other cooks. It is easy to imagine a student superficially saying something like "Oh, Tutorial? Yeah, it's great, I'm having fun and learning a lot!" Tadao went well beyond what would be necessary to save the interviewer's face with a polite lie.

b) Previous physics classes were a "pain".

Soon after this statement, Tadao elaborated on his dislike for physics prior to Physics Exercises(22:10). Even though he had not taken physics until last year at Gakugei, he *had* taken mathematics classes in middle school where there had been calculations to find distance or to find an angle. He said that he had known that "calculations that use pictures" are prevalent in physics as well, and he "hated that kind of thing" (24:12). The class that he did take the previous year at Gakugei confirmed that physics is about solving problems and that he doesn't like it. In that class, he said, knowledge came from the teacher, in the form of students memorizing what the teacher wrote on the blackboard (22:27). He reported that Physics Exercises, in stark contrast, is about working together as a group: they think together and derive answers themselves (23:17). He said that he feels like the material in the class is making sense and that he is "really understanding that equations, for example, of physics are applicable in the real world" (21:51).

I asked Tadao about how he had reacted initially to the new style of physics class, and Tadao replied that he had been surprised to learn that physics can be approached in this way. In an attempt to paraphrase what Tadao had said, I tried to confirm that the previous approach had been using equations, but Tadao clarified: last year's class had felt like stuffing knowledge into your head. Physics Exercises, on the other hand, is about putting answers out from within (26:46). Tadao's hand gestures at this point speak even more loudly than his words. While talking about the previous style of class, he waved his hands, palms facing his head, towards and away from his head on either side, as though actually stuffing his head. When describing Physics Exercises, on the other hand, he reversed the motion, starting with his hands close to his head on either side, and flinging them away as though releasing something from within. He repeated both of these gestures several times. These words and gestures speak to a description of Physics Exercises featuring an active learning environment, whereas the previous year's class had been learning passively.

With this data alone, two possible interpretations stand out. One is that, although Tadao used to think that physics could only be learned by stuffing the teacher's knowledge into your head and doing calculations, he has "seen the light" that physics can also be learned using intuition and one's own daily experiences. The other possibility, however, is that he merely enjoyed Physics Exercises because it was like elementary school, with no deeper implications. For example, a skeptic could argue that although Tadao said that he was surprised to learn that physics can be approached in this new way, what he really meant was that he was surprised that there exists a class that is taught like elementary school was, while claiming to do physics. It is true that Tadao never said anything along the lines of "Physics Exercises is great, but it's not really physics. Physics, really, is just calculations." However, the absence of these words does not necessarily mean that he did not think such a thing.

c) Tadao has changed his image of physics and physics learning

Additional evidence that Tadao genuinely changed his epistemology about physics, however, occurred near the end of the interview, when I asked Tadao if physics is something that anyone can do if they try long enough, or if it's a subject that only some people can do. Actually, I could not ask the full question, because Tadao adamantly interrupted me halfway through.

> *[00:58:09.17] Tadao: I think everyone can. I originally didn't like physics, but I believe that I've started to be able to do it a little. So I think everyone can do it.*

Tadao had learned through Tutorials that physics is a subject that he can learn. This suggests that Physics Exercises had affected the way that Tadao was thinking about physics as a whole. His peaceful smile and reassuring tone of voice when he said this suggest not only confidence, but satisfaction as well. It suggests that he was thinking something deeper than "yeah, Physics Exercises is a nice class, but *physics* is just a lot of painful calculations".

(1) Physics can be understood in terms of personal experiences.

As said above, Tadao mentioned that he now understands that equations are applicable to the real world (21:51). At the same time, he has emphasized that he thinks physics can be learned with "your own thoughts" (16:21). Given this data, it would not be surprising if Tadao was thinking that physics does not just loosely relate to reality superficially, but that it can be understood in terms of personal experiences that one actually has in the real world. At the end of the interview, Tadao provided more explicit evidence supporting the presence of such an epistemology.

I asked Tadao if he thinks intuition is useful in the class, and he answered that, since the goal of the class seems to be "connecting one's own experiences in the real world" with "the physics way of thinking", intuition is indeed necessary (1:01:41). I then asked if Tadao thought that that process of "connecting" is an effective means to learn physics. He answered that if he only used the physics way of thinking, that he wouldn't really understand the material, even if he could succeed in the class. He further argued that

> *(1:02:33) Tadao: ...even if you can succeed in the world of physics, I think you have to apply that knowledge in the real world or it's meaningless. So I think it's important.*

For Tadao, it is not only that physics *can* be learned from one's own ideas and experiences (16:00, 1:01:41). To get a true understanding, an understanding that can actually be used outside of the classroom (which is, he said, an intent of education (1:02:22)), one *should* draw upon personal experiences in understanding physics.

2. How Tadao solved the Two Rocks Problem

During the interview, Tadao was given a few physics content-based prompts to see whether his explicit statements about Physics Exercises and the nature of physics were representative of how he actually engages with physics material. He consistently demonstrated what he had described as being important (1:02:22): he connected the physics formalism with everyday experiences.

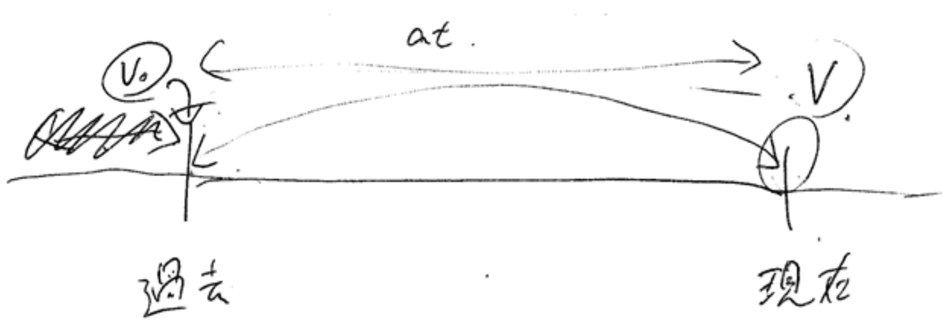
Tadao was shown the equation v=v0+at and told that "v is velocity, v0 is initial velocity, a is acceleration, and t is time" and was asked to explain the equation to a friend in his college class, on a physics exam, and to a 12-year old. He was then asked to solve a typical physics problem that can be solved with that equation. His responses to these prompts are presented here.

a) Explaining the velocity equation

(1) To a friend from class: Tadao's focus is on the process of how the object has come to change its speed.

Tadao's first explanation of the equation was to a friend from class. His written work is in the figure below.

> *[00:28:35.08] Tadao: Speed is, uh, from the past... the past... (drawing) and now... It's the, from here to here... I will talk about the process; I'm talking about the process, but... v0 is up until this point, uh, it's the past speed, and this "at", acceleration times time, is, from here til here, what kind of process, what kind of, uh, type of force application - it shows that... no, that's a mistake. (scratches out left-most line) v0 is the speed at this point, and "at", acceleration times time, is here, from the past to the present, that, if the force is going up, if the speed went up, if it went down, it's that feeling, and, in addition, here is the v, speed, of the present now.*



Tadao's focus was on the "process", the mechanism by which the object changed from the speed that it had in the past to the speed that it now has. He was thinking about the formal mathematical term "at" as connecting to something physical: how much the speed increased, because of a force acting on the object. He did not talk about a specific object or experience that he may have had in the real world. On the other hand, many students gave explanations that connected far less with physical reality. In Appendix B.5 are excerpts from two such students, Daisuke (who explained the equation as being the integral of acceleration) and Gorou (who focused on the units of each variable). For both students, the individual terms of the equation (i.e., "at") did not connect to something physically taking place.

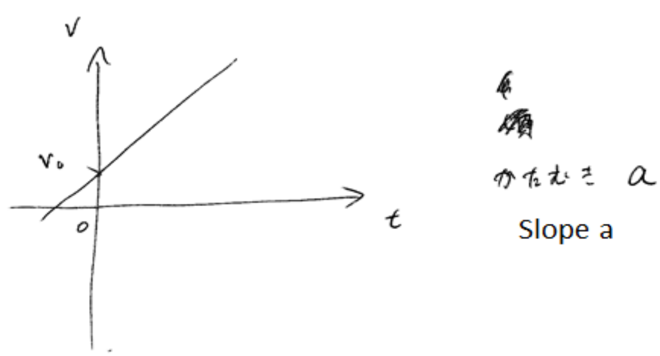
For Tadao, on the other hand, this mathematical term represented a *process* that is occurring. Although when explaining to a friend from class, the process was not attached to a particular real-world experience, it was nevertheless abstracted from intuitive thinking that comes about from everyday experiences of how things change from an initial state to a final one.

This kind of reasoning (connecting the formal structure to processes in the real world) about an equation is a cognitive structure termed “symbolic forms” by Sherin (B. L. Sherin 2001) and has been discussed by other researchers as well. (Tuminaro and Redish 2007; Izsak 2004; Hestenes 2010; Vanlehn and van de Sande 2009; Kuo et al.; Hull et al.) Symbolic forms based reasoning is a form of sense-making that can help students translate between intuitive understanding about a real-world situation into equations (B. L. Sherin 2001) and, from a mathematical solution to a problem, refine their conceptual understanding about the underlying concepts.(B. Sherin 2006)

(2) To a 12-yr old, he continues to merge formalism with everyday experiences.

Tadao was next asked what he would do if there were a physics exam with the question “Explain this equation” and then what he would say if a 12-yr old came up to him and requested an explanation of the equation.

> *[00:30:26.29] Yeah, I will use a graph (on the exam), but... v is, let's see, the intercept on the v axis. When time is 0, the intercept is v0, and, this... ah, I made a mistake… Let's see, let's see, (talking to self: "slope...") the slope of this graph is "a" and as time passes, speed goes and rises just by "a". I would explain by using this graph.*



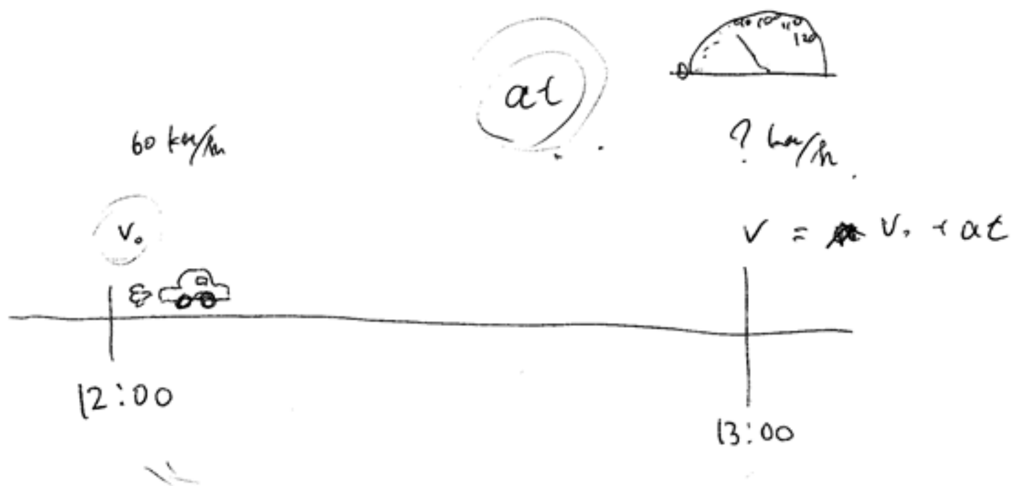
> *[00:32:19.09] Tadao: A 12-yr old child? That's fifth or sixth grade in elementary school, isn't it? This equation... Let's see, I would explain with an example, but... from 12 til 1 pm, a car moves. The, um, speed of the car when it is 12, there is this kind of speed, and the speed meter is, um, v0, well, for example, 60, 60 km, 60 km/hr., is what it's progressing at. At the time of v, well, how many km/hr. is it? That's the style I would go and explain with.*

> *[00:34:41.00] Interviewer: How does that explanation connect to this equation?*

> *[00:34:50.16] Tadao: Ah. v0 is, um, 12 o'clock, for example, for example, when it's 12 o'clock, the car is at v0, speed v0, and, at 13 o'clock, at 1 pm, this car, um, "it is reaching v km/hr., you know" is how my explanation would go. Um, when you spend 1 hour, um, if the speed (increases???) by just "at", from 12 o'clock til 1 o'clock, in the duration*

of that 1 hour, speed is increasing by just "at" and, v=... ah, I made a mistake.

[00:35:45.03] The speed at this time is v0 +, um, the speed that it went up in one hour, "at". That turns into v.



With both of these explanations, Tadao did not initially bring up the forms-based reasoning he had mentioned when explaining to a friend from class. In fact, in both cases, he did not initially talk directly about why “a” and “t” are multiplied together at all. However, when asked how the explanation about the car actually connects to the equation, he again talked about how “at” is how much the speed increased. Tadao was again demonstrating what he had described as being important: through his forms-based reasoning, he was merging physics formalism with everyday, intuitive ideas.

It may be that, had I asked how the physics exam explanation connects to the equation, that Tadao would have again talked about how “at” is how much the speed increases. However, it is also possible that he would have remained content with his explanation that “a” is how much the speed increases “as time passes”. What is known is that Tadao found it natural to tie the formal mathematical term “at” to a physical process both in his explanation to a friend from class, and when explaining to a 12-yr old.

More generally than his use of symbolic forms, Tadao showed that he connects formalism with every experience by choosing a real example of a car moving when he explained to a twelve-year old. This explanation seems the most consistent with his description of how one’s own experiences in the real world are important for understanding physics. Since he was clearly framing this activity as “explaining to an elementary school student” (as opposed to taking a physics exam, where more formal approaches like graphs with things like intercepts and slopes are valued), it might not be surprising that he *was* more consistent with what he described as his new approach to physics, since he learned that approach in Physics Exercises, which, he said, reminds him of elementary school. The implications of this will be further discussed below.

b) Solving the Two Rocks Problem

After he had explained the velocity equation, Tadao was asked to solve the Two Rocks Problem:

> *Suppose you are standing with two rocks on the balcony of a fourth floor apartment. You throw one rock down with an initial speed of 2 m/s; you just let go of the other rock, i.e., just let it fall. I would like you to think aloud while figuring out what is the difference in the speed of the two rocks after 5 seconds – is it less than, more than, or equal to 2 m/s? (Acceleration due to gravity is 10m/s2)*

One solution that many students provide to this problem is to substitute numerical values into the velocity equation for each rock. The speed of the thrown rock after five seconds is calculated to be 52 m/s, whereas that of the dropped rock is 50 m/s. By subtracting, the thrown rock is 2 m/s faster than the dropped rock. Thus, the answer is "equal to 2 m/s". This solution will be referred to as the "**plug and chug solution**". Tadao did not solve the problem in this way. Rather, Tadao consistently thought about his own experiences in the real world when solving. In fact, it is questionable how much he utilized the equation at all. The full transcript from his solution is available in Appendix B.4.

(1) Tadao first answered with his gut feeling and then "everyday experience".

Tadao first explained his solution half-joking, that he just has a feeling that "the second rock that you throw is still faster than the one you just drop" (36:52). The fact that Tadao offered this as an explanation might be a demonstration of his value for intuition in solving physics problems. At the same, time, however, the grin that slowly grew and turned into a little laugh that he exchanged with me at this point suggests that he was aware that simply answering with that would not be sufficient, and it suggests that he did not really think that an explanation consisting only of "I just have a feeling" is acceptable.

With a little effort, he was able to unpack that feeling. He began by talking about what *would* cause the rocks to reach the same speed: if they had been dropped from high enough, they might have both reached their "maximum speed" (38:20).

> *[00:37:23.24] (Given sufficient height) uh, I do think that the falling speeds will come to be the same. But with it taking place on the fourth floor balcony, uh, when I considered whether or not the rocks' speeds would become the same, I thought that in the realm of my own experiences until now, I've never experienced that.*

Since Tadao had undeniably been outside on a rainy day, he had quite likely experienced the phenomena that roughly identical objects, despite starting from different heights or different downward speeds, will reach the same terminal velocity by the time they hit the ground. However, we cannot know whether he was thinking about such an experience or not at this time in the interview. What we can see, however, is that, whether or not he had actually experienced rocks falling from a balcony, he was satisfied with an explanation that depends heavily upon (what he perceived to be) his own experiences.

Again, it seems most likely that Tadao's sense that the fourth floor is not high enough comes not from his own experiences in the real world, but rather from the physics that he's learned in school, where the teacher likely lectured about what kind of long distance is needed for the speeds to become equal. Nevertheless, it is interesting that Tadao

1) *explained* his answer as coming from his own experiences, and
2) seemed *satisfied* with such an answer.

It may very well be that his answer of "my experiences say it should be like this" was acceptable to him only because he was in the context of talking with someone he was associating as being responsible for the creation of this class at Gakugei. Whether he would solve a physics problem in this way in a traditional physics classroom is not a question I'm trying to answer here. Let it merely be noted that Tadao's first inclination to solving this traditional physics problem was to first rely on his gut instinct, and to then find support for that instinct in his daily experiences, which is very similar to what he said explicitly is an important thing to do when learning physics.

(2) If there's no air, there's no reason for the gap in initial speeds to close.

I next asked what would happen if there were no air (which, I assumed, Tadao was associating with the cause of objects having a maximum speed). Tadao found this to be an even easier situation: now that there is no resistance pushing back on the rocks, there is absolutely no reason for the gap in initial speeds to close. They will continue to fall "just like that".

Again, at this point in the problem, Tadao's solution appears to have invoked the equation only modestly, to say that the v0 of the two rocks is different (39:30). It is not, however, clear how that association helped his reasoning. What is clear is that he was envisioning air resistance physically having an effect on the speeds of the two rocks (39:56). He was visualizing the air as shrinking the gap in speeds, again, attaching a physical process to the formalism of the physics problem he was solving.

At this point, however, it seems that Tadao had not completely answered the problem correctly. Although he had provided an explanation for why there is nothing to make the difference in speeds be *less than* 2 m/s, he had not provided evidence of narrowing down between the other two possibilities.

(3) Tadao finally solves the actual problem: the equation is used with forms-based reasoning.

When I asked Tadao why the difference would not become *more than* 2 m/s, it took him some time to understand the question. However, this may be more reflective of language difficulties than Tadao's difficulty in making sense of the concept contained in the question. Supporting evidence is that Tadao, once understanding the prompt, was quickly able to rephrase the question in more natural Japanese, and, having done so, immediately answered the question.

It was at this point that Tadao at last clearly used the equation, but not for plug and chug. He associated the term "at" with the amount that each rock increases its speed. Since gravity acts on both rocks the same, and since both rocks "become faster by just the same speed" (42:13), the initial difference in speeds between the two rocks would not increase as time passes. It is possible that this notion was implicit when Tadao referred to the equation earlier to make his point about v0 being different (39:30), but one can only conjecture.

Looking at the data that is available, it seems that Tadao, when using the equation to solve the problem, did so with the same forms-based reasoning that he demonstrated when explaining the equation itself. The "v0" term is how much speed the rock has in the beginning and "at" is how much the speed changed; hence, if the change to both rocks is the same, the difference in the end will be the same as the difference in the beginning.

c) Virtually no in-class evidence of Tadao reasoning in this way

"It's great that Tadao actually thinks about the real world when doing physics problems in the interview," a critic might say. "But what does he do in the classroom?" Unfortunately, there was only one video taken of Tadao working in the classroom, and during that episode, he did not speak very much. The episode is analyzed in Chapter 9, section C.2.b, and the transcript, which contains some of Tadao's utterances, is in Appendix C.2.

3. Tadao himself viewed his approach as consistent with his explicit epistemological statements

It has been argued that Tadao solved a traditional physics problem and demonstrated his conceptual knowledge about an equation he used in a way that is consistent with how he said that he approaches physics. Specifically, he said that Physics Exercises revealed to him that physics can be learned using one's own thoughts (16:21, 25:12) and that one should learn physics by drawing upon one's intuition and own experiences (1:02:33) so as to connect the "physics way of thinking" to reality. He then consistently demonstrated that approach with his forms-based reasoning to visualize the occurring process that the physics formalism described (28:03, 34:50, 42:13) and reliance upon his own experiences (37:23).

This section strengthens the argument that there is consistency by presenting Tadao's own characterization of his solution to the Two Rocks Problem and explanation of the velocity equation.

> *[00:46:53.24] Interviewer: Um, a little earlier, um, the thing you said was, um, before you entered Physics Exercises, um, thinking about that approach… um, before entering, um, like, in order to learn physics, you, like, stuff knowledge into your head, but... and, if I write it, that was the "before" opinion (writes "before"), the before impression and, um, after entering, um, physics is, you can put out answers from yourself*
>
> *[00:47:42.22] Tadao: Right*
>
> *[00:47:44.09] I: That, um, it became that opinion(writes "after")*
>
> *[00:47:45.28] T: Right*
>
> *[00:47:52.09] I:Um, this is perhaps kind of a strange question, but*
>
> *[00:47:58.06] T:OK*
>
> *[00:48:01.25] I: Your way of solving this problem, and this way of solving (points to solution provided by interviewer), how do they compare with these ways of thinking (points to "before" and "after")?*

The solution provided by me and Tadao's classification of it will be presented below.

a) Tadao classified his own solution and equation explanation as "after"

Tadao associated his solution with the "after answer" with the justification that it is similar to what he was doing in Tutorials.

> *[00:50:58.23] Tadao: Problems in Physics Exercises, uh, it was a feeling of what is a good thing to do in teaching people who don't know…*

Tadao considered his solution as being one that would be easy to understand by someone who is not familiar with the formalism, similar to the kinds of arguments he was making in Physics Exercises. In other words, both Physics Exercises and his own approach to physics are alike in that they are not immersed solely in formalism; rather, emphasis is on everyday reasoning, so that any everyday person could understand it (e.g., a 12-yr old kid). Similarly, when I asked him how he would classify his explanation of the equation to a child, he again said that it was closer to the "after" way of thinking.

It could be that Tadao identified his own explanation and solution as being closer to the new approach to physics merely because they were his own and his pride was at stake, or at the least because he wanted to portray himself as being self-consistent.

However, such arguments lose some traction since Tadao actually told me that he *prefers* the plug and chug solution that I provided.

b) Tadao preferred the plug and chug solution?!

After Tadao had provided his solution to the Two Rocks Problem, I asked if there was another way to solve the problem. Tadao answered that there probably is, but that it isn't coming to him (42:29). I then asked Tadao to evaluate a solution that I "had previously seen" (the plug and chug solution).

> *[00:43:35.24] Tadao: I think this is good too. But, this is, um, I do think that this is a way of answering for people who are accustomed to calculations and good at mathematics, you know. For someone good at mathematics, this way of explaining is easier to understand I think… this kind of style, um, showing properly in numbers – it's easier for it to really click I think. "No matter what numbers you put in, the difference becomes 2 you know", doing a calculation in this style is easier to understand, isn't it. I prefer this direction.*

Although this data discredits the counterargument that Tadao said his own solution was like Physics Exercises because he wanted to protect his pride by asserting that his solution was the "best", it also gives rise to a curious puzzle. Immediately before Tadao was asked whether his own solution was close to the "before" way of thinking, the "after" way of thinking, or neither, he was asked to categorize this plug and chug solution. He said that it was very much the kind of thinking he had often done in his first-year physics class at TGU (48:47). *How can it be that he prefers a solution that reminds him of last year's problem solving, which he hated?*

One reconciliation of this seeming contradiction would be if, although Tadao hates doing such plug and chug calculations himself and thus prefers solving problems as he demonstrated, he prefers plug and chug solutions because of their apparent versatility. This is consistent with his saying how, with numerical solutions like that, no matter what the numbers are, the technique would still work. Perhaps he also felt that he had been struggling for some time to clearly articulate his conceptual thinking of what is happening in the problem, whereas my solution was eloquently stated, short, and direct, and perhaps thus more persuasive. Tadao himself recognized this seeming contradiction when he was asked to categorize the plug and chug solution.

> *[00:48:37.11] Tadao: The thing I said myself will come to change a little, but, um, I said that I like this direction better, did I not? Even so, this way of solving is closer to the before, the "stuffing" way of solving, isn't it? It's a calculation, if you will. What is it... There's a machine-like feeling to it. "If you do it like this, you do it like this" - that kind of, "if you do this one step, you do it like this" kind of... I get the feeling like the answer is decided - that's why. It is simple, you know. I do think that it can be easily understood. Once you insert numbers, it's all over, right? It's not making sense of words, but rather, when you see the*

numbers, you get it already. So, I do think it can be understood easily. But, uh, in looking at the point that the one answer is decided, in that regard, I think it more resembles the before "stuffing answers" way of thinking about physics.

He elaborated on the values of the two solutions when associating his own problem solution with the "after" way of thinking:

[00:51:04.27] Tadao: So if this solution (plug and chug) *is for someone who understands physics, it will quickly come and get into his head. That's why I thought the solution was good. But if the goal is to teach a person who doesn't know, well, for example, the 12-year old kid we were just talking about, I do think that he kind of wouldn't understand this* (plug and chug).

and near the end of the interview, when asked:

> *[00:59:57.27] Interviewer: Tell me again, why was it that you preferred this one?*
>
> *[01:00:00.14] Tadao: Um, this one is more, right away you can put out an answer, and it is easy to understand, you know. Um, between people who understand, when talking, this way of thinking is more, um, easy to transfer to the other person, and I do think it is more quickly transferred, you know. If it's a person who doesn't understand, he would absolutely not understand this, zero, the percent of understanding is 0, but if it is between people who understand, I think it's 100, 100 (moves hand to gesture two people), you know. And, as for my own thinking, I myself answered this way, did I not? If it's the way of answering that I answered, even if it's a kid who doesn't understand, um, 50% for example, an understanding of 60%, he would understand, but... um, even a person who does understand, I do think their understanding would be about 70-80% you know.*

A story that could be told that is consistent with all of this data is that, although Tadao recognized the value of the machine-like quality in this plug and chug solution and in other problems that he solved during his physics class last year, it is of value to *other* people, specifically, people who are good at math and physics. For people like him, however, for people who "don't know", Physics Exercises has introduced a way of approaching physics that is enjoyable (16:40), productive (58:09), and important (1:02:33).

4. Did Tadao actually change?

Tadao said that Physics Exercises surprised him by showing him that there is an additional way to do physics: using one's own ideas and experiences as a source of knowledge. However, just because he claimed that he had not been aware of this before Tutorials, how can we really know that he actually had not been in the habit of doing this kind of sensemaking in physics from the start? In other words, what we have seen in this chapter is the final state that Tadao is in presently. From his words alone, what kinds of claims can we make about his initial state? Is it fair to use Tadao as an example of the kind of beneficial effect Physics Exercises had on students? Certainly, Tadao credited Physics Exercises with having this effect. Furthermore, there is ample evidence to show that reformed curricula *in general* can have this kind of effect on students. Unfortunately, Tadao was not interviewed while he was taking the physics class the previous year at Gakugei, and we cannot know for certain how much or how little sense making he was doing.

It is plausible that Tutorials were very successful with Tadao, in that it introduced to him a more sense-making way to approach physics. It is certainly the case that Physics Exercises was successful at leaving Tadao in a state where he values everyday experiences in learning physics and left him with conviction that it was Tutorials that brought him to that point. In other words, although it cannot be proven that Tutorials did, in fact, help Tadao find personal meaning in physics, it is clear that Tutorials, for example, did *not* have the opposite effect, namely, of convincing Tadao that physics is something that just needs to be memorized and has only superficial relevance to the real world (which is an effect that many traditional physics classes have on students).

In either case, it is important to bear in mind that the claim is *not* that Tadao had a stable view of what physics learning is before Physics Exercises and that that view changed to a different stable view as a result of Tutorial. Indeed, if Tadao would engage again with a traditionally-taught physics class, it should not be surprising if he approached the material in the way he did during his previous year at Gakugei. The argument for the nature of the effect that Tutorials had is that, having learned that this kind of approach exists towards physics, Tadao will be *more* likely to utilize such an approach again in the future when dealing with physics.

5. Did elementary school really help Tadao do this?

It is perhaps surprising that Tadao freely mentioned how Physics Exercises is similar to elementary school. A skeptic might wonder how heavily scaffolded he was in saying such a thing. He clearly remembered taking the survey and his responses on it when he entered the interview, and I verbally asked Tadao about his elementary school at the beginning of the interview as well. Could it be that the only reason Tadao made the association between Physics Exercises and elementary school is because the interviewer was clearly interested?

It is certainly less likely that Tadao would have made this connection had the interviewer and survey not asked about elementary school. However, at the same time, that cannot be the entire story. I asked not only about elementary school, but middle and high school as well (similarly, the survey also asked about high school). Thus, although Tadao's past educational experiences may have been recently resurrected when he was talking about Physics Exercises, there was little to suggest to him that I was interested in connecting elementary school to Tutorials. Furthermore, Tadao was quite articulate about *what* exactly was the similarity between Physics Exercises and elementary school. Although Tadao might not have entered the interview determined to tell the interviewer about how Physics Exercises is similar to elementary school, the potential context-dependency of the connection's saliency does not make it altogether inauthentic.

I showed at the beginning of this subsection that Tadao found Physics Exercises to be a familiar experience, because he recognized it as being similar to what he had enjoyed in elementary school. I have also shown that, in Physics Exercises, Tadao became aware of a new approach to physics, and that he has taken that same approach to heart and adopted it in how he approaches physics problems (or at least, so he said). It is natural to try and ask the question "Did Tadao recognizing Tutorials as being a familiar experience help him happily adopt the new approach to physics?" It certainly seems plausible. To really validate such a claim, however, would require data showing, for example, that when Tadao thought about elementary school, he behaved differently than when he didn't. Of course, the *manner* in which his behavior changed in this hypothetical data would also be important.

Such data could resemble what happened when Tadao was asked how he'd explain the velocity equation to a 12-yr old (which I described above). When I asked him this prompt, his type of explanation *changed*. Whereas his first two explanations had not specified an actual physical object undergoing motion, the explanation to an elementary school student involved a car with a speedometer going at 60 km/hr. The most generous interpretation of this data is that because of Tadao's time spent in an elementary school where one's own experiences and opinions are valued, he found it easier to draw personal experiences into the classroom (or, in this case, an interview room in a school), especially when he was remembering those elementary school days. If thinking about elementary school provided Tadao access to thinking about everyday experiences in the interview, it is likely that if Tadao thought about elementary school during Physics Exercises class itself, that such resources would similarly manifest themselves. And, if Tadao was seeing Physics Exercises as being similar to elementary school, it is likely that he would, indeed, think about elementary school during class.

The question would thus become "could having greater ease of thinking about one's daily experiences during Physics Exercises class assist in recognizing and valuing actually using such experiences in learning physics (i.e., making the change that he described)?" Perhaps. But it seems contingent upon whether or not those daily experiences that are recalled during Physics Exercises actually *help*, in a way noticeable to Tadao, with his understanding of the physics. And this is where the data in the interview falls short. Thinking about a car with a speedometer did not seem to noticeably improve how Tadao understood the physics content itself. His understanding of the velocity equation seemed equally adept before and after he used such an example. Specifically, forms-based reasoning is found throughout his explanations. In conclusion, we are unfortunately left with little more than a plausibility argument that the connection Tadao found between Physics Exercises and elementary school actually helped him adapt to the new approach towards physics.

a) Tadao thinks elementary school might have helped

Near the end of the interview, I asked Tadao how it was that, although the Tutorials were so different than what he and the other students had been expecting to find in Physics Exercises, they had been able to adapt so easily. Tadao first confirmed that, indeed, it had been easy to adapt. In fact, he hadn't felt anything unnatural at all (53:50). He next answered that perhaps the reason why American students complain about the class but Japanese students do not is because of the high esteem that Japanese students hold for their teachers and their willingness to follow whatever their teachers say. I then asked if he had experienced something similar to Tutorials before.

> *[00:56:07.27] Tadao: Well, uh, since elementary school classes, for example, had essentially that same kind of feel... yeah.*
>
> *[00:56:09.19] Interviewer: Oh like what you were talking about before, right? Physics Exercises is like elementary school. And the thing that is similar is that, in a group…*
>
> *[00:56:15.16] T: Chatting in a group, uh, one's own... in elementary school, we told our own opinions to the teacher for example, but, in this class, the structure is that we write on paper and the teacher reads it for us. And, well, uh, (…) the form is a little, the way of doing it is a little different, but it has the same structure of the teacher seeing our own opinions for us, and then, in a group, you make the people around you hear your opinion, and then you in exchange listen to how they are thinking for them.*
>
> *[00:56:58.00] I: Do you think those elementary school experiences helped you adapt?*
>
> *[00:57:01.19] T: Ah, yeah, I think so. Unsurprisingly, the fact that we've had classes like this before now that were in a similar style... if it's when you're little, naturally, you want to try different things, right? Uh, you don't have the feeling of "I'm not going to do the things that I don't want to do", but rather "let's try it once." That is, pretty much, a characteristic of children I think. So, unsurprisingly, if it's something that you've tried doing when you're small, uh, there's also a feeling of nostalgia, so it is easy to adapt.*

We see in this interview excerpt that it was also plausible to Tadao that his experiences in elementary school had made it easier for him to adapt to Tutorials. Children naturally have an open mind and so would not resist such a style of schooling when they are young. Then, once they have had such an experience, they can feel nostalgic when they experience something similar in the future (like Tutorials), and that can make the experience more enjoyable and easier to adapt to. As was discussed in chapter 5, students were comfortable in Physics Exercises even on the first day. It is likely that their willingness to change so quickly to this kind of "elementary school mode" was aided by a prior experience that they could connect to Tutorial. However, to really prove that this connection between Physics Exercises and elementary school helped Tadao adapt to Physics Exercises, it is necessary, for example, to see the connection being made during Tutorial, and not just in the interview. Unfortunately, in the one video of Tadao's group engaging in Tutorial, none of the group members ever mentioned elementary school.

Note that no claim is made that Tadao would have been unable to make the change to Physics Exercises had he not had his elementary school experiences. In fact, there are many students in America, for example, who are able to appreciate the new style of learning physics that Tutorials offer without having had such constructivist experiences in academia. In fact, like these American students, Tadao himself undeniably had had experiences outside of school of using his own intuition and ideas to solve problems and coming up with solutions with his friends. It is likely that the reason why Tadao found the connection between Physics Exercises and elementary school, as opposed to Physics Exercises and shopping at the grocery store, is because the similarity of being in academia was salient to him. Were the academic resource of elementary school taken away, he still would have the experiences of, for example, figuring out how many bags of chips to buy at the store for a party, and these experiences could also have helped him adapt to Tutorial. The argument is only that the elementary school experience plausibly *helped* Tadao adapt. Hence, were this experience stripped away, it would not have been impossible for him to adapt to Tutorial; however, it would have been *less* likely.

F. Other students

Although case studies are illustrative, one is left with the question "how common was this phenomenon observed?" Although the four students described above were perhaps the cleanest and hence most convincing cases of changing, many other interviewees also provided evidence that their attitudes towards physics had changed as a result of this course. Prior to Maeda, this was not something that the interview protocol was probing for. However, Maeda, when asked what he thinks "physics" is freely responded

> *[00:27:44.00] Maeda: "Well, I do think that there is one thing since taking this class... unsurprisingly, it is necessary for understanding daily things... well, not so much necessary, but rather... it gives a concrete explanation for why daily senses become the way they do. Especially mechanics, motion... you look back on the everyday, if you will, you change your perspective."*

This shows that Maeda didn't merely "go along" with Tutorials in a superficial way so as to get through the class easily. Rather, he engaged with the epistemological substance of the exercises in a way that led him to reconsider his own views about the nature of physics. Especially in consideration of the case studies reported above and the prior physics experiences that most of the students described (which was presented in chapter 5 but does not diverge very far from the accounts of the above four students), there is good reason to believe that, as Maeda said, Tutorials gave him a new perspective on the nature of physics.

Following this interview, prompts were added into the protocol to more explicitly ask students if they felt their attitudes towards physics had changed. Maeda was the 14th interviewee out of 28. Of the remaining 14 interviewees, 11 were coded as reporting that they had changed. The four case studies above are examples of students who were coded in this way. Briefly, I now present data from two of the three students who were NOT coded as changing.

1. Chinatsu

Chinatsu was the only one of the three "non-changers" who did not take Physics 2 in high school. Her high school, however, was a "super science high school" which emphasized science education. Her classes were similar to Physics Exercises, in that students would argue with each other in class. When describing Physics Exercises, she asserted that it feels like her pre-college classes, and that it was clearly influenced heavily by science education research.

I asked her during the interview whether or not she was surprised when she entered Physics Exercises, and she responded that she was. She said that she is bad at physics and that she was worried about her grades and was worried that the class would be even more difficult than the physics classes she took her first year at Gakugei, but she found it to actually be pretty easy. When I asked, she said that she feels like Physics Exercises is more of a teacher-training class or an opportunity to really learn what they had already learned. It doesn't feel like "college physics" to her.

> *[00:24:05.05] Chinatsu: Physics Exercises is not about problems with a high degree of difficulty; rather, it's about the way of thinking, the way of capturing physics, if you will… it's like learning the way of teaching elementary school students and middle school students and high school students. It's really, like, elaborating our way of thinking - that's the feeling I get… Like, the educational aspect is big - that's the feeling I get. I guess it's aimed towards students in the education department...*
>
> *[00:25:38.20] Interviewer: When you entered Physics Exercises, I wonder if you had this reaction: "Is this really physics? It's so different than prior physics classes..."*
>
> *[00:26:00.07] Ah, I thought that it's not college physics. It's like, review the physics of elementary, middle, and high school ... kind of, "are you deeply and properly understanding?"... that's the sort of feeling that I got… I don't think the name Physics Exercises agrees with what we do in the class and I would call it "the way of physics education" – it's that kind of atmosphere… sort of really aimed towards education teachers...*

[00:26:59.08] Interviewer: Do you still feel that way? The physics in Physics Exercises is close to physics through high school - college physics is not like this. Does that impression remain?

Chinatsu: Yes

Unlike Tadao, Madoka, Miu, and Rina, we see in Chinatsu an assimilation of Physics Exercises that keeps it separate from "college physics". Her response to the curriculum is not "Oh, wow, physics can be learned this way!" The experience does not redefine what physics is for her; rather, Physics Exercises is an activity for pre-service teachers to solidify their understanding of physics and learn how to teach it to their own students.

2. Takahiro

In his interview, Takahiro (who is a physics major) talked about how his first experiences in physics were a struggle, but how he overcame by looking up whatever he needed to bridge the gap in understanding between himself and his classmates. While his classmates had already previously learned trig functions like sin and cos, he had to learn how to use the functions on his own. When he had completed Physics 2, he did not like topics such as electronics, current, and voltage, because he had trouble making sense of the material. He said:

[00:18:29.15] Takahiro: I totally couldn't grasp the sense there, it was only somewhat over there... like, if it would come to me according to my own senses, I'd understand, and, um, I would study it and it wouldn't be a bad feeling but, it's whether I get it or not... it's this distressful image- I am doing it and it's an uncomfortable feeling... I can solve, but, I am always feeling discomfort- only somewhat over there... like, it is distasteful, if you will, a bad feeling, like, it wasn't clean and neat.

He said that his image of what physics is hadn't changed as a result of Tutorial. Both before and after, his image of physics remained a means by which you can show things that you experience in everyday life like throwing a ball with mathematical equations, which is "awesome".

3. Survey given to 2012 students reveal that changing was common

It was not practical to interview all of the 140 students taking Physics Exercises. However, additional data, albeit less informative, can come efficiently from a large number of students in the form of a survey. The creation of a survey for the Gakugei students was a product of careful deliberation and discussion from watching many videos of the 2011 Physics Exercises students. Needless to say, it was not possible to give it to the 2011 students while they were still taking the class. From personal correspondence with Professor Uematsu, however, there is reason to believe that the 2011 class was not markedly different from the 2012 class, and these latter students did offer a viable target for a survey.

Via the survey, I asked the spring 2012 students the same prompts that I had asked the latter 14 interviewees: "Were you surprised when you entered Physics Exercises?" "What do you think physics is?" and lastly, "Did your image of what physics is change as a result of Physics Exercises?" The precise prompts are provided in Appendix A.5 and A.6.

As in the interviews, the first two prompts were designed to warm the student up to the idea of considering whether her attitude towards physics had changed or not. Thus, for analysis purposes, I largely ignore the results of those prompts and instead focus on the answers to the third. Forty-five students from the 2012 class began the survey, and 42 of them completed the survey up to this point. Twenty-four of those 42 students

1) said that their attitude about what constitutes physics learning and knowing physics had, in fact, changed, and
2) were able to describe their before and after images about physics in a way that demonstrated a positive shift.

One student wrote "I was thinking that the way of learning physics is to understand and memorize the contents of the textbook" but came to feel that "The nature of physics is not memorizing blindly, but rather thinking is important". Another student used to think that "Physics formulas are calculations" but changed to thinking that "Physics formulas are like words".

Sixteen of the 42 students reported no change, and there is insufficient data to tell whether that is because they entered the class already thinking that "physics formulas are like words" or if they still think that "physics formulas are calculations".

Two students had answers that could not be interpreted. For example, one student replied that his attitudes had not changed, but then offered in the free response box "It changed to understand about daily life from the meaning of formulas". Because this student answered that his epistemology had not changed, he was not given the follow-up prompt asking what his prior views had been. In addition to this core group of 42, five additional students from the 2012 class acted as validators for the survey. Three of these students said that they did not change, and two students did change. Finally, two students from the original 2011 class completed the survey (one year after taking the course) and one of them completed these questions. This student reported a change in epistemology.

In summary, the majority of survey participants provided evidence that their epistemology about physics changed as a result of Physics Exercises. This reinforces the main point of this chapter, which is to show that students accepted Tutorials not just on a superficial level of passively going along with whatever the instructor tells them to do; students were engaged deeply enough that they were able to reconsider their own epistemological stance towards physics. This epistemology was a central feature of the cultural script towards learning in a physics classroom that students brought with them into Physics Exercises, and it changed quickly and fluidly. This challenges the predominant view in the cross-cultural education research community of students having stable, unitary cultural scripts.

G. Conclusions

Stigler, in his writings on cultural scripts (J.W. Stigler and Hiebert 1998) would perhaps explain the phenomenon of Rina (and the other students described above) as follows: Rina developed a script, or set of expectations, about physics and learning physics from her experiences from middle school up until her first year of college. Upon entering Physics Exercises, however, her script of what to expect from physics underwent a slow and gradual change (that was perhaps accompanied by resistance to the curriculum) to what was observed both in the interview and in the classroom itself.

There is, however, an alternative explanation for the stance we see Rina presenting. Rather than having *a* view of what physics is at any given time, Rina's epistemology towards physics is one that is composed of smaller pieces that can be reassembled into either the attitude she says that she had before Physics Exercises, or the attitude that is manifest in the interview and classroom, and that the assembly selection is situation-dependent. As was the case with Louis (David Hammer et al. 2005), Rina's new epistemology could be relatively stable.

Critical evidence to tell between these two explanations would lie in looking at how easy it was for Rina to change to this new approach. Although I have shown that, for the most part, there was surprisingly little resistance from the Gakugei students at the new style of doing physics, I unfortunately do not have data of Rina from the first two weeks of class, and so I cannot say specifically what her reaction was. In fact, it's possible that she was one of the few students that Shuji-TA reported had just sat and waited for the TA to give the answer.

Other data that could help resolve which description is more accurate would be to observe Rina as she goes from Physics Exercises into more advanced traditionally-taught physics courses and to see how she approaches the physics she finds therein. If her epistemology reverts to what she described her previous approach to be, then that would support the argument that her epistemology is more fluid.

Whether we look at Rina as having a unitary belief about physics learning that can only change through time and conflict, or a fluid one that can quickly shift when put into the right environment, it is undeniable that Physics Exercises introduced to Rina a way of approaching physics that was comfortable for her and allowed her to engage in and make sense of the physics content.

H. Bridge to next three chapters

The following three chapters aim to describe the learning environment of the course at Tokyo Gakugei University that utilized tutorials. There are two motivators for providing this description:

1) To give an example of what it looks like to use the "borrowing" method proposed by this dissertation. As opposed to observing superficial differences between successful foreign classrooms and one's own classroom (like whether students are working in groups or not) and trying to superimpose these features, I advocate getting a deeper, more holistic sense of what the overall learning environment is to find potential mechanisms for how that learning might have occurred. In these three chapters, I describe this learning environment at Gakugei.

2) To make a plausibility argument for some of the scaffolds available that may have helped Gakugei students approach physics as something that they can personally understand and make sense of. This serves the broader purpose of arguing that student approach to physics is not rigid and unitary, but rather dependent upon context. Specifically, the epistemological coherence constructed in elementary school was not inaccessible to these students; rather, because of the classroom characteristics described in these three chapters, students were able to quickly take it back up.

The first scaffold I will discuss is how students found Physics Exercises to be an experience similar to what they had encountered in primary school. This recognition likely triggered the sense-making stance observed in students, much like how Hammer's suggestion of explaining the course material to a 10-year old acted as a trigger for Louis. (David Hammer et al. 2005)

Then I will discuss two scaffolds that likely helped stabilize that sense-making stance. First, students found a consistent pedagogical message from the curriculum and course educators reinforcing the idea that it is appropriate to sense-make in learning the material. Second, students found the sense-making approach to learning as one that would serve useful in their future profession as educators.

A resources-based model can describe how these three mechanisms can mutually reinforce each other and the students' behaviors to form the locally coherent epistemological stance that many students exhibited.

VI. Mechanism # 1 – Epistemologically Similar Prior Experiences

A. Introduction

This is the first of three chapters aimed at describing pervasive features for students at TGU that arguably helped students adapt with unexpected ease to what we might have thought to be a very strange experience for them. Note that the factors described in these three sections are not intended to be an exhaustive list of everything that helped students adapt - there are undeniably other factors (for example, it probably would have been more difficult for the Gakugei students to accept the course had the original English documents been used instead of the translated materials) that are not discussed here. Furthermore, I do not claim that all students were affected by all of these factors.

The intent of these chapters is to describe factors that are less obvious but nevertheless pervasive. Casual observation of a video taken from the class might reveal such details as a hot crowded room of students working in groups on worksheets. More detailed analyses like those described in the literature review might go so far as to look at how often it was for TA's to tell students answers to questions. These chapters will examine the class at a level beyond this surface account, at a sort of "deep structure" of the class.

In this chapter, I discuss the feature of Physics Exercises being familiar. Again, although students finding the class similar because they've worked in groups before likely did help their adjustment, it's rather obvious that prior group work experiences (in and out of school) would be helpful. What is a new and interesting finding, however, is that students by and large found the Physics Exercises environment to be epistemologically similar to prior experiences, predominantly experiences in primary school. This sense of familiarity was likely a factor for student success.

1. How this mechanism would work

Rogers (Rogers 1995) studied who adopts an innovation and at what time. In one case study, Rogers looked at Los Molinas, a village of 200 families in Peru, and at attempts to teach the residents about germ theory and motivate them to boil their water. The attempts were largely unsuccessful, because boiling water was seen as something that only sick people do. Rogers concluded that "An important factor regarding the adoption rate of an innovation is its compatibility with the values, beliefs, and past experiences of individuals in the social system".

As was discussed in the Literature Review of this dissertation, Hammer (David Hammer et al. 2005) wrote a case study of Louis, a student who was able to fluidly change his epistemological stance about what it means to learn physics in part because of his prior experiences working with little children. Louis quickly "adopted the innovation" of approaching physics in a new way because it was compatible with his past experience of being an older brother and a tutor. I argue that something similar happened with many of the Physics Exercises students.

Generally, the argument of how this feature of familiarity could have helped is that some kind of prior epistemological experience can provide resources to tap into for the students in the new learning environment. Just as Hammer telling Louis to try explaining to a child when he studies physics acted as a trigger for him to begin drawing upon those previously-assembled resources, Gakugei students recognizing Physics Exercises as being something like what they've done before was a trigger for them to draw upon a constructivist stance towards learning that they had previously assembled in prior learning experiences.

In this particular study, the bulk of the data pertains to student experiences in elementary school.[20] This is not surprising, considering the existing literature (see Literature Review chapter) describing Japanese elementary schools as drawing upon and utilizing student ideas (similar to what Tutorials do). Arguably, however,, similar experiences in middle school, high school, or even out of school could have provided students with the same tools as their elementary school did. One-on-one interviews with students revealed a wealth of data demonstrating that Physics Exercises was, in some way, an epistemologically familiar experience for students.

From some early interviews, I found students spontaneously connecting elementary school learning to what they were doing in Tutorials. From these observations, I changed the interview protocol for subsequent interviewees, so as to focus more explicitly on this issue[21]. I found intriguing evidence that for many students, elementary school helped to develop pools of epistemological resources that they could tap into while taking Physics Exercises. Finally, including some quotes from several of these interviewees, I created a survey that was administered to the 2012 cohort of students taking Physics Exercises to see how common it was for students to adapt easily to Tutorials and how common it was for these students to have had epistemological experiences in elementary school that might have helped with this.

The survey results confirmed the patterns suggested in the interviews. Like with the interviews, the pattern that I eventually found was not that students go around thinking about how Physics Exercises is similar to elementary school. Rather, I found evidence that, for many students, those past experiences served as resources for student adaptation, even if students were unaware that they were using those resources when they were engaged in the Tutorials.

[20] These descriptions were not limited to math and science. Sometimes students said that basically all of their classes in primary school took a constructivist form, sometimes the student said that only certain classes took this form at times.

[21] Details of how the interview protocol evolved can be found in Methodology (chapter 3, section C).

2. Data overview

The following are the prompts from the interview protocol that will be referred to below (excerpted from Methodology chapter):

3. "I am interested in education in Japan in general. First, what was your elementary school like?"

    3. If needed: "I'm wondering how education prior to college affects a student's attitude towards college physics"

4. "How about middle school? High school?"

5. "In general, from the perspective of a college student, was there a school that stood out the most?"

    4. If so: "So then the biggest change would have been going from (e.g.) elementary school into middle school. Was that a shock?"

6. "If you compare primary school with secondary school, what was the biggest difference?"

    5. If student does not mention teaching: "Did the way of teaching change?"

        2. If student does not say this herself: "I heard that Japanese elementary school teachers ask their students what they are thinking, but in high school, the teacher basically lectures and students just quietly take notes. Was it really like that?"

7. If student identifies different styles of teaching: "Which style did you prefer? Why? From the perspective of a college student, which parts about (e.g.) the elementary school style are good? Which parts are bad? And for the (e.g.) high school style?

9. Ask student about Physics Exercises, reminding her that her instructors will not see the video, so what she says will not impact her grades. Assure her that since you are not teaching the class but, rather, are researching it, whatever she says will not hurt your feelings.

    6. If needed: "Suppose a student is thinking about taking your physics class, but before signing up wants you to tell him about the class. Is there something you would say?"
    7. If student does not already say something: "Is there something good/ bad about Tutorial?"

12. "How does the physics you took before compare with the physics you're taking now?"

    8. If student does not already say so: "You described Physics Exercises as (e.g.) students thinking for themselves. Was that similar to previous physics classes you took?"

13. "When you first started this class, were you surprised? What was surprising? Did you think 'what are we doing? Where are all the equations? This isn't physics!' "

9. If yes: "At that time, what did you think physics is? What do you think now?"
10. If no, but student used to hate physics: "When you say that you hate physics, what do you think 'physics' is? You think that way now? Did you think that way before Physics Exercises as well?"

18. Explain that while observing students during Physics Exercises, you were surprised at how well students adapted to this new style of physics, although their previous physics experiences were very different. "Why do you think it was so easy to adapt?"

11. If they talk about how the class is great: "But the same class is not as effective at (my school). Have you had an experience similar to this before?"
    3. If no: "Maybe not another physics class, but maybe in high school, middle school, or elementary school?"
        2. If no: "Have you experienced solving problems in groups before?" If student had previously described Physics Exercises as such: "Have you experienced students coming up with answers in class themselves before?"

Interviews with the 2011 cohort of TGU students began with open-endedly asking students to describe their elementary, middle, and high schools (prompts 3-6). Some students at this point described how high school had focused more on just writing down what the teacher lectured about, whereas in elementary school, the ideas of students had been valued. If students did not relay that on their own, I asked them to evaluate a second-hand account of that distinction (prompt 6.1.1). At this point, most interviewees confirmed, to some degree or another, that the adage is true. I consider students who provided this information only after given prompt 6.1.1 to have had considerable leading.

Twenty-one of the 28 interviewees were asked why it was so easy for Gakugei students to adapt to Physics Exercises (prompt 18). At this point, 6 of the 21 volunteered that prior similar experiences of some kind had helped with the adaptation, mostly experiences of working together in groups in other various classes. Appendix D contains a list of student responses to this prompt.

Most of the remaining 15 students were next directly asked if they had experienced something like Tutorials before (prompt 18.1). At that point, many more of them described prior experiences of working in groups, and some also added that Physics Exercises was similar to internships or volunteering as a tutor. Students who still did not provide such information were given yet more leading prompts, culminating in prompt 18.1.1.1, which was the most leading.

a) A disclaimer is needed for this interview data

A disclaimer is needed here. The primary intent of this chapter is to show that the Physics Exercises experience at Gakugei can be characterized as being similar epistemologically to something students have experienced before. The ideal data for making such an argument would be in-field (*e.g.,* classroom video): students talking to each other naturally about how the class is similar to other things they've done before. In contrast, although it might be possible for an interviewer to get students to confess that Physics Exercises is similar to previous experiences by twisting their arms until they cry "uncle", that doesn't tell the research community anything about TGU students being familiar with the Tutorial style of class. Hence, although students did find connections when asked if they had experienced anything like Physics Exercises before (prompt 18.1), it was an activity rather forced by me. Although it was possible for students to still say "no" (and indeed, many students did, which is a point that will be addressed in a later section), students who contributed a connection may have been doing so more to appease the interviewer than because Physics Exercises was actually similar to something they had done before.

This same argument can hold, to a lesser degree, even with the question of why Physics Exercises was easy to adapt to (prompt 18). It is not unthinkable that upon hearing "why was (…) easy to adapt to?" that some interviewees would immediately equate that question to "what similar experiences have I had before?"[22] Let us thus look in more detail at some of these students, and at some other students as well, to make a more informed decision about what confidence we can place in such responses, and hence about how familiar Physics Exercises really was.

B. Connecting Physics Exercises to elementary school – case studies

I collected very little data speaking to how Physics Exercises was similar to prior college classes and work experiences in this study. To a large degree, this was a result of how we designed the interviews – with the goal of probing how Tutorials are similar to elementary school classrooms. Had interviews delved more deeply into certain work experiences or college classes, there would potentially be evidence found to support that those experiences are, in the minds of the students, similar to Tutorials as well. It is clear, however, that for almost every student, Physics Exercises was *not* similar to prior physics classes.

The intent of this and subsequent sections, then, is not to discredit the accounts of other students who did report that Physics Exercises is similar to specific experiences in college or work; rather, elementary school is focused on because it is

[22] For both of these points, students giving an experience similar to Physics Exercises may have just been intended to appease me as their interviewer. However, the substance that they drew on to make that similarity must have come from somewhere. This gives at least some minimal support to the authenticity of the connection students found between Physics Exercises and primary school.

the example for which most data exists. The goal will be to show that Physics Exercises was likely made familiar by previous experiences, using elementary school as a key example.[23]

I analyzed Tadao's case study in chapter 6, part E, and the connection he found between Physics Exercises and elementary school is clearly an important piece of his story. When I asked him if the teaching style changed from primary to secondary school (prompt 6.1), he replied:

> *[00:09:45.02] Tadao: … elementary school was like, we would pretty much talk together in a group, um, students would meet together (…) but in high school, it felt like that was absolutely not there*
>
> *Interviewer: At that time, did you prefer the elementary school style or the high school style?*
>
> *Tadao: I preferred the elementary school style. It was pretty much thinking yourself... we got a lot of time to do that - just thinking ourselves.*

And, when I later asked him to tell me about Physics Exercises (prompt 9), he replied

> *[00:16:00.06] Tadao: Uh, the calculations of physics, for example, that kind of thing, I thought it was a real pain. Physics really was not a class where I was thinking "I like this and want to do it!"; however, the Physics Exercises class is pretty much the thing that I like, since it feels like elementary school classes... because it's the kind of class where you think in a group, where you organize your own thoughts.*
>
> *[00:16:37.24] Interviewer: Sorry, say that again, how is Physics Exercises like elementary school classes... ?*
>
> *[00:16:40.07] Tadao: Um, you think in a group and uh, the things that you yourself are thinking, just as they are you can write them down and organize them. So I'm thinking that it's pretty much a class that makes you like physics.*

For Tadao, Physics Exercises was like elementary school – the emphasis is not only on talking in groups, but also on spending time with your own thoughts.

In this section, I showcase the way that other students described Physics Exercises as being similar to elementary school for epistemological reasons. In-depth analyses are provided for Kaede as an example and of Tadashi as a counter-example, and key data from Manami, Nao, Chinatsu, and Maeda are presented as well.

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[23] Section E of the Discussion also speaks to potential criticism about the data being skewed.

Bear in mind that the argument is that elementary school gave students epistemological experiences that helped them draw up a productive stance towards learning physics in Physics Exercises. As such, it is not necessary that students consciously be aware of the similarity between Physics Exercises and elementary school (for example, while they were in class). It is sufficient for this to occur subconsciously, and hence sufficient evidence of this occurring can be found in students seeing the connection between the two when given the interview prompts discussed below. A much higher level of proof would be needed if I were arguing that students consciously tap into elementary school experiences when adjusting to Tutorials.

1. Kaede

> *[Why was it easy for Gakugei students to adapt to Physics Exercises?] (prompt 18)*
>
> *[00:58:06.21] Kaede: Unsurpringly, they (Physics Exercises and some elementary school classes) resemble each other, do they not? That conversing of students with each other, not in the style of the teacher strongly teaching – it's that style of class of students conversing with each other, for example. Everyone has the experience of seeing that kind of class somewhere with some teacher, so I don't think there are many kids who will think like "Eh, this kind of class... is this thing called a **class**?"*

Kaede's full transcript is available in Appendix I.1.

a) Description of elementary school contrasts with middle and high schools

With Kaede, prompt 6.1.1 was not necessary. When asked to describe her elementary school (prompt 3), her first remark was that it was not the kind of school that makes you *study*, and she elaborated with an extensive example of her arithmetic class. True, there was a problem to be solved, and there were review problems (that were perhaps more rote) (8:02), but there was always an importance placed on students sharing their solutions with each other, and learning from each other.

In contrast, when asked about her middle school and then high school (prompt 4) she said that the two were similar, and, for the first time, she mentioned lectures. She said how the class style depended on the teacher: some teachers tended to use worksheets[24], some teachers gave classes that captured the interest of the students, and some teachers used lectures. She repeated that middle and high school were

[24] Although the interviewer did not ask for details about how students used these worksheets, Kaede used them as an example to contrast with her elementary school experiences (57:43), suggesting that they were the kind of worksheets done individually.

similar experiences when asked if there was a school that stood out the most for her (prompt 5). When asked why elementary school was distinct, she explained how in middle and high school there was a feeling of necessity to learn the material and that, because of being forced to study (13:15), she remembered very little of the material. The subject matter felt distant and impersonal:

> *[00:13:06.11] It was like "the textbook, the work, (gestures to desk) and me (points to self)"*[25]

Elementary school, in contrast, did not have this feeling of being forced to "learn" a corpus of knowledge removed from the student's sense of self; rather it was more like taking everything in, soaking it up like a sponge (12:21), and she had been able to remember what had happened in class well. This distinction parallels Kaede's first statement (above) about how elementary school wasn't really about *studying*, and it can also explain the "Not really" at the beginning of her statement in 4:29: Although middle school and high school classes were just focused on students getting the right answers (15:18), elementary school was *not really* about that.

She did hedge when she pointed out that it wasn't the case that students were leaving the arithmetic classes in elementary school without the correct knowledge (it is also true that they *were* solving problems), but the atmosphere was different. In elementary school, it felt like they were using knowledge to build a foundation (10:51).

To get a clearer idea of this difference, I asked Kaede to contrast "absorbing" with "learning" (13:23). Kaede used different words to elucidate the difference between elementary school and middle/high school. Earlier in the interview, she had made a gesture of waving her hands towards herself, as though wafting a pleasant scent, to describe the absorption of material in elementary school. Here, she used the same gesture for middle/high school to describe passively receiving knowledge. She reversed the gesture when talking about how learning in elementary school was active.

Although the gesture she used was different than Tadao's (who had simulated stuffing knowledge into your head and then flinging things out from within), the way in which Kaede's two gestures were reversals of each other was in common with Tadao's two gestures. For both students, the style of learning found in constructivist classes is the utter opposite of the lecture-based learning they experienced in high school.

To explain what she meant by active learning in elementary school, she gave the example of how everybody wanted to participate when the teacher would ask a question (15:07). Unlike middle and high school, students were actively engaged

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[25] Translation note from Dr. Kishida: Yes, the student says "the textbook, the work and me". I don't know what exactly the student means by "waaku (work)" but I guess she means "students work on some assignment-sheet-like stuff" (contrary to do experiments) and "zibun (me)" implies "I have to do study by myself, not with other students via conversing"

with the material. It wasn't important whether they answered correctly or not (15:23); rather, it was about taking the ideas that were relevant for the lesson and personally interacting with them.

b) Physics Exercises is like elementary school

Ten minutes later in the interview, I asked Kaede to describe Physics Exercises (prompt 9). She explained that she hates physics, and physics classes that are like what she experienced in middle and high school just don't work for her. Here, she added more descriptions to her middle and high school experiences: lectures were stiff, condensed, and streamlined. Taking classes was a "heavy" experience. Repeating what she had said earlier about middle and high school in general, she explained that content learned in such physics classes doesn't stick with her. With physics classes, this problem is so severe that despite having been present in the classroom, it's as though she never even took the class.

Physics Exercises, however, was not like the physics classes she took in high school and the prior year in college. Physics Exercises was not stiff; it was relaxed, and she was glad that she might be able to learn something.

Towards the end of the interview, when I asked Kaede why she thought it was easy for TGU students to adapt to Physics Exercises (prompt 18), she first replied that, whereas fish can only live in environments suited to their body types, Japanese are not like that. Even if they had been living in the sea of rigid physics lectures their whole lives, they could easily adapt to new environments, including the river of Physics Exercises. When asked why that was particularly true for Japanese, Kaede began by describing how, generally, Japanese are just not strong-willed people. She recognized that that sounded pretty negative, so she recast it in the positive light of

> *[00:57:18.14] the width that we can take in is wide.*

Having said this, Kaede immediately hedged to say that maybe that isn't because of being Japanese but because of being a student and having arrived from encountering various educational experiences. She talked about how she had taken classes in elementary school that remind her of Physics Exercises, and she imagined all of her classmates had experienced a similar class before as well.

In response to my surprise, Kaede offered the quote at the beginning of this section (58:06). Just as she had done fifty minutes prior, she explained how elementary school classes focused not on the teacher's lecturing, but rather on students talking with each other. And she identified this common element in Tutorials.

It is interesting to note that Kaede did not accredit all of her elementary school classes as focusing on this kind of interactive engagement; in fact, she recalled only arithmetic and social studies doing so (58:59). Nevertheless, those classes left such a strong impression on her that she not only remembered that feature many years later (and remembered it well enough to voluntarily compare it with Tutorials!), but characterized her elementary school experience overall as using that style.

c) Is the similarity epistemological?

At the beginning of the interview, Kaede had discussed how elementary school had had not only peer interaction, but also emphasis on students actively thinking about the material. Here, however, she only brought up the peer interaction. To probe about the second piece, I asked if Physics Exercises and elementary school are similar because of the peer-peer interactions or because of learning on your own and making your own discoveries. Kaede answered that since the Physics Exercises content level is so high, the self-learning is not the factor that is in common; rather, it is, in fact, the group work.

When I asked if Physics Exercises is active like elementary school was, Kaede made it clear that although she hadn't been thinking of that, there is a positive drive to learn in Physics Exercises like there had been in elementary school. Her use of "ah, but" in 1:00:27 suggests a recognition that she might be contradicting what she had just said about there not being a commonality as far as self-learning goes.

Although at times Kaede separated the group work and the active learning in her description of elementary school, at other points, such as her original description of elementary school, it seems that the two are coupled into a single experience of group-based active learning. If this coupling is strong enough, even when she was focusing on the group work aspect of Physics Exercises and elementary school, the relevant epistemological resources from the active learning experience would likely be coming along as well.

d) Returning to the disclaimer – did she genuinely see a similarity?

Let us return now to the original skepticism of students like Kaede mentioning elementary school when given prompt 18 in the interview. Is it possible that she made this connection chiefly because she was asked why Physics Exercises was easy to adapt to, equated that with "what similar experiences have you had?", started looking, and then decided elementary school was close enough to work? How much was I twisting her arm when she made this connection?

Perhaps an appropriate way to address this challenge is to ask "If Kaede were making a stretch in connecting elementary school to Physics Exercises, what would we expect to see?" We might expect to see more hedging than usual, indicated perhaps by more sentences ending with kana(I wonder), toomou(I think), etc. We might expect a long break in the conversation while Kaede was thinking of something that could answer the my prompt, perhaps containing self-directed remarks like nandarou(what could it be?), hissing, or, as Kaede did several times in the interview when a question was difficult for her, looking upward with a prolonged "Eh?". We might expect to see an unusual amount of fidgeting and looking away from the interviewer. With these things in mind, let's look more carefully at what Kaede actually did. I will again present Kaede's transcript, only this time in smaller pieces, interspersing descriptions of her body language as she made these utterances.

[00:55:06.14] K: Eh? Perhaps that is -

At this point, Kaede leaned back in her chair, looking upward. There was a pause after these words, and when she returned to the table she played with her hands and continued with a quieter voice.

- because we're Japanese.

The pause is no longer than average for her, and she frequently would change her speech volume to this level throughout the interview. She was smiling, but that is also characteristic of her interview performance. It is possible that this question was, at first, a little difficult for her to respond to. However, it is also possible that her momentary surprise and leaning back in the chair were reactions of simply finding the question unusual and interesting.

She at first laughed at her explanation, perhaps indicating that she found the explanation of "we adapted well because we have high adaptability" inappropriate for answering this question. However, in response to my request for clarification, she gave the example of fish with relative confidence. She began to rub her left shoulder when I asked if she had said that that is particularly true of Japanese, and she confessed (using the –teshimau verb extension, which is used when one makes a mistake or regrets something) that she does think it's especially true of Japanese.

She became further uncomfortable when I asked her why she thinks that's the case. She kept her hand on her shoulder until I had finished looking up the definition of the word shuchou(opinion) and had asked for clarification, at which point she moved her hand to her face and said

[00:57:04.21] K: Right, right. I have a feeling that we don't really have that, and

She then paused briefly, with her fist on her chin. When she resumed, her pitch was high, as though she had just had an insightful idea. When she said

[00:57:14.10] with a good meaning,

her hand had moved to the paper, and she was moving her fingers over it as though scratching, while staring at it thoughtfully. She paused for the longest of her pauses during this section before looking again at me and resuming

[00:57:18.14] the width that we can take in is wide.

She perhaps became abashed, resumed moving her fingers over the paper while gazing at it, and gently mumbled

[00:57:24.26] That is perhaps, well, I think it's not because we are Japanese,

She paused for a moment and then briefly looked up to say *but perhaps it's because we're students - that's there too, like... but I don't know*

This is the point that marked the embarkation to the idea of her elementary school experience being similar to Physics Exercises. She used the word "perhaps" consistently throughout the interview, which suggests that it does not express lack of confidence so much as temperance of speech. However, her "but I don't know" is a significant hedge. This was one of the few times that she said this throughout the interview and this can support the counter-argument that her elementary school was not *actually* similar to Physics Exercises in a way that would make Physics Exercises more familiar. Furthermore, there was a pause following this statement, which could indicate lack of confidence in this idea. However, there was another brief pause after

[00:57:36.02] Regarding that class,

which could suggest that these pauses indicate careful consideration (perhaps because this is her first time talking about this idea) and are not so much because she doubts the validity of what she is saying.

This argument that her pauses reflect consideration more than lack of confidence gains traction in that Kaede, after making this statement, picked up speed and briefly looked again at me when she said

til now everyone has come having taken various classes, so,

and when she said *for example,* there is a noticeable rise in pitch, as though she is making a rhetorical argument. The increased speed with which she talks, the eye contact she makes with the interviewer, and the more dynamic variations in pitch suggest a growing comfort with the idea she is putting forth. This increase in comfort seemed to build as she continued. She began to maintain eye contact when she said

[00:57:43.07] For example, til now, in every class and in every school, with the same system,

Both times that she said "every", she stuck her fingers out as though counting with boldness that contrasted with the demure gesture of scratching the paper just moments prior. When she described how students would have reacted if they had taken nothing but middle/high school – style of classes where focus is on worksheets, she used both hands to energetically gesture pushing Physics Exercises away. Although she followed that with the hedge of "I think", she said

[00:57:57.10] that was not necessarily the case,

quickly and crisply, showing conviction. When at last she came to

[00:57:59.29] in elementary school, I could do the class of this year's Physics Exercises

she was making frequent eye contact and speaking quickly and with more monotone, as though pulling up something that had already been mentioned earlier in the interview. When I asked for clarification, her response of

> *[00:58:06.21] K: Uh, unsurpringly, they resemble each other, do they not?*

was said while making eye contact and getting her hands ready to make gestures that would demonstrate the similarity in the next few lines.

After she said the words "til now everyone has come having taken various classes", Kaede's apparent confidence that elementary school was similar to Physics Exercises grew and grew, culminating with her saying that it isn't surprising that they were similar, and using the rhetoric "do they not" as though daring the me to challenge her. Her conclusion was that Physics Exercises is, after all, not so unfamiliar as it first appears.

Kaede's reason for this claim is that the peer-peer style of learning that goes on in Physics Exercises is similar to what she experienced in elementary school. At first, she explained that because Physics Exercises is "high-level", the feeling of students making their own discoveries and learning for themselves is not really there; however, when asked if Physics Exercises is "active" like elementary school classes were, she backed off her previous claim somewhat with her "Hm, ah, but" (1:00:27) and recognized that the spirit of wanting to learn is another similarity.

(1) Analysis: The connection Kaede found was not a forced one

Although reaching the explanation that students have had a similar class experience to Physics Exercises was not an idea immediately available to Kaede (and indeed, she first began with the explanation of "being Japanese" instead), once she arrived at the idea, it was able to take a strong hold. The fact that she did not show signs of doubting this idea once she reached it is evidence of her genuineness.

More significantly, the fact that she began at an alternative idea makes it hard to support an argument that she was equating the question with "how is Physics Exercises similar to other things you've experienced?" Thus, her eventual decision to answer prompt 18 by looking at similar experiences was significantly less influenced by me.

In light of this, it becomes more likely the difficulty she did have initially at answering prompt 18 came about not because she perceived that I wanted her to find a way that Physics Exercises is similar to something else, which was difficult for her; rather, she perceived that I wanted her to explain why it was easy to adapt, and this question itself was difficult for her (indeed, it would not be unreasonable to think that she had never been asked this question before, and so found it unusual and strange.) In other words, she spent her energy trying to find a type of answer to the question; once she had chosen to answer the question via finding an experience similar to Physics Exercises, the rest proceeded smoothly and naturally.

Again, evidence that would refute the authenticity of the elementary school connection would be if she had said something like "hmm… maybe there was a similar prior experience somewhere… I wonder what it could be… maybe elementary school? Yeah, I guess elementary school sort of was like Physics Exercises…" Kaede, however, did no such thing. The greatest doubt she faced was when she first tried out the claim that the ease of adaptation was because they are college students, which had not yet become the idea of "we've had similar experiences in the past."

Perhaps most convincing is that Kaede's comparison is self-consistent. Her description of her arithmetic class in elementary school is vivid, indicating that it left a lasting impression. When she later made the comparison to Physics Exercises, she focused on features that align with that initial description.

This concludes the argument that, at least for one student, a feature of the Physics Exercises environment is familiarity because of previous similar experiences, not just in the social nature of it, but in the emphasis on one's own knowledge (an epistemological similarity) as well. Although at times Kaede decoupled these two aspects (like when she first described how Physics Exercises resembles elementary school), at other times they are coupled (like when she described elementary school at the beginning of the interview), and it was not difficult for her to recognize the epistemological similarity between elementary school and Physics Exercises.

2. Key data from some other students

Although I am not providing full case studies of the students in this subsection, I will streamline some important data from their interviews.

a) Manami – Physics Exercises is like primary school – student ideas are important

Manami described thinking time in primary school that was absent in high school, and how teachers would elicit responses from students in the former. I asked her which style she preferred (prompt 7) and she replied

> *[00:10:53.25] … I liked high school better, but once I became a college student thinking about education, unsurprisingly, classes where the students are made to think, more like elementary and middle school – I learned more in [elementary and middle school] classes*

Later in the interview, I asked her to tell me about Physics Exercises(prompt 9), and she replied that "of course, what we are studying is higher than a high school level, but it looks like what we did in elementary school and middle school , for example, since it's a class where students think..."(26:37)

For Manami, Physics Exercises was similar to primary school – in both, student ideas and thinking for oneself are important.

b) Nao – Physics Exercises was easy to adapt to because students remember the value of teaching each other in groups

I asked Nao if his experience in moving from primary to secondary school had been consistent with the adage (prompt 6.1.1). His focus was on the social aspect of the class (there was a lot of student talking):

> *[00:16:47.06] In elementary school, during classes, there were a lot of conversations with the teacher; other students also had a lot of conversation with the teacher. Students became quiet in middle school and high school. In elementary school, even in Japanese class, even in arithmetic, even in science, even in social studies, even in any class, unsurprisingly, everyone was talking, but in middle school and high school, depending on the teacher and the class contents, it would be different whether we would talk or not talk.*

Towards the end of the interview, however, he expanded upon that image of talking to include an emphasis on your own ideas and teaching each other. I asked him why Physics Exercises was so easy to adapt to (prompt 18), and he replied

> [00:50:40.17] Nao: Middle school, high school, so many years passed, but even so, during the time of elementary school, chatting, talking, solving problems all together was fun. *Talking with people about things that you know, being taught the things you don't know that others do know, the importance of that, since we know that…* til now, that kind of being taught one-way by a teacher - even if we take those classes… so, getting used to this class quickly - there is elementary school experience

For Nao, the experience of valuing and comparing student ideas with classmates was not only a common link between elementary school and Physics Exercises; it was a link strong enough to give him explanatory power for why the new style of physics learning was easy to adapt to.

c) Maeda - Unlike high school, elementary school had you think for yourself, like in Tutorials

I asked Maeda to describe how primary school contrasted with secondary school (prompt 6). He answered that the biggest difference was in the amount of group work, again, mentioning the social aspect of the classes.

> *[00:10:08.20]Doing things on our own or doing things that included group work, like researching some topic – in high school, if you compare to middle school and elementary school, the amount was absolutely less.*

When I asked him to compare Physics Exercises to previous physics classes (prompt 12), however, he elaborated that those times of group work had also been times of thinking for yourself.

[00:23:15.04] The classes I took last year are like high school. The teacher explains ways of thinking or general ideas including formulas. Well, in that meaning, inside of my impression is the thing that this class is, um, a type of class closer to something in elementary school or middle school. Because it's a class where you think largely for yourself

Maeda found Physics Exercises to be more similar to primary school than previously-taken physics classes. In both settings, there was an emphasis on student thinking.

3. Tadashi

I will now give an example of a student who, while finding Physics Exercises to be similar to elementary school, did not find it so because of the epistemological nature of his experiences. I tell this student's story here to give a contrasting case of what I mean by "epistemological similarity", to make it more clear what I mean by the connection observed with Kaede.

a) Tutorials are like elementary school because of the group work

When I asked him to describe his elementary school (prompt 3), and even when I asked if the teaching style changed from elementary to high school (prompt 6.1), Tadashi did not discuss how elementary school had students focusing on their own ideas. When I at last asked whether or not the rumor (prompt 6.1.1) is true, he agreed with it, because the elementary school teachers gave students a lot of attention, one-on-one. High school teachers, on the other hand, were more likely to tell the class "do it yourselves" (14:10)[26] . This reinforced what he had said on his own in response to whether or not the teaching style had changed from primary to secondary school. He had said that high school teachers don't pay individual attention to students, and that students with bad grades are "not taken care of".

We gain more insight into Tadashi's elementary school experiences with his response to the interview prompt of whether or not he was surprised when he entered Physics Exercises (prompt 13).

[00:32:20.23] Tadashi: Hmm, well, off-hand, I remember that I was thinking the class would be done in that traditional style. (…) That kind of class where everyone is talking together is something like what went on during elementary school... because middle and high school didn't have it. It (Experiencing that style in Physics Exercises) was absolutely fresh.

[26] The following interview excerpt about elementary school (32:20) suggests that when Tadashi's high school teacher told the students to "do it themselves", it wasn't "done" as a group, but rather individually.

[00:32:59.23] Interviewer : OK, you said that in elementary school, something was there, but in middle and high school, something wasn't there. That thing was the act of talking together?

[00:33:08.17] T: Ah, yes. Um, you learn in a GROUP, you go and answer as a GROUP - it's that thing.

We see Tadashi freely making a connection between Physics Exercises and elementary school. Whereas Kaede, Nao, and others made explicit that the way students use their own ideas in Physics Exercises is similar to what was done in elementary school (Kaede talked about how students in elementary school were eager to engage personally with the material and didn't care about whether their ideas were correct or not (15:23)), the connection Tadashi was making seems like it could be solely at the level of interpersonal communication between students. In other words, it could be that elementary school was distinct from middle and high school not so much because of the emphasis on students' ideas, but rather because students were working in a group and solving (perhaps algorithmic) problems together.[27]

b) Tadashi valued the epistemology of Tutorials

I argue that there is no evidence to show that Tadashi connected primary school and Physics Exercises epistemologically. If such evidence *did* exist, it would be at points of the interview where he discussed the epistemological atmosphere of either primary school or Physics Exercises. I will present the places in the interview where Tadashi discussed epistemology, and show that he did not make epistemological connections between Physics Exercises and prior experiences.

At the end of the interview, I invited Tadashi to ask me any questions. He told me that he and some of his classmates would be taking quantum mechanics the following year and he wanted to know if they would be able to approach the material like they had done with Physics Exercises - specifically, it they could make the material "match their intuitions" (1:09:03). I told him that it could be done, but that it isn't easy.

As part of my explanation, I asked him what intuition is. He replied that intuition is about one's "way of seeing things" - not with the eyes, however, but rather understanding something "as an image within your head." (1:10:11)

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[27] One might argue that Tadashi's first statement about high school teachers telling the students to "do it themselves" leaves room to think that elementary school had more of a focus on the teacher's knowledge than high school did. It is most likely, however, he was not thinking about using one's own ideas in class learning one way or another at that early stage of the interview. After he had discussed how high school teachers tell students to "do it themselves", he was asked which style he preferred, and he answered the high school style, because he liked having the freedom to make his own decisions. In his case, he continued, he had chosen to not study and to instead get involved with school festivals.

Despite it being past the hour that the interview was supposed to last, I was unable to resist the urge to ask him one last question that seemed directly relevant to the one he had asked. I referred back to how he had explained that he now viewed physics as being much closer and able to be "taken in his hand" and asked if he thought that way of approaching physics would help in the next year's classes.

> *[01:14:10.12] Tadashi : It SHOULD help. Unsurprisingly, if you don't know the meaning of an equation... I think it's no good if you look at that equation and can't make an image of what is going on, so it absolutely SHOULD help.*

Thinking that he had perhaps not understood my question, I specified that I was asking if this year's Tutorials would help when he came across *new* equations next year, and he said that he had understood my question, and that he thinks it should be helpful. In Physics Exercises, he said, he had "learned we have to understand the written equations inside ourselves and be able to create an image."(1:14:24)

He regretfully acknowledged, however, that he might not be able to do it with difficult equations. I asked with an air of skepticism if he had not been finding the meaning of equations prior to Physics Exercises, and he confirmed that he had just accepted equations "as is", that were defined to be the way they are, not open for interpretation or personal understanding.(1:15:23)

Clearly Tadashi recognized that Physics Exercises had been more than just group work; it had been a time to use one's own intuition ("images inside one's head") to grapple with new physics concepts to reach a deeper personal understanding (for example, to "create an image of what is going on" in an equation), and he recognized this as being a productive thing to do that he hoped to continue in his future learning. For whatever reason, however, he did not connect this attribute to elementary school.

Near the end of the interview, I asked Tadashi why it had been so easy to adapt to the new way of doing physics (prompt 18). He answered that because of his limited prior physics knowledge, the physics class he had taken the previous year had been very difficult. The physics content in Physics Exercises, on the other hand, is "lower" and easier for him to grasp; furthermore, because the material is close to everyday experiences, it is not difficult to understand.

I then asked if he had experienced something like Physics Exercises previously (prompt 18.1). He answered, emphatically, that he had not, probably reinforcing what he had previously said about how the class was very different than other physics classes he had taken. I then asked him prompt 18.1.1.

> *[01:00:50.12] Interviewer : For example, maybe not in another physics class perhaps, but, for example, in another college class, middle school, elementary school, for example, somewhere, have you experienced something like this?*

[01:01:05.27] Tadashi ：Mostly in elementary school… we decomposed starch using saliva as a group - I remember that well.

[01:01:21.17] Ｉ：You had that experience, and do you think it is helpful now?

[01:01:25.11] Ｔ：Huh… The truth is that I am now 26 years old, so… when you become 26, just the fact that you remember something is itself meaningful I think. Because the things that you can't recall comes to grow in number.

Here, again, Tadashi seemed to emphasize the group-work aspect of elementary school as being a relevant experience for Tutorials, without reference to one's own ideas. Although it would have been opportune to have asked if the way that students use their intuition and create their own understandings in Tutorials (using and creating "images in their own heads") is similar to what students did in elementary school, I did not think at the time to give such prompt, and all that one can do is speculate.

What is known, however, is that Tadashi did find Physics Exercises to be a familiar experience, at least at the level of working in groups. It is plausible that the elementary school experiences of working in a group made the potentially strange class style less foreign, and easier to adapt to. However, that is not the mechanism that I am emphasizing was prevalent amongst many of the Gakugei students, and which I have used case studies of Kaede and Tadao to illustrate. Rather, my point is that Physics Exercises was similar *epistemologically* to prior experiences.

C. What about the students who said "no"?

Although there is data to support the plausible argument that experiences in primary school were helpful for many of the Gakugei students, there are a number of students for whom such evidence is lacking.

As described in Methodology (Chapter 3) part C, students were first asked openly why they thought Physics Exercises was so easy to adapt to, considering they had come from very different physics experiences in high school and college (prompt 18). Students who did not compare Physics Exercises to elementary school were then usually given a series of follow-up prompts to see if they could be led to do so (prompts 18.1, 18.1.1, and 18.1.1.1). For example, if students had mentioned experiences in elementary school that seemed like they might be relevant for Physics Exercises, I would say "you said that in elementary school, you would (…) in what ways is that similar or different to Physics Exercises?"

Despite such strong prompting as this, some students still continued to say that they had never experienced anything like Physics Exercises before.

Yui, when asked if she had experienced something like Physics Exercises before (prompt 18.1), said that she had not; Physics Exercises was totally fresh and new.

When next asked if perhaps she had had an experience prior to college, like in high school, middle school, or elementary school (prompt 18.1.1), she flat out turned the idea down. There was no room for follow-up prompts because Yui had said that she did not remember primary school well, but that she remembered science in high school fondly. Although she had briefly agreed with the adage of teachers in elementary school asking students what they are thinking (prompt 6.1.1), she had been quick to say that she had really preferred high school because the lectures had been interesting to her.

Yasu similarly responded with "no" to "perhaps you've experienced something like this before college?" (prompt 18.1). Yasu had identified in the interview that Physics Exercises is marked by thinking deeply about your own ideas. When asked if he had experienced doing that before (prompt 18.1.1.1), he replied that, probably in other physics classes, he had from time to time stopped taking notes to think about a new equation.

When, at the end of the interview, I asked him about the rumor (prompt 6.1.1), Yasu said that in his case, it was just the opposite. In elementary school, the teacher was always at the board, whereas in high school the teacher was very interested in different solutions. He volunteered that his elementary school had been a new and unusual school and that the teachers had not yet figured out what they were doing.

Madoka had discussed how, in his elementary school, they had worked in groups (prompt 3). However, when asked if this was similar to what they do in Physics Exercises (prompt 18.1.1.1), he replied that they had not solved problems in elementary school like they do in Physics Exercises. The way of thinking was also different: whereas in elementary school students would give their opinions about what they were seeing in the moment, in Physics Exercises, they brought prior content knowledge with them to use.

Certainly, for some students like Yasu, there is no evidence that they have had prior experiences that are similar to Physics Exercises. For other students, even if they *have* had previous elementary school experiences that are similar to Physics Exercises (like perhaps Yui), there is no evidence that those experiences remain relevant. That is, even if a student had had elementary school experiences like Kaede, if no trace of that experience remains in her mind, then those experiences will not be brought into the Physics Exercises classroom. On the other hand, the experience could remain in the mind, but at a subconscious level, and could still affect student behavior (and acceptance of the new curriculum).

Lastly, there are students like Madoka who found significance in differences like whether students are bringing prior content knowledge into the classroom with them or not, and thus maintained that Physics Exercises really is not like elementary school. A student genuinely believing that Physics Exercises is similar to a previous experience is great evidence that students *are* finding Physics Exercises to be a familiar experience. However, the lack of such a conviction does not necessarily *rule out* the idea that Physics Exercises is more familiar to students with those experiences. In other words, although Madoka resolved that Physics Exercises is different than elementary school, it could very well be that if he had not taken those elementary school classes, Physics Exercises would have been more of a foreign experience for him.

The evidence to support claims of subconscious effects in students like Yui and Madoka is that their accounts of elementary school are consistent with accounts from students who *did* declare Physics Exercises to be similar to elementary school. These subconscious effects, if they exist at all, would likely have a smaller effect on a student than if the student consciously acknowledged the connection between primary school and Physics Exercises, but that does not necessarily mean that the effect is negligible. This dissertation cannot resolve these issues, but studies of such subconscious effects might be interesting for future research.

D. How widespread is this? Survey results

The argument in this chapter so far has relied on case studies of Tadao and Kaede to show beyond reasonable doubt that, for some students, similar experiences of academic activities in the past created pools of epistemological resources that students could tap into in the Physics Exercises classroom. This plausibly formed a powerful mechanism to help them adapt to the new learning style effectively.

Next, as was done with Madoka, I assert that, plausibly, students who identified their elementary schools as having features that, for example, Kaede and Nao identified, could find Physics Exercises to be more familiar than if they had not attended that elementary school.

This data can be obtained in the form of a survey. Note, however, the importance of the case studies for this process. One of the questions on the survey is "Why was Physics Exercises easy to adapt to?" As was discussed above, if students would only be asked "Why was Physics Exercises easy to adapt to?", there is a risk of students equating the question to "What prior experiences are similar to Physics Exercises?", and, in such a case, results must be regarded with skepticism. To make a convincing argument that the connection is sincere, it is necessary to look not only at what words students use to respond to this prompt, but *how* students use those words, and to look not only at that prompt, but at the holistic story that students bring with them about their interaction with Physics Exercises and previous academic experiences. Only with the case studies analyzed above serving as reference examples can we now consider that some fraction of students responding to the survey with "we've had experiences like Physics Exercises before" have similar stories to those of Kaede and Tadao. The Methods chapter 3 section C.5 discusses other ways in which the qualitative interviews informed the creation of the quantitative survey.

In 2012, a total of 42 students took and completed the survey associated with Physics Exercises. An early prompt on the survey asked them "Have you experienced anything like Physics Exercises before? Please also include experiences other than physics class (other science classes, classes outside of science, elementary, middle, and high schools, for example)." Although many students replied with something, no students mentioned using their own ideas, reconciling intuitions with what they were learning, or anything else that could be considered similar in an epistemological vein to Physics Exercises. The closest was student who answered that Physics Exercises was similar to ethics class in elementary school, but did not elaborate on why. However, 9 students answered either "applies well" or "more or less applies" to the prompt "In Physics Exercises, student ideas and opinions are focused on." AND were able to give a reasonable example to the follow-up prompt of: "Have you experienced that thing of focusing on one's own ideas and opinions like in Physics Exercises before?"

Of the remaining 33 students, 21 of them answered "applies well" or "more or less applies" to at least one of the following prompts (see Methods chapter 3, section D.8 for the full prompts):

- "In my elementary school, the teacher would often make students think up their own ideas themselves"
- "In my elementary school, the teacher would often use ideas that students had thought up themselves"
- Aoi: "In elementary school, it's not about the answer to the problem, but rather how you can solve it. You think how you can solve it, that is different for different people, so I think being able to say one's own thinking was emphasized."

Thus, it seems that for about a quarter of the students who took the survey, there is no evidence that elementary school provided the resources that would be necessary for them to recognize the epistemological nature of what students did with Tutorials as being a familiar activity. For the majority of students, however, it is plausible that students were finding Physics Exercises to be familiar.

E. Conclusion

This chapter has focused on elementary school as an experience that for some students clearly created pools of epistemological resources that students had available for tapping into during class and for other students plausibly did so. Utilizing these resources could serve as a mechanism for students quickly adapting to the unfamiliar style of learning.

To go beyond the plausibility argument for this mechanism would require in-class data of students adapting as a result of tapping into these resources. Data to that effect was absent in my study, as described in chapter 5, because students seemed to adapt immediately to the new style.

An example of the kind of data that would be necessary, however, was seen by Professor Uematsu while teaching students in the physics lab class in the fall of 2011.

> *"I asked a student why the moment of inertia increases with rod length and mass. He answered "Because we can calculate it according to this formula…" Then I said "If you were asked by an elementary school student?" He said "Ah!" and I saw he looked different at that moment.*

> *He tried to explain intuitively what a moment of inertia is and gave a concrete image of vibrating one of rods." (Personal correspondence, June 18th, 2012)*

I am making no argument that a Tutorials-like epistemological experience in elementary school will better prepare students than a similar experience anywhere else in academia. There is no evidence to discount students who said Physics Exercises was easy to adjust to because of having worked together the previous year on activities that drew upon students own ideas and experiences.

At the same time, however, elementary school is an important example, because although many students in the class had not yet had teacher-training classes or even lab classes at Gakugei, and many more students had not volunteered or worked as a teacher, they had all attended elementary school. According to literature, most of these schools follow similar pedagogical strategies.

It is interesting that, at least for some students, memories of elementary school classroom experiences persisted all the way to their second year at Gakugei, and were tangible enough for them to recognize, on their own, how Physics Exercises is similar. However, the main argument is that, for various reasons, Physics Exercises was a surprisingly familiar epistemological experience for a significant fraction (but not all) of the students.

This factor and the two factors described in the following two chapters likely helped students shift quickly from an epistemology that physics is about getting and memorizing knowledge from the instructor to an epistemology that one's own experiences and ideas are valuable sources of knowledge. Whereas seeing Physics Exercises as a familiar learning environment likely acted as a trigger for the shift in epistemology, the other two factors likely served as stabilizers to reinforce this new epistemology. In the Discussion chapter, I will argue that the speed with which students shifted under these scaffolds suggests that the currently popular framework of cultural scripts is over-simplified and that a framework of manifold epistemology can better explain this observation.

VII. Mechanism # 2 - Seeing Relevance in the Curriculum to Future Goals

Gakugei students basically want to understand physics even if they do not like it now because they know they will need it when they become a teacher - (Professor Uematsu, e-mail)

A. Introduction

There are many factors that can motivate a student to engage with a class. For example, at the University of Maryland, students with aspirations of becoming medical professionals take classes implementing Open Source Tutorials because these introductory physics classes are required for graduation. This is a form of "extrinsic motivation"; such students are motivated by "performance goals". (Ames 1992)

Although, similarly, most of the students taking Physics Exercises at Tokyo Gakugei University were students who needed to take the class to get their teaching license, many students had an additional, more immediate incentive to take the class. For many, not only was completing the course important, but what was learned in the course was seen as relevant to their future profession as well. These students were "intrinsically motivated", with "learning goals". (Ames 1992) Students who are motivated in this way may be more likely to be open-minded to learning approaches like what Tutorials require, since the emphasis is on deep conceptual learning. On the other hand, much of the resistance to reformed curriculum comes about from students being grade-focused and worried about not being able to perform as well in the unfamiliar learning approach. (Carlone 2004; Edward F. Redish, Saul, and Steinberg 1998; Cruz et al. 2010; Mauk and Hingley 2005; Villasenor and Etkina 2007)

Interestingly enough, although there was some contention between students as to whether the physics content covered would be helpful in the future or not (described below), no students at any time voiced a doubt about the usefulness of the learning style used in Tutorials for their future. Three students, in fact, when asked why it was easy to adapt to Physics Exercises, replied that since the students will become teachers, it was not difficult to value engaging with this kind of class.

B. Three students freely talked about how the Tutorial approach will be relevant for their future teaching profession

Beginning with Yui (in other words, after Saika, Yamato, Akane, Sakura, and Manami), I added prompts to the interview protocol to get at why it was easy to adapt to Tutorial. In total, I interviewed 21 students with these prompts. The responses of all students to these prompts are in Appendix D, and the answers of the three students who talked about becoming future teachers are repeated here as well:

> ***Maeda:*** *[00:51:52.12] Well, a big thing is that people at this university are into figuring things out, thinking, and making others think. I went to a different university and did research in science, but the focus was on getting knowledge… But since people here are going to become teachers, they are thinking about teaching people... There's a lot of work done at Gakugei, more than at other schools, to rethink what people have learned in high school so that they can teach it themselves… Gakugei has more of an emphasis on asking why something is the way it is, whereas at other schools it would be like "if it's this equation, then it's an equation." … Gakugei has a lot of work in other classes too of rethinking what was learned in high school*
>
> ***Ren:*** *[00:50:51.17] We've had a year to get to know each other… well, the physics majors have. I don't know about the biology people. Also, this is an education school - we want to teach people who don't know… People who don't know write down the answers and if they don't understand something, they ask.*
>
> ***Taichi****: [00:45:33.02] It might not have been so much getting used to it, as it was that we did it, and it was fun. If it's fun, you can get used to it, right? Since other physics classes were different, people around me in the class also felt "new" (as did I)… til now it's just been classes where the teacher teaches one-way, and you'd have to think for yourself... so, yeah, it's fun… The way that Physics Exercises asks us is like, what would you say to people who don't know, there are a lot of questions like that, and Gakugei students are interested in teaching, so they're thinking about that and like Tutorials*

Maeda, Ren, and Taichi found relevancy of Physics Exercises to the future professions of themselves and their classmates. However, this was not because they will necessarily teach about Newton's Third Law or other content covered in the curriculum. Rather, for Maeda, "teaching people" meant "making others think", and so it's necessary not to memorize equations and principles, but rather to "rethink" what was studied in high school. Although Ren did not say so explicitly, his relating "teaching people who don't know" to the type of discussions taking place in Physics Exercises suggests that just having the right answers and writing them down doesn't mean you really "know" the material. Again, rather than an emphasis on regurgitating the correct answers to one's students, to make one's students "know" requires their personal understanding. For Taichi as well, "teaching" meant explaining in the way Physics Exercises asks you to. Physics Exercises does not ask students for the correct answers or procedures to use equations, but rather for something that can help someone make sense of the material. We see that it is the epistemology of Physics Exercises that at least these three students were finding in common with their image of their future professions.

C. Although students had negative things to say about Tutorial, "this won't help me in the future" wasn't one of them

In addition to these students explicitly saying that the class's style of learning is relevant because of their future ambitions to become educators, it is also noteworthy that no student said the contrary at any time during the interview.

One might argue that perhaps this population of students would not have said that the course is irrelevant regardless of what style of class it is. One might argue something like "Maybe these students always find relevance in what they learn" for example. Although there is not much data to contest this specific point, I provide one quote here that does:

> *[00:21:03.19] Interviewer: Is what you're learning now just something you need to memorize?*
>
> *Sakura: What we've done so far makes sense, and you can use it with everyday thinking. But last year's class was like "Am I ever going to use this?"*

Clearly, at least Sakura was capable of feeling that material learned in school is useless. Although it was not common for students to talk specifically about previous physics classes as being irrelevant or useless (and I did not have interview prompts to get at that), it was common for students to talk about how they did not *enjoy* the previous physics classes they took.

A cynic might next question if perhaps the reason why students did not complain about irrelevance is merely that they were hesitant to complain about Physics Exercises at all. (After all, they were well aware that the interviewer had been largely responsible for its presence in their lives.) This too, however, cannot be true, because students were, in general, perfectly willing to complain about the course.

When asked to freely talk about Physics Exercises, many students described how they enjoyed it and how it was showing them that physics can connect to the real world in a way they had never thought possible. At the same time, they were able to offer something they disliked or found problematic about the class. Amongst students who did not bring up something negative with the prompt "tell me about Tutorial", every student who was asked "is there some bad point about this class?" was able to say something. Student criticisms are provided in Appendix E but summarized here.

1. Student complaints in interviews

Students complained (often without being prompted) about many facets of the class. Many complaints were about specifics of how the ideal of the class was being carried out. For example, some students complained that the language of the worksheets was hard to understand (Haruka, Nao, Taichi) and others were concerned about the worksheets not being clear about how they should discuss (Shiori) or incorrectly anticipating their logical process (Mayu, Teiko).

Along a different vein, it wasn't clear to Saika why interpretations were so important. Others complained about the content overall, that it was redundant of what they had already learned (Manami, Yamato). Many students complained about not getting enough correct answers, because it affected their grades unfairly (Chinatsu, Miu) or hindered their understanding of the material (Ren, Tadao, Tadashi, Takahiro, Manami). Tadashi pointed out that this class wouldn't help someone who wants to get good at calculations.

Many other complaints were more general, regarding the style of class overall. For example, some students complained that not everyone is actively engaged (Saika, Yasu) and others complained that there are some places that are too hard for students (Takahiro) or that there isn't enough time (Yui, Yuriko). A few students complained that the class is difficult because they are accustomed to the old way of doing physics (Daisuke, Madoka).

Some students complained that the material could not be learned unless there was someone in the group who had done physics before (Kaede, Yui). Maeda, on the other hand, pointed out that students who have already learned physics have a difficult time taking this style of class seriously. Some students thought it was a bad idea to mix students who have taken physics with those who had not, since the latter was overly dependent on the former (Aoi, Rina, Shiori). Saika complained that she doesn't understand why it's important to talk in groups at all.

In these complaints we see that some students did not in fact feel that the course was adequately preparing them for their future goals, especially those who found the class repetitive and teaching them what they already knew. Noticeably lacking, however, are any complaints about the *nature* of the class being irrelevant to their future careers. There are no complaints akin to "We're going to go on and be teachers; we're going to need to know the right answers, but Physics Exercises is just making us more confused!"

D. Professor Uematsu's survey reveals the same trends

These complaints were echoed outside of the interview as well, in the end-of-semester survey that Professor Uematsu gave her students. There was an optional free response question where students could say whatever they wanted about the course. The student responses are in Appendix F and summarized here.

Once again, three students positively affirmed that the Physics Exercises style of class would likely help them as teachers in the future. Since these results were recorded anonymously, there is no way to know whether or not these three students are the same students who made such comments during the interview (Maeda, Ren, and Taichi). However, the 28 interviewees were chosen at random from a list of 100 students, and so it is very likely that students other than Maeda, Ren, and Taichi would have also mentioned this connection if interviewed.

As in the interviews, many students used this prompt as an opportunity to complain about the course; however, none of the complaints related to future goals.

E. My survey for the 2012 cohort explicitly looked at this mechanism

The survey that I created for the 2012 Physics Exercises class allows my claim to expand beyond the small number of students described above.

Students were asked how well the statement "Physics Exercises will help me in my future profession" applies. Almost all of the 42 students either said that the statement "applies well" (12 students) or "More or less applies" (19 students). Another 5 students were neutral. A large number of the students who agreed with the statement explained that the way of thinking in Physics Exercises would be helpful for their futures (as opposed to the specific content being learned).

Thus we see that many students felt that Physics Exercises would be relevant for their futures. Although we cannot know that this recognition served as a source of extrinsic motivation, it is often the case that seeing something as relevant for one's future goals is a strong motivator. As Husman and Lens wrote, "students' total motivation to learn… derives, in part, from learning and academic achievements' utility or instrumentality for… goals in the near and distant future." (Husman and Lens 1999)

F. Conclusions

It is interesting to observe that students connected the Tutorial way of learning with their own future teaching. One could imagine that students leaving a high school where the style of teaching had been lecture-based and focused on memorization (as these students reported) would maintain an image of teaching being about imparting the correct canon to one's students. If they had continued to view physics teaching as making students memorize equations and problem-solving algorithms, they would not have likely considered Tutorials to be good preparation for teaching. If students left high school with the cultural script that "physics teaching means lecturing and making students memorize", they would likely see the teaching style in Physics Exercises as contrarian and inappropriate – certainly not a useful experience for their own future teaching. For the students who would go on to teach high school physics, this strange style of Physics Exercises would be counter-productive for them. For students who would go on to teach elementary school science, the Physics Exercises style of thinking would at best be irrelevant, and at worst, again, counter-productive.

The fact that students did see Tutorials as useful preparation for teaching shows that they were envisioning teaching as involving conceptual explanations and/or sensemaking, despite the supposed cultural script that they would have developed about physics in high school. With this data alone, we see a challenge to the idea that students have a rigid, unitary cultural script about what teaching and learning looks like.

The argument of this dissertation is that students were able to change their view of what learning and teaching physics should look like much more fluidly than would be predicted by the unitary treatment of cultural scripts. Students were triggered into their new epistemological stance by seeing Physics Exercises as a familiar experience (described in the previous chapter). This stance was then stabilized by their seeing the learning as relevant to their future teaching professions. In the next chapter I will discuss an additional stabilizer – that students received a consistent message from various aspects of the course about what kind of learning was appropriate.

The fact that students were able to make this shift (as they self-reported and demonstrated in interviews and in class) and that scaffolds such as these three may have helped, stands as the argument against cultural scripts as a unitary concept.

VIII. Mechanism # 3 - Consistent Pedagogical Message

A pedagogical message can come from various places in a course. Certainly what instructors convey explicitly to students is important. However, implicit messages about what matters in the course are sent by the homework, the exams, and, in this case, the guided worksheets that students engaged with. One sub-surface, but pervasive feature of the Physics Exercises classroom at Gakugei was the consistency of certain messages throughout the teaching of the course. Across the eight instructors, and across the contexts of exams, homework, and classroom activity, there was consistent emphasis on:

- sensemaking (instead of memorization)
- conceptual reasoning (instead of using formulas for calculations) and
- valuing and reconciling one's own personal experiences and ideas (instead of just accepting knowledge that doesn't make sense).

In chapter 6, I argued that these are all areas in which Tadao and other students developed in their epistemology towards physics as a result of Physics Exercises. In this chapter, I will analyze the pedagogical messages that were sent by the worksheets and the graded material, and I will show that they reinforced the three points above. Since Physics Exercises had multiple educators, I will also show that although the instructors sent messages that differed from each other in various ways, they were uniform in reinforcing sensemaking, conceptual reasoning, and utilizing personal experiences and ideas.

A. Message sent by the worksheets

1. As described by the authors

In this section, I will discuss the pedagogical messages contained within the curriculum utilized in Physics Exercises. To that end, I will provide some examples taken from the curriculum. First, however, to give background necessary to understand those examples, I will discuss the underlying philosophy of the curriculum.

Open Source Tutorials at the University of Maryland were developed as part of a project titled Learning How to Learn Science: Physics for Bioscience Majors (Edward F. Redish and Hammer 2009) to

> *"promote students' epistemological development along with their conceptual understanding, as part of our response to research indicating that even the best reform materials don't typically improve students' views about the nature of physics knowledge and learning."*
> (Scherr and Elby 2007)

OSTs aim to promote student discussions about, for example, the degree to which physics should make personal sense, and at the same time stress connecting everyday experiences and subsequent intuitions with formal physics knowledge. (A. Elby 2001; A. Elby et al. 2007; Edward F. Redish and Hammer 2009; Scherr and Elby 2007) Quoting the curriculum creator, OSTs were

> *"designed to help students understand that learning physical laws involves refining one's intuitive ideas in order to reconcile them with the physics. In other words, these materials try to push students toward Einstein's view that science is ''the refinement of everyday thinking.'' (A. Elby 2001)*

2. Examples of this manifest in the worksheets

In the very first Tutorial given at Gakugei, students were asked to give interpretations of various quantities, and they were given the example that if there are 500 g of sand spread even over an area of 10 square cm, then an interpretation of 50 is "the number of grams of sand on each square centimeter". Thus, an appropriate interpretation for constant speed would be "the number of centimeters that an object travels every second."

As opposed to other answers to the question *what is speed?* (such as "how fast something is going" or "distance/time"), an *interpretation* goes beyond an abstract notion of "fast" but still firmly roots mathematics in experiences that one can visualize taking place. A second elapses, and you see how many cm the thing has moved. If it continues at a constant speed, then that distance in that unit time interval is the speed. Here, the goal of connecting everyday experiences with formal physics knowledge is clearly evident. (A. Elby 2001; A. Elby et al. 2007; Edward F. Redish and Hammer 2009; Scherr and Elby 2007)

The second Tutorial continued this pattern of finding physical significance in formal objects like calculations and graphs.

The third Tutorial focused on students reconciling their intuition that a car feels more force in a collision than a truck with Newton's Third Law (which asserts that the forces are equal). First, students recognize that their intuition does not agree with the physics formalism. Then, from intuition about how much the speed of the car and the speed of the truck would change (many intuit that the truck, which, students are told, is twice as massive, would change its speed by half that which the car changes), students see that the car's acceleration is twice that of the truck. From Newton's Second Law (F=ma), they see that their intuitions predict a result consistent with Newton's Third Law. Students are then asked to consider whether intuition can be useful in understanding physics or not.

This and the fourth Tutorial (described in section C.2.b below) are clear examples of materials that were "designed to help students understand that learning physical laws involves refining one's intuitive ideas in order to reconcile them with the physics.'' (A. Elby 2001)

These two tutorials are also clear examples of how the worksheets emphasize that it is important to vocalize one's thoughts and confusions and to compare answers with others.

Note that the Tutorials were not devoid of calculations that utilized equations. In the sixth Tutorial, for example, students used a formula to solve a collision problem. However, such calculations play a minor role in the Tutorials and they do not stand alone. In that Tutorial, students are told to create an equation for "oomph", "the ability something has to knock something else over". They are guided through questions like "Does a massive bowling ball have more of an ability to knock something over than a lighter ball moving at the same speed? How much more ability does something twice as massive have to knock something over?" and likewise for keeping mass constant and varying speed. From their intuitive ideas about knocking things over, students generally produce the canonical equation for momentum and then the law of conservation of momentum. It is this equation that they then use to solve a collision problem algebraically that could not have readily been solved with the intuition that created the equation in the first place. Students are then asked whether or not the equation captures their intuition, and how it can be that something made from intuition can surpass results obtainable from that intuition alone.

In the subsequent Energy Tutorial, students found the height that a rocket would travel by an equation for the conservation of mechanical energy. That part of the Tutorial is followed, however, by a statement that the height was actually measured to be smaller and a question of where the extra energy went.

Although I will not belabor the point by deconstructing every Tutorial that the students engaged with, I offer these examples as quintessential for describing the worksheets: they send the message that sensemaking, conceptual reasoning, and drawing upon one's own ideas and intuitions are important; they devalue rote memorization and acceptance of information that clashes with reality, and they place a smaller value on using equations for calculations.

B. Message sent by the homework and exams

Although in class, students can go horribly astray and write only "wrong" answers on the Tutorial worksheets without immediate consequence, this is not the case in the high-stakes settings of homework and exams. Whereas the point in the classroom is to discuss your ideas with your group mates, homework could be done individually, and it would have been considered cheating for students to work with each other on the exams. Thus we see that there were clearly discrepancies in messages about the value of correctness and whether to work in groups or not. However, I will show that in the homeworks and exams, like on the worksheets themselves, there was a consistent epistemological message about sensemaking from everyday conceptual reasoning. First, I will describe the assessments in Physics Exercises. Then, I will discuss the messages that one might expect these assessments to give. Lastly, I will present evidence for what messages were heard by the students.

1. The homework assignments and assessments

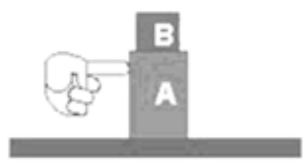
Homework assignments were exclusively Tutorial homeworks, but sometimes the overlap between the assignment and the worksheets was not obvious. As was learned in the first Tutorial and practiced in the second Tutorial, early Tutorial homeworks had exercises asking students for interpretations of new quantities (like the slope of a line). Tutorial homework 5, on the other hand, which accompanied the Tutorial titled "What's the Purpose of a Free Body Diagram?" did not involve any free body diagrams.

Homework assignments were graded on a check, check plus, check minus system, and comments were not systematically provided. There were no solutions available to the homeworks.

There were two quizzes, one midterm exam, and one final exam. Care was taken to make these assessments consistent with the Tutorials both in content and in style of question, but there were some areas that students may have perceived as inconsistent. For example, the second quiz included two collision problems similar to what students had solved for in the Oomph Tutorial. However, the final exam contained questions on buoyancy, which had not been addressed directly in Physics Exercises (although it was also in Tutorial homework).

Although there was often partial credit awarded for reasoning regardless of correctness, there were also multiple-choice problems, where points were awarded only for which letter the student selected. An example problem is below.

・→　は右向き
・←　は左向き
・↑　は上向き
・↓　は下向き
・0 は，その瞬間にはたらいている力がないことを示します．



-> is to the right, <- is to the left, ↑ is up, ↓ is down, 0 means that at this moment, there is no acting force.

ブロックが動き始めます．ブロック B も滑ることなく一緒に動きます．ブロックが速さを増している場合について，次に挙げるさまざまな物体の間にはたらく力の向きを示しなさい．

The blocks begin to move. Without slipping, block B moves together. In the case where the blocks are gaining speed, show the direction of the forces between the objects mentioned:

(e) B から A にはたらく摩擦力 $f_{B\to A}$ ______
(f) A から B にはたらく摩擦力 $f_{A\to B}$ ______
(g) テーブルから A にはたらく摩擦力 $f_{T\to A}$ ______
(h) B から A に垂直にはたらく力 $N_{B\to A}$ ______

e) The acting friction force of B on A
f) The acting friction force of A on B
g) The acting friction force of the table on A
h) The acting normal force of B on A

Characterized by the example above, homework and assessment problems were such that students would be able to answer them correctly *if they were reasoning correctly*. In contrast, there were no problems where students were rewarded for memorizing the correct equation, substituting values, and performing algebra.

2. Messages that such homework and assessments would plausibly send

By looking at the characteristics of these assessments, we can hypothesize what messages would have been received by students.

Since the homeworks were directly related to that week's Tutorial, the message that it's important to take Tutorials seriously was reinforced.

By consistently having questions that required students to explain their reasoning, the message that it's not just about being correct - reasoning is important too would have been sent. Furthermore, since students were asked to do this alone on quizzes and exams, the message sent would be that one should be able to sense make alone. Since the reason for taking points off on the homework was rarely explained and solutions were not provided to students, the idea that students are actively responsible for their own learning and they should not depend upon authority might have been reinforced with some students; more likely, this would have sent the message that authority is arbitrary. Assessments also included prompts of students giving reasonable explanations that are incorrect and asking students what they would say to help that student, reinforcing the idea that it is not enough to just know the right answer and to pass that off as knowledge. Rather, it is necessary to find consistency between your expectations and the correct physics answer.

3. Evidence for what messages students received

To what degree did students perceive the homework and assessments as actually doing this? Firstly, there is no evidence to suggest that students found a disconnect between the worksheets and the assessments. If students did notice any inconsistency, they did not voice such complaints either during the interview or on the end-of-class survey (see Appendix E and F). This suggests that the message of "it's important to take Tutorials seriously" was getting through. At the same time, no students talked about the assessments stressing calculations, memorization, or regurgitating knowledge that doesn't make personal sense.

Although one might question if perhaps students were simply unwilling to complain about the assessments altogether, this was obviously not the case, considering the list of complaints in Appendix E and F. One of the most common complaints about the written work was that answers were not given to the assessments, that the check marks placed on their homework were uninformative about what they did wrong, and that all they could conclude was that although they thought they had understood the material, they "just don't get it".

C. Message sent by the educators

In this section, I analyze the pedagogical messages sent by the TA's and instructor (and how those messages were heard by the students). First, to help understand the way that the educators interacted with the students (and hence what messages they were sending out), I will present explicit statements from the educators regarding how they tried to teach. Then, I will show some example interactions of TA's with students. Lastly, I will triangulate the interactions with the explicit comments.

1. Words of educators

The data that I will present in this section comes from one post-Tutorial debriefing session that lasted an unusually long two and half hours. This session took place two weeks before the end of the semester, when five educators from outside Gakugei had come to observe that day's Tutorial. The visitors included Dr. Jun-ichiro Yasuda (an assistant professor who would be implementing OSTs in his own classroom the following semester), a high school physics teacher, and an emeritus professor. The research advisors of the TA's were also present.

I focus on this episode for several reasons. First of all, it is the episode densest with data pertaining to the views that the educators had about the reformed curriculum and how they approached being a teacher in it.

More than this, however, there is reason to believe that data in this episode is particularly authentic. In the pre-Tutorial training sessions or the other post-Tutorial debriefing sessions, the room was full only of supporters of the Tutorial approach. Here, however, as the data below demonstrates, there was open skepticism. In talking with me and Professor Uematsu about what had gone well or not so well in that day's Tutorial, it would have been socially awkward for a TA to say that she doesn't think the Tutorial system is a very good one. Here, however, it would have been very easy to agree with the doubt that the visitors brought.

Although the TA's acknowledged the limitations that the visitors mentioned, they supported the Tutorial style of learning with a sincerity that made me deeply moved.

a) At the cost of student correctness and confidence…

During this debriefing session, one of the observers expressed concern about how, if students are drawing upon their own experiences and ideas rather than the authoritative knowledge of the teacher, there is a risk that students will leave the class without having learned the physics correctly. Shuji-TA explained that one thing they had been doing was to tell groups who weren't getting the correct answer something like "Another group was thinking (correct answer), but… what do you think about that idea? If that isn't right, what do you think is wrong about it?" That way, he explained, it still would not be students taking from the instructor knowledge that had no meaning to them; rather, they would need to evaluate the idea as that of their peers.

The visitor responded by asking about how confident students could be in the answers that they come up with in class if it is not knowledge coming from an authoritative source.   Hayate-TA responded.

> *[video 2, 00:07:07.15]Hayate-TA: That gaining confidence thing is kind of different from person to person I think but, yeah, this Tutorial's, that number one purpose is in those familiar, everyday... and, various phenomena that are related to physics, is it not?   If it's that sense, for example, if it's that momentum, for example, how does it become when the truck and car collide, for example - those kinds of familiar phenomena - if you just hand it out (gestures passing something)... instead, asking what they thought with their intuition… that intuition is, well, I think there are a lot of wrong things, you know.   If you think with intuition, there are a lot of wrong things, but that, like, if there are also correct intuitions… presumably there are correct intuitions as well, and it's a matter of refining the intuitions that have those hard-to-understand everyday explanations. Within those various correct thinkings and wrong things that you are thinking, if you ask which refinement is it to get to the correct thinking (gestures multiple paths, as though envisioning the intuition refinement diagram of Tutorial 4 – see figure in section C.2.b below). Eventually, you tie together your own, that intuition, the thing you are thinking, and the correct concept.   It's in the style of "it's nice if you can go and connect them." So, for me, that's what I'm thinking. Therefore, this time, concerning current and voltage too, naturally inside of a person are, well, things that he did in class can be included, and intuition can also be included - there are also those things that you are thinking are wrong, there are also things that are wrong, correct things too, various things are mixed together, but, unsurprisingly, in the course of going through an argument, you can follow the correct path and progress, I think.   But, if you ask if, with just this class, with just a 90-minute class, can 100% confidence be attained, then that is perhaps not included.*
>
> *However, through this class, those things that one wonders about, like "why in the world?"... it's really important.   Personally, I am thinking "These are people making predictions, aren't they?" Therefore, within this class, even if those answers are not gotten… for example, today, just now, the group with Mr. (student name) that wanted to be putting out a conversation, for example… they didn't really, in the beginning they had little motivation, but today, "that current will change, I wonder" - that kind of wondering...when I said "Try discussing it once", it was a feeling similar to ???.   Since student motivation concerning physics has been raised, I think there is meaning, I guess.*

To paraphrase, Hayate-TA pointed out that the objective of Tutorials is not to feed knowledge to students, but rather to get them to make connections between their everyday experiences and formal physics knowledge. He discussed how many student ideas do not match the physics, but that there are some ideas that do, and it's a matter of analyzing that mess of ideas to see how to "refine your intuitions" (a phrase introduced within the first month of the class). He suggested that students can come to the correct answers via this process, but acknowledged that the 90 minutes per week is perhaps too short for students to walk away convicted about conclusions they reach. He amended this by saying that even if students aren't able to reach the correct answers, he has personally witnessed students gaining an interest in physics, and he thinks that that makes the class meaningful.

In saying this, Hayate-TA was clearly being explicitly and articulately consistent with the intent of the tutorials (as I described above).

b) What the educators said that they did

This debriefing session began similarly to the other debriefing sessions, with the Physics Exercises instructors comparing notes about what was difficult during the Tutorial, asking each other for advice about what they could do next week, and coming up with ideas about how to modify the curriculum for use the following year. The visitors were then invited to ask any questions they wanted.

Dr. Yasuda asked what had been challenging about the class, and this led to a conversation that produced Hayate-TA's quote above. After that, he asked what advice they could give him for implementing Tutorials at his own school. Mizuki-TA explained that it had been important to make it clear to students that the TA's aren't there to teach the student, but that they really want to hear, in the student's own words, what he is really thinking. She had found that without giving a strong impression of that, students would just look at her face and play a guessing game, saying things until they noticed a change in her expression. Miwa-TA explained that she had been transparent about her low level of physics content knowledge to tell her students "I don't actually know… let's figure it out together!"

Shuji-TA described how, by learning the names of students and looking in their eyes, one can ask how they are thinking. Akiko-TA added that she found it helpful to physically lower herself so that she is not looking down at the person and, although she often forgets, to thank the student after he tells his opinion.

At the end of the debriefing session, one of the observers asked if the TA's had grown in their professional development as teachers as a result of this experience. Mizuki-TA explained that it had helped her understand the physics content knowledge: although she had heard and read a lot about physics, being a TA had helped her think about the material in a way that really makes sense to her.

Akiko-TA said that although there were some things that she hadn't liked about the experience, she had not previously realized that intuition can be used with physics, and she was glad to have been able to develop that attitude.

Miwa-TA explained that she had learned the importance of understanding what it is that is confusing the student. She explained how she is going to be an elementary school teacher and she's realized that when students ask her "is this right?", she can't just say "yes".

Katashi-TA described how it was a good experience to listen to students describing ideas that he would not have ever imagined himself. Yasuo-TA explained how, although they had taken a lot of time during TA training to anticipate what problems students would have with the material, those issues rarely appeared. Instead, students had problems with unexpected things and so he had learned the necessity of being flexible and thinking then and there. Shuji-TA agreed with this – he had learned that it's necessary to really listen carefully to students – successful teaching was more about listening than talking.

Hayate-TA's answer became the last comment of the meeting:

> *[video 2, 00:50:15.03] [video 2, 00:50:15.03]Hayate: Right. Um, me as well, it's similar to the previous persons, but be listening to the opinions of people. My resistance to just totally listening went away. To strain myself in that way is important (with emphasis) – that's what I thought. And, well, it's not only this Tutorial… I'm playing that soft tennis, and from time to time I make an appearance in the school team meetings, but at that time, naturally, people who are good at tennis – they understand the force - they are like "It's good to be doing it this way, no?" They are like "It's good if you do it this way, no? It's good if you send it out like this, no?" Really, they say (sense of misfortune or mistake) that easily, but, naturally, there is an understanding of why people who can't do it are that way, and, like, that "if you do it like this you'll get good", for example - more than saying that, first you listen all about what kind of situation the other person is in, and from there, inside of that, you sweep away the place that is best to fix. "If you tried to twist your waist more", for example, "your legs were slow in getting prepared, you know" for example (others begin to smile and Hayate-TA laughs for a moment). I thought someone's simple advice makes a difference, so..." (people are forcing back their laughter), and a little bit, "this will be applied to tennis, will it not?" (laughter), that.... yeah. (laughter grows). I thought that, yes. (more laughter)*
>
> *And, well, if you allow me to continue, although I think there might be laughter (more laughing), in long seriousness (he joins the laughter and there is louder laughter), unsurprisingly, um, for example, with college entrance exams, to some degree it is taking poison. If you ask if people coming to college are really understanding physics, well, there are also people who aren't understanding I think and that, well, I like the example I made from tennis, but furthermore, you can look at a book, for example, "ah, it would be good to do it like this" for example. Even if you look at that and are understanding, it does not imply that you are actually playing tennis, you know. And, that physics, in the same way, memorizing those equations, for example, if you substitute numbers, you*

do produce answers that match the correct solution, but if you ask if they are really understanding what kind of actual phenomena it is showing, unsurprisingly, there are a lot of people who aren't understanding. That is what I am thinking. Therefore, during this Tutorial, I was thinking that it's important to not just memorize those equations, but to become able to use them, and to become able to connect them with familiar phenomena.

Not only was Hayate-TA able to articulate the purpose of Tutorial, but also he and the others have ideas about what kinds of teacher behavior is necessary to successfully implement such curriculum. These ideas are very consistent with the advice given in the tutorial instructor guides, and with the general guidelines given to the TA's who run the Tutorials at the University of Maryland. (Edward F. Redish) Their teaching tips and insights about personal knowledge and learning are consistent with the Einsteinian view instantiated in the Tutorials.

Generally, the TA's practiced what they preached. Classroom observations of TA's showed that, indeed, they listened much more than talked. Furthermore, when they did talk, it was almost always in the form of an open question, even if students initiated the conversation with a question of their own. Below are two examples of TA interactions with students, both within the S302 classroom.

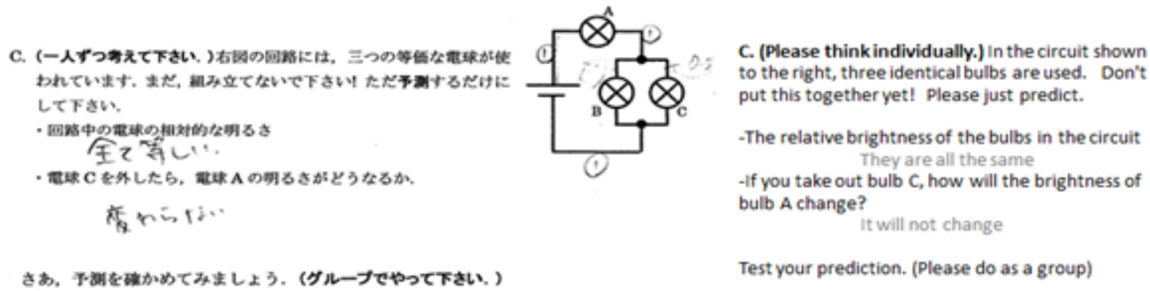
2. Deeds of educators

Here, I will analyze two examples of interactions of TA's with students to discuss what messages were being sent. At the same time, I will present student reactions to discuss what messages students were actually hearing.

a) Katashi-TA in Tutorial 10 (of 11) (Circuits 2 in S302)

Four students (Haruka, S2, Rina, and Yui) worked approximately 80 minutes on the guided worksheets of Tutorial 10 together. During that time, Katashi-TA visited them three times, for 2 minutes, 5 minutes, and 4 minutes respectively. No other TA spoke with the group, although TA's frequently passed by the group, stopping briefly to observe it's conversations. This suggests that, for the most part, TA's viewed the group conversation as desirable and allowed it to progress without intervention.

At about 30 minutes into the class, the students reached the experiment in 1.C (Haruka's work is below). An English transcription of the episode is in Appendix C.1, and the episode is summarized here.



C. (一人ずつ考えて下さい．)右図の回路には，三つの等価な電球が使われています．まだ，組み立てないで下さい！ ただ予測するだけにして下さい．

・回路中の電球の相対的な明るさ

全て等しい．

・電球Cを外したら，電球Aの明るさがどうなるか．

変わらない

さあ，予測を確かめてみましょう．(グループでやって下さい．)

C. (Please think individually.) In the circuit shown to the right, three identical bulbs are used. Don't put this together yet! Please just predict.

-The relative brightness of the bulbs in the circuit

They are all the same

-If you take out bulb C, how will the brightness of bulb A change?

It will not change

Test your prediction. (Please do as a group)

Figure 10. Haruka's answers to a Tutorial page

The results of the experiment in the worksheet excerpt above surprised the students. Haruka would later find it easy to draw and articulate (36:59) that she was thinking that if a current of 1 flowed through bulb A that a current of 0.5 and 0.5 would need to flow through bulbs B and C. At the same time, however, her surprise and written work suggest that she did not expect the brightness of the bulbs in B and C to be different from that of bulb A.

In addition to Haruka's idea of the current of 1 dividing into 0.5 and 0.5, there was a competing theory on the table that had had explanatory power earlier in the Tutorial, when the students had observed that two bulbs in parallel are equally bright as the single bulb in a one-bulb circuit. Rina described this theory in 40:57. Basically, the idea is that the wires act as a sort of network of irrigation canals, and the height of water is roughly the same everywhere in the network. This water height corresponds to the brightness of the bulb. Hence, whether there are two bulbs in parallel or a single bulb, the water height (and thus the brightness of the bulbs) is the same. Implicit in this model is the common student idea that the battery is a supplier of constant current (constant water height), but, more relevant for this portion of the group discussion, it fails to explain why bulbs B and C are darker in the circuit above.

Katashi-TA spoke almost exclusively in questions. His first question (36:25) was to ask what happens to the current when it reaches the junction after passing bulb A. Haruka then responded with:

> *(36:25) Haruka: The current passes through A, here it again becomes the same amount of current, since it's going in parallel, it's exactly the same part I have to think. I wonder if that is not so?*

Katashi-TA's next question took this vague idea of Haruka's and made it more concrete by putting numbers to the various parts of current she was talking about.

> *[00:36:46.05]Katashi-TA: Well... if we say that here, for example, 1 is flowing, 1 is flowing here, and here, how much will flow in each one?*

Haruka was then able to more clearly express that she was finding the idea of it being a constant current of 1 in bulbs B and C difficult to swallow: the idea that the current flowing in each of them would add to the current flowing in A was powerfully intuitive for her. She at last concluded that if bulbs B and C had a current of 1 in them, then at the end, you'd have a total current of 2, which would be more than you started with, and that would be strange.

Katashi-TA then suggested that with that way of thinking, they might be able to explain what's going on. Once Haruka said "Ah, I see" (37:21), suggesting that she understood the implications of what she had just said, Katashi-TA walked away.

When Katashi-TA next interacted with the group, it was because Rina had told him that she was still not getting it. Whereas the irrigation canal analogy had worked with the two bulbs in parallel, it wasn't working with this more complicated circuit, and she wondered if, because the current splits in 2, maybe there would be twice as much current flowing through bulb A. Katashi-TA again asked for clarification about this idea, asking specifically if she would be thinking that there is a current of 1 flowing in bulbs B and C. Rina seemed to favor the irrigation canal idea, but explained that it didn't work out well in this case. Katashi-TA asked for clarification about what she meant by "not go well", and she explained that the bulbs got darker when they did the experiment in part 1.C. (see figure 10, above).

Katashi-TA then asked for clarification about the irrigation canal idea, asking if it would be the case that a current of 1 would flow through bulb A and then through bulbs B and C. When Haruka remarked that that is strange, Katashi-TA repeated her previous insight that the implication must be that current would be increasing. He did this in the form of a question, as though trying to discern Haruka's discomfort, and she readily agreed with the description of the problem.

Rina then pointed out that if that is the case, then it should have similarly held true with the two bulbs in parallel. That is, the current should have divided in half, resulting in bulbs that are not as bright as the single bulb. Again, implicit in the argument is that the battery is a constant current source. Katashi-TA again asked for clarification, asking if she was saying that because of the experimental results.

At 45:16, Katashi-TA asked the students to repeat the 1.C experiment so that he could concretely ask his clarification question of why the bulbs in parallel become darker when there is a bulb in series put in front.

Katashi-TA next instructed the students to go on. The Tutorial was designed aware that students will see the battery as being a constant "source". It is likely for students to associate that with a constant current, as these students were doing. However, by being exposed to the concept of voltage, students are able to satisfy their intuition by recognizing that the battery is a constant source of voltage, and this can make it more acceptable that the current coming out of the battery is variable. Katashi-TA instructed them to continue and to see if learning about voltage would help them out. It didn't.

When he returned 45 minutes later, the students, realizing that when current is big, voltage is big, were thinking that maybe you can compare the brightnesses of bulbs with either voltage or current, and S2 was concerned that they don't have an understanding of what the difference is between the two concepts.

At this point, there remained only 5 minutes left in the class, and, realizing that the students are in danger of leaving the classroom having learned very little of the content knowledge, Katashi-TA changed his approach to be more of a direct lecture-style. First, he answered their immediate concern. He told them that one needs to know more than just current to determine how bright a bulb is; one also needs to know the voltage. He then returned to the question of whether the same current is flowing through the battery when it is connected to different circuits. Haruka was still unsure, so he asked the rhetorical question of "if it were the same amount, since its split at the parallel junction, wouldn't it be darker?" He then finished by explicitly telling them the answer: since that *doesn't* happen in the experiment, it is *not* the case that the current flowing through the battery is a constant.

In these last few minutes of the class, Katashi-TA taught the students as a physics authority, and the results are seen in how the students talked to each other after he had left. When Haruka said "Right, right. Current divides, does it not? It becomes dark, does it not, is what he was saying", she is clearly looking to Katashi-TA's authority as the source of knowledge.

However, this was not the way that Katashi-TA tended to teach. This was the first time that he directly "taught" these students physics content during the lesson, despite their misleading ideas and constant confusion. It is not difficult to imagine a Tutorial TA giving authority to this logical chain of reasoning (if the battery were a constant current source, then two bulbs in parallel would be more dim than a single-bulb circuit. Since they are the same brightness, it must be that batteries are not constant-current) much earlier in the class, especially since the students were already considering it themselves. However, Katashi-TA did not do so, perhaps because he valued the experience that Tutorials strove to promote – having students reach such conclusions on their own. Even when Katashi-TA was lecturing, he did so in a way that built on and addressed the ideas that the students had brought up earlier. This would likely result in students still feeling that their own ideas are important.

In this episode, we can see multiple messages that Katashi-TA was sending to the students. At the very end of the class, his action of telling them the answer portrayed a message of "You have failed to independently figure out the knowledge that I have as a physics authority." By looking at how students were quoting him for giving the correct answer, it seems that the students received this message.

However, throughout the rest of the class, the infrequent interruptions by Katashi-TA and the other TA's created a message of "what you are doing (discussing your own ideas as a group) is desirable." In considering that the students only asked for help twice, it seems that this message too was received. Although the students were having a disagreement about what was going on, they did not call in authority to intervene until they felt it absolutely necessary.

Looking now at the substance of what they were talking about, Katashi-TA frequently asked about their own idea of how the circuit is like an irrigation canal. This created a message of "your own ideas are important for understanding physics".

The students did not abandon this idea, showing that they were receiving the message that it is appropriate to use their own ideas.

The major hang-up of the group was that this irrigation canal model did not explain the experimental result. When Katashi-TA did at last tell them the answer, it was done through an argument that all bulbs having the same current is inconsistent with the intuition at least some of the students were recognizing about how each of the bulbs in parallel must take half of what the single bulb takes. In other words, rather than merely giving the students something to accept without reason, he at least situated the knowledge as reconciliation to a problem they were having. Students heard this message that it is important to have consistency: it is the fact that the model does not produce expected results that bothered the students and prompted them to consider alternative solutions.

In summary, we see that Katashi-TA delivered (and students received) messages that it is important to make sense of experimental phenomena, to reason conceptually, and to reconcile seeming inconsistencies.

b) Shuji-TA in Tutorial 4 (Newton's 2nd Law) S302

Tadao, S2, S3, and S4 were openly cognizant of the camera, and for this reason were videotaped only once during the semester. S4 on several occasions made strange faces at the camera and both S3 and S4, after learning from the researcher how the microphone works via vibrations of the desk surface, spoke short phrases loudly to the desk in English like "I am from Japan" or "let's play lacrosse". However, since they were openly discussing their plans for Golden Week (Japanese spring break) with each other during this lesson, there is reason to suggest that the recording of the students did not affect their behavior too strongly. Furthermore, cursory observations of both the students and of Shuji-TA in lessons where they were not being taped showed patterns of behavior consistent with what was captured on film.

Shuji-TA's appearance in the episode below occurred after the four students had already completed a large amount of the worksheet, which the TA was able to see as he spoke with them and decided what questions to ask. First, I will present the student answers to the Tutorial and then the interaction with the TA.

(1) Student answers to the worksheets show that they were totally lost.

Tutorial 4 has students consider a child named Timmy (some Gakugei students thought this was a girl's name) weighing 250 N, stuck in a well, and being pulled up by a rope at a constant speed. The work of student 4 follows:

A. (グループでやって下さい) 右の四角にこの状況を描いて，以下の議論の間見られるようにしておきましょう。

B. (一人ずつ考えて下さい) 子どもが一定の速さで引き上げられているときに，ロープが上向きに加える力は 250N より大きいでしょうか，小さいでしょうか，それとも同じでしょうか，説明して下さい。もし，異なる考えが２つ浮かぶのであれば，どちらも挙げて下さい。

大きい。

C. (グループで考えて下さい) B で，ロープが 250N より大きな力を加える，と直観的な理由なしに答えていたら，ここで直観的な理由をつけて下さい。

同じ力までは動かないと思うから

D. (グループで考えて下さい) B で，ロープの力が 250N より大きいか，小さいか，同じか，を決めるのに，ニュートンの第２法則を使っていなければ，ここで使って下さい。（ヒント：ロープは，一定の速さで子どもを引っ張っています。では，加速度はどれだけでしょうか。）

加速度=0

E. (グループで考えて下さい) このような状況を理解したことに，100%満足ですか，それとも，まだ歩み寄る必要が残っていますか，説明して下さい。

満足

A. (please do as a group) Draw this situation in the box to the right to reference in the following discussion

B. (please think individually) When the child is being pulled up at a constant speed, is the upward force exerted by the rope more than 250 N, less than 250 N, or equal to 250N? Please explain. If you have two different thoughts, give them both

Bigger

C. (please think as a group) If you did not answer part B with an intuitive reason for why the rope exerts a force larger than 250 N, please put an intuitive reason here

Because I think she won't move up until the force is equal

D. (please think as a group) When you decided if the force of the rope would be bigger, smaller, or the same in part B, if you did not use Newton's 2nd law, please use it here. (Hint: the rope is pulling the child at a constant speed. Well, what is the acceleration?)

Acceleration = 0

E. (please think as a group) In understanding of this situation, are you 100% satisfied, or is there still a needed reconciliation remaining? Please explain.

Satisfied

The Tutorial asks how the force of the rope compares with 250 N. S4 answered that the force is larger than 250 N. When asked to give an intuitive rationale for why the rope would be more than 250 N, S4 answered that until it is the same force (i.e., if it is less than 250 N), the boy will not move. S4 seems to have not answered the question of why it needs to be *bigger*, but rather the question of why it cannot be *smaller*. Since S4 wrote about the boy *not* moving, as opposed to thinking about the boy falling, he seems to have been thinking here about the boy being on the ground and what would be needed to get him up.

Students were next asked to answer the question using Newton's 2nd Law with the hint of "what is the acceleration", and S4 wrote "Acceleration = 0" and nothing more. The following question asks if something needs to be resolved, or if the student is fully satisfied with the situation. S4 wrote "Satisfied" and nothing more.

To reconcile expected contradictions, the Tutorial then guides students through several thought experiments, beginning with having students think about when the boy is first on the ground and needs to be raised.

A. (グループで考えて下さい) 初めは止まっていた子どもが，ロープに引き上げられ始めたちょうどそのときのことを考えましょう．この運動の**初期**段階では，ロープからの上向き力は 250N (子どもの体重) より大きいでしょうか，小さいでしょうか，等しいでしょうか．

1. この問題について，ニュートンの第 2 法則からは，何と言えるでしょう．(ヒント：運動の初期には，子どもは加速されていますか)

大きい

2. ここでのニュートン力学による答えは，日常感覚に合いますか．

合う

B. (グループで考えて下さい) ひとたび子どもが動き出したら，今度は初期段階の**後の**子どもの運動を考えましょう．

1. **直観的に言って**，ロープの力が子どもの体重より大きいままだったら(初期段階のように)，子どもは加速し続けるでしょうか，減速するでしょうか，一定の速さで上るでしょうか．簡単に説明して下さい．

一定の速度で上がる

2. ニュートンの第 2 法則は，あなたの答えと一致しますか．説明して下さい．

一致しない

3. **直観的に言って**，ロープの力が子どもの体重より**小さく**なったら，子どもは加速するでしょうか，減速するでしょうか，一定の速さで上るでしょうか．簡単に説明して下

落下する

A. (please think as a group) Let's think about the when the rope first starts to pull up the child who is initially not moving. In the initiation of this motion, is the upward force of the rope more than 250 N (the child's weight), less than 250 N, or equal to 250N?

1. What can Newton's 2nd law say regarding this problem? (Hint: in the initiation of the motion, is the child being accelerated?)

Bigger

2. Does everyday sense agree with the answer according to Newtonian mechanics?

Agrees

B. (please think as a group) Once the moving child has set off, this time let's think about the child's motion after the initial stage.

1. Say intuitively, if the rope's force continued to be larger than the child's weight (like in the initiation stage), will the child continue to accelerate, decelerate, go up at a constant speed? Please give a simple explanation.

She will go up at a constant speed

2. Does Newton's 2nd law coincide with your answer? Please explain.

Does not coincide

3. Say intuitively, if the rope's force becomes less than the child's weight, will the child accelerate, decelerate, or go up at a constant speed? Please give a simple explanation.

She will fall

S4 said that, through Newton's law, the force of the rope must be "bigger" than 250 N in this situation, and that this "agrees" with intuition. Part B asks, intuitively, what would happen if the rope force continued to be larger than 250 N. S4 answered "she would ascend at a constant speed" and he recognized that this "does not agree" with Newton's law.

At this stage, we see a problem developing. The Tutorial works most smoothly when students intuit that if a larger rope force caused the child to get faster (from rest to moving), then if that larger rope force continued, the speed would continue to get faster. S4, however, was un-budged from his original intuition that he answered on the first page (that you need a larger upward force for upward motion). The Tutorial then asks, intuitively, what would happen if the rope force became less than 250 N. S4 answered "he would fall", and he wrote that this "does not match" Newton's law.

Part 5 of the Tutorial tells students the answers to the previous questions. If the rope force continued to be larger than 250 N, the child would continue to get faster. If it were less, the child would decelerate. The Tutorial asks students to, considering this, say what the speed of the child would be if it is neither of those cases, if the rope's force is exactly equal to 250 N. S4 answered that the child would "ascend at a constant speed" and that this "is consistent" with Newton's law.

In part C, the Tutorial introduces students to Intuition Refinement Diagrams, and explains that the same raw intuition of "force is necessary for motion" can be refined into either "a net force is necessary to maintain an object's motion (speed)" or "a net force is needed to initiate or change motion(speed)".

4. ニュートンの第2法則は，あなたの答えと合いますか．説明して下さい．

合わない

5. これを全部結び付けましょう．(i)もしロープの力が重力より大きいままだったら，子どもは加速し続けることになります．そして，ロープの力が重力より小さくなったら，子どもは減速します．(ii) ロープの力が重力より大きいままだったら子どもは加速し続け，ロープの力が重力より小さくなったら子どもは減速する，とすると筋が通ります．この直観的な考えの流れで言うと，ロープの力が子どもの体重と等しいとき，つまりロープの力を子どもの体重より大きくも小さくもなくすると，子どもの運動はどうなるでしょうか．説明して下さい．

一定の速度で上がる

6. ニュートンの第2法則は，あなたの答えと合いますか．

一致する

☆先に進む前に，TA に声をかけて下さい．

C. (グループで考えて下さい) 下の**直観絞り込みの図**を考えましょう．

素の直観 運動には力が必要である

?　?

絞り込んだ直観 物体の運動(速度)を**維持する**には，正味の力が必要である　物体の運動(速度)を**生じたり変えたりする**には，正味の力が必要である

1. 上の(2ページ目の中ほどから始まる)B の部分では，2つの絞り込みのうちのどちらを(たぶん，無意識に)使いましたか．

使った。

2. 2つの絞り込みのうちで，どちらがニュートンの第2法則に合いますか．

右!!

3. このチュートリアルの初めのページにある I B と I C の部分では，2つの絞り込みのうちのどちらを(たぶん，無意識に)使いましたか．

右

4. Does Newton's 2nd law agree with your answer? Please explain.

Does not agree

5. Let's tie all this together. (i) if the force of the rope remained greater than gravity, the child would continue to accelerate. And, if the force of the rope became smaller, the child would decelerate. (ii) It stands to reason that if the force of the rope continues to be larger than gravity, the child will continue to accelerate and if the force of the rope becomes smaller than gravity, the child will decelerate. If you speak with the flow of this intuitive thinking, when the rope's force is equal to the child's weight, in other words, the rope's force is neither larger nor smaller than the child's weight, what will the motion of the child be? Please explain.

She goes up at constant speed

6. Does Newton's 2nd law agree with your answer?

Agrees

* Before proceeding, please call over a TA

C. (please think as a group) Let's think about the intuition refinement diagram below.

Raw intuition: Force is necessary for motion

Refined intuitions: To maintain an object's motion (speed), a net force is necessary　To initiate or change an object's motion (speed), a net force is needed

1. Above (beginning on the middle of the 2nd page) at part B, which refinement did you use (perhaps unconsciously)?

I used

2. Which of the two refinements agree with Newton's 2nd law?

Right!!

3. On the first page of this Tutorial (parts 1B and 1C), which of the two refinements did you use (perhaps unconsciously)

Right

The Tutorial asks which refined intuition the student used two pages back. S4 did not write an answer to this question. The next question asks which refined intuition agrees with Newton's law, and S4 wrote "right!!". The next question asks which refined intuition the student used on the first page. Here, S4 again wrote "right".

To an educator, this could appear to be a very mangled situation. For most students, the Tutorial goes well when students have a knee jerk reaction that the rope must have a larger force to maintain Timmy's speed, but when thinking with the intuition about how he would slow down or keep speeding up if the rope force were anything BUT 250 N, they intuitively think that Timmy will go up with a constant speed. It is then in reflecting how these two intuitions are both intuitive but conflicting that the epistemological message of the Tutorial can be effectively taught to students: it is not that intuition disagrees with physics; rather, the same raw intuition can be refined in a way that *does* agree with physics formalism. S4, however, seemed to be under the impression that his original intuition that the rope force needs to be larger for constant motion (which he reaffirmed when he said that if the force of the rope continued to be larger, Timmy would go at constant speed), is already consistent with Newton's law.

Tadao similarly began the Tutorial by saying that the rope force must be larger than 250 N, and, intuitively, this is because "if it were equal, the boy would balance". Despite writing that Newton's law says that "acceleration=0", he wrote that he is completely satisfied with this situation as well. His answers on the next part match those of S4: if the rope force continued to be larger than 250 N, Timmy would travel at a constant speed, but this does not match Newton's law. He took the Tutorial's lead and made the conclusion S4 did that the speed must be constant. His final record shows that that intuition is the refined intuition on the "right", but he had previously written (and then erased) "left". His next two responses are the same: originally he wrote "left", but wrote over them with "right".

S2's answers up until the Intuition Refinement Diagram are almost the same as S4 and Tadao. He, however, wrote that he used the "left" intuition when saying that the speed must be a constant. He originally wrote that Newton's law agrees with the "left" intuition, but he scratched it out and wrote "right". His intuition on the first page he has written as "left".

Lastly, S3 seems to have been the most confused of all. His answers match those of his group mates. In fact, his words on the first prompt are identical to S2's, and, just like S4, he wrote only "I used" for the prompt immediately after the Intuition Refinement Diagrams. He initially wrote "left" for the next two prompts but rewrote them as "right". If any situation could warrant strong TA scaffolding and guiding, it would be this one. Let us see how Shuji-TA responded.

(2) Video narrative

Shuji-TA appeared on the scene when S4 and S3 loudly called out "TA!" As Shuji-TA approached, S4 prefaced with "some answers came out". Shuji-TA began by calling on Tadao to answer the question about the force needed to start Timmy traveling up the well (II.A). Shuji-TA checked to see if S4 had the same answer. Shuji-TA then called on S3 to answer the question about what would happen if the rope force continued to exceed Timmy's weight (II.B.1). S3 answered that Timmy would continue to go up at a constant speed, and that that does not agree with Newton's law.

Shuji-TA repeated S3's answer that Newton's law does not agree with the intuition and Tadao supported that that is what their intuition is. When S2 said that the next intuition (II.B.3) also did not agree with Newton's law, Shuji-TA asked for an explanation. S2 explained that, intuitively, Timmy wouldn't be helped if the rope were less strong than his weight. Newton's law, on the other hand, predicts that Timmy will gradually slow down until he stops. It is unclear whether S2 had considered that, after Timmy gradually stops, he would begin to fall, and it is also not clear if his intuitive picture of what would happen included Timmy slowing down before falling. Tadao's comment, however, explains that, at least for him, the discrepancy is that, intuitively, Timmy would fall immediately, whereas Newton's law would predict that Timmy would first slow down (45:35).

Shuji-TA next asked what the students had decided with the following two questions (II.B.5 and 6). When S3 responded "Even if the strength of the machine's force is strong, right - the speed that the machine is winding at is the same, so, right - so there's no meaning, you know" and another student voiced his agreement, it is unclear what they were thinking, but it seems as though they were completely missing the point. Shuji-TA told them to continue and he returned at the next checkpoint.

All of the students except for S4 (incorrectly) said that their answer of "constant speed" in II.B.5 matches the "left" intuition. Shuji-TA assured S4 that it's fine for him to disagree with his group members, and S3 reinforced that, only half joking. Only S3 thought that Newton's law says that a net force is needed to change or initiate motion (1:12:30). The others answered that the "right" intuition is the answer to C.2.

Although C.2. asks which intuition matches Newton's law, S2 and Tadao seemed to not be referring to Newton's law at all when they explained their selection. S2 began his explanation by saying that you need a net force to maintain motion, but then gave an example (of friction resisting a pushing force) that failed to support his argument and he immediately realized was not correct anyway (because friction can never be larger than the pushing force) (1:13:38). Tadao again reasserted that it is just true that you need a net force to preserve motion.

The students had been using the technical word "net force", and perhaps to ensure that he was understanding their use of the jargon correctly, Shuji-TA asked S4 to specify what they mean by the word (1:15:35). S4 explained that it is the force that is left over after the forces have canceled each other out – it's the force that the object takes with it. Shuji-TA agreed that if that is what they mean (in other words, that "net force" is what an object takes with it as a result of forces acting), then indeed, a "net force" is needed for motion.

Shuji-TA next had them return to the first page where they drew a picture of Timmy so they could illustrate what the net force is. S4 explained that the net force is from gravity, the knot of the rope, and the pull of the rope (1:17:23). On a large piece of communal scratch paper that was not collected, S4 drew a diagram with two T's, one up (the pull of the rope) and one down (tension).

Shuji-TA asked if the two T's don't cancel each other out (1:19:00). S3 concluded that they do cancel each other out, which means all that is left is gravity, and Shuji-TA drew the conclusion for them that Timmy could then not be helped (1:19:11).

S4 then asked Shuji-TA if the implication is that they should only draw one T in the diagram, but Shuji-TA asked a different question - how big T is in that diagram (1:19:38). S4 explained that it's small, whatever is necessary to keep Timmy harnessed. S3, in growing desperation, said that maybe T wraps around with the rope, so that it's both pulling up and also in the knot, and thus wouldn't cancel. Perhaps he sensed that if there was only a small amount of tension (or worse, no pull upwards at all) that Timmy could never be saved. He voiced his frustration, asked if this was one of those parts that they didn't have to think so hard about, and said essentially that he was ready to give up (1:20:23).

> *[01:19:38.14]Shuji-TA: How big does this become?*
>
> *S4: This is the force needed to stick to the rope. It's the force necessary to not become disconnected. It's just a little bit.*
>
> *S3: Is it? We do it like this, right? This way is force T acting like this and like this, so this doesn't cancel? I don't know. Is it OK to not think too hard about this part? I don't know, already!*

S2 and then S3 decided that T must depend upon the weight of the child. Shuji-TA had them think about the idea that a net force is needed to maintain motion (or lack thereof) and he asked them "if T is not bigger than mg, does it mean that it cannot be preserved?" (01:21:25) Although it is unclear what Shuji-TA meant by this, perhaps it was something like "is it not necessary for T to be bigger than mg to break the equilibrium?"

Although he used Shuji-TA's explanation as justification, S4 was perhaps changing the subject when he gave his explanation for choosing the right box. S4 was the only one of the four to say that his thinking when he answered "constant speed" (II.B.5) was the "right" refined intuition. He explained that he just has an intuition that if it's just going along at a constant speed, then there is no net force (1:22:59). If you had another force, then it would "change".

Shuji-TA asked S3 if, having heard S4's explanation for the box on the right if his thinking had changed any. S3 said that it makes total sense, but Shuji-TA was not satisfied with this (1:23:31). The TA asked if S3 was really going to change his mind so easily. S3 carefully read the description of the box on the right, and decided that that is the one. Shuji-TA again checked to ensure that everyone was OK. Tadao agreed that it is the box on the right, and Shuji-TA then checked in with S2 to see what he was thinking.

(3) Analyzing Shuji-TA's actions and the effect they had on students

Shuji-TA's first move was to go from student to student, asking for answers and checking if other students had matching answers. With both II.B.1 and II.B.3, the students had the "wrong" answers to the Tutorial. However, Shuji-TA only asked for clarification about the latter part. Perhaps this is because Shuji-TA felt he understood why the students had said that their intuition with the II.B.1 situation is different than the result of Newton's law. Perhaps he thought the students were thinking that Newton's law would predict that the speed would continue to increase, while their intuition, they explained, was that Timmy would ascend at a constant speed. On the other hand, why they said that Newton's law does not support their intuition about II.B.3 may have been less clear to Shuji-TA. Indeed, if, during the inaudible part, the students read out loud what they wrote on their worksheets, it would not be immediately obvious what the contradiction is. Thus, it is possible that the reason why Shuji-TA had them explain here was not because their answers did not match what he was expecting, but rather because he felt that he was not understanding a part of their reasoning.

After Tadao's explanation, a TA could respond by making students reimagine the situation: for example, "if Timmy were traveling really really quickly upwards and the rope was then cut, do you think he would immediately fall, or would he slow down first?" It is not likely that Shuji-TA was unaware of this possibility, since we had discussed this approach the previous day at TA training. Nevertheless, this is not the intercession Shuji-TA chose. Instead, he chose to first hear what the students had come to with the following Tutorial prompt.

When students answered that whether the rope is pulling strongly or not, the speed upward will be the same, determined by the crank of what is pulling the rope up, Shuji-TA could see that they were really missing the point. Here, again, Shuji-TA could have guided them through the thought experiment himself. Even if he had not been successful at getting them to personally feel that Timmy's speed would need to continue increasing if the rope force remained larger than 250 N, he could have asked if they could understand how that idea *would* be intuitive to *someone*. If that had been successful, he could have then repeated the leading Tutorial prompt by saying something like "if someone has the intuition that 1) if the force of the rope is larger, he speeds up; and 2) if the force of the rope is smaller, he slows down, how would he answer this question: if the force of the rope isn't larger (so he isn't speeding up), and it isn't smaller (so he isn't slowing down), but it's exactly equal to 250 N, what must his speed be?" The students probably could have guessed "constant". Then, with the Intuition Refinement Diagrams, Shuji-TA could have referred back to that chain of intuitive thinking to make sure the students understand that although someone, like these four students, might have a first reaction that the force of the rope must be larger than Timmy's weight, that student might have an alternative chain of intuitions that leads to a different result, one that agrees with Newton's law. We discussed this strategy of "well, maybe it's not intuitive for you, but you can see how it might be intuitive to someone else, right?" too at TA training, not just the previous day, but with other Tutorials as well.

However, Shuji-TA did not do this either. When I brought this idea up in TA training, I described it as a "last resort" technique. Thus, perhaps Shuji-TA choosing not to pursue this path speaks to his hope that the students would be able to get something more out of the class than "well, this thing works for other people, but my intuitions are just hopeless in physics".

By choosing to let the students continue as they were instead of performing this drastic pedagogical intervention, Shuji-TA ensured that the students maintained their poise, confidence, and willingness to continue thinking for themselves and discussing with each other. Indeed, immediately after he walked away, S4 announced that the instructions of the next task were to think as a group, and Tadao cheered confidently and cheerfully "Here we go, one more time!"

Looking at how comfortable these four students felt around each other, it was perhaps unnecessary for Shuji-TA to assure S4 that it's OK for him to disagree with his group mates. However, the effect of peer influence on the Gakugei students should not be underestimated. During the pressure Tutorial, for example, the students were instructed to draw on the blackboard pictures of what water streams leaving their beakers looked like. Seemingly regardless of what their actual beakers were doing, group after group of students looked at what pictures had already been drawn on the blackboard, and drew a matching image.

(a) Shuji-TA didn't teach them what "net force" means or make them think in terms of Newton's 2nd Law.

Shuji-TA continued calling on students to give answers to questions and then, cuing in to students using technical jargon, asked them to define what they mean. When S4 gave his explanation, Shuji-TA could have told them that they were using the word incorrectly. In fact, an object does not take a force with it. For that matter, he could have told them that the net force can be found from the F in F = ma: when acceleration is zero, the net force is zero. However, he instead took interest in the substance of their ideas rather than their verbiage and agreed that if they are using the term to mean something like momentum, then indeed, a "net force" is needed for motion (just as a body without momentum does not move).

If Shuji-TA had taken this opportunity to teach them that they were misapplying the formalism, we might expect them to lose confidence in their understanding and perhaps be less forthcoming with their own ideas. The discussion that took place regarding whether T is just big enough to keep Timmy in the harness and whether it wraps around following the rope or not might not have been so forthcoming following such an intervention. Supporting evidence for this is that *even without such a conversation taking place*, S4 at (1:19:11) asked Shuji-TA for confirmation (indicating a view of him as a knowledge authority): "So therefore, this way, it's good to just have this one, isn't it? (looking at TA's face)."

At 1:12:30, it is clear that the discussion was supposedly about Newton's 2nd law. However, when Shuji-TA asked S2 to explain how the box on the left matches the law, it does not seem that S2 was doing any kind of rule quoting. Indeed, he talked about an actual situation, of trying to push something on a surface with friction. Similarly, when Tadao was asked the question, he did not reply with "that's just what Newton's law is: you need a net force to maintain whatever motion you have." Instead, Tadao, like S2, seemed to be answering what he thought was the *physically correct* answer here. Shuji-TA could have shifted the emphasis of the conversation to, specifically, Newton's law, and if necessary, even taught the law to the students. The acceptability of such a move had been, again, affirmed during TA training. However, he instead never again asked about Newton's law at all. Perhaps he felt that, since the goal of the Tutorial is to show students that their intuition can agree with what they think is supposed to happen in the physics world, it doesn't really matter whether students know Newton's law or not. Thus, he was perhaps focusing on *the students'* ideas about what is supposed to happen in the world of physics (as well as on their intuitions) and if the authority of a pre-memorized law was not important for them, he wasn't going to unnecessarily make it important for himself either.

Such TA behavior would presumably reinforce the idea that it is appropriate for students to answer Tutorial prompts with their own ideas, as opposed to trying to quote rules. In fact, it may be the result of such behavior in previous lessons that provided the scaffolding needed for Tadao and S2 to feel comfortable focusing on their own ideas of what should be physically true - "you need a net force to maintain motion", as opposed to pulling out a memorized physics rule.

(b) When Shuji-TA shifted to an authoritative role, he quickly reverted back.

We see a change in Shuji-TA's behavior when he asked if the two T's of the diagram wouldn't cancel each other out. While previously he had been asking open questions and having students tell answers and checking for inter-student agreement, here he asked an almost rhetorical question. He became even more in control of the conversation when he concluded for the students what would happen if only mg is acting.

We might expect the students to break out of their "we are going to make sense of this ourselves" mode and instead begin looking more to Shuji-TA as an authoritative source of knowledge. Indeed, when Shuji-TA asked about the two T's canceling out, S4 looked up at him after S3 had given his explanation as though to ask "is that what you had in mind? Or, what's your point?" However, when Shuji-TA pointed out that you can't get Timmy out of the well in that case, S4 returned his attention to S3 to talk jokingly about how Timmy would just keep going farther and farther down. After this, however, S4 asked the TA for confirmation that there should be only one T, and watched his face carefully for a reaction.

Perhaps sensing how the dynamics had changed and wanting to avoid the students looking to him as a source of authority unnecessarily, Shuji-TA refrained from answering S4's question. Instead of getting frustrated by this, however, S4 effortlessly returned to the activity of reasoning in a group, pointing out to his group members that it must be that there is only one T, because otherwise Timmy cannot be rescued. Once Shuji-TA returned to asking another open question (how big T should be), the group seemed to have been restored to its natural state of using one's own ideas for sensemaking. Although S4 looked at Shuji-TA when he gave his answer, it did not have a rising tone of voice as though asking for confirmation; rather, S4 was explaining his idea. S3 then responded to S4, looking at S4 and pointing at his paper.

We thus see that the student stance towards sense making and reliance on one's own ideas was robust enough that the TA's temporary shift to a more authoritative position did not disrupt it. We also see that Shuji-TA's stance was robust enough that, even when he gets out of the "facilitator role" and into a sort of "lecture mode", he is able to catch himself and get back on script.

Shuji-TA's question about the size of T led to a variety of answers, including that T is just big enough to prevent Timmy from falling out and that T depends on the mass of Timmy. Even this latter idea, in and of itself, is not correct. Rather, the larger T is, with mg constant, the more the acceleration is. Shuji-TA, however, did not take a divergence here to explain, for example, that you can pull on the rope with varying strength and that it's not just the weight on one end that matters. Instead, perhaps recognizing this as potentially being sufficient for them to make the connection between their intuitive sense of the force in the rope pulling the child up and what role it plays in determining the net force, he returned to the point they had correctly reached before – that Timmy can't leave the ground unless the force in the rope is larger than his weight. This time, however, Shuji-TA had the students think about the situation from a formal physics approach, with the "force in the rope" being the T labeled in their diagram. From that diagram, he had them think about net force.

Again in this move, he was more aggressive than usual. He gave them a specific challenge: they had said previously that Timmy isn't going to move up off the ground unless the force in the rope is larger than the child's weight. Does that not mean that a net force is necessary to change the child's motion?

If Shuji-TA had left there, the students might have been able to use his significant clue and realize that, in fact, if they say that the child is moving upwards at a constant speed when the rope force is the same as the child's weight, then they are using the intuition that a net force is needed to change, not stabilize motion. However, perhaps concerned that he had guided them too much, he had the student with the correct answer be the last voice instead of himself.

> *[01:22:49.13] S4: Unsurprisingly, in the preservation, the thing of a net force. If a force were acting, would it change I wonder, is what I'm saying… If it's just as it is, it's fine to be just as it is, isn't it? If you want to move it, you do it like this - apply a force.*

When S4 gave his answer, Shuji-TA did not say "that's right" or even leave it at that. Instead, he encouraged the other students to continue the debate if they continued to disagree. And, finally, he made sure to check in with all the students.

(c) Summary of Shuji-TA's messages and how they were heard by students

It is not clear what the students were thinking in this episode (for example, if they thought that Newton's law says that a net force is needed to maintain motion, why did they claim inconsistency with their intuitive answer that the speed would be constant if the force in the rope continues to be larger than 250 N?) More importantly, it is not known what Shuji-TA was thinking. He was not even asked to watch this video and recall his thoughts via stimulated recall. And so, the above is mostly speculation about Shuji-TA's intentions. If the speculations are correct, it shows that Shuji-TA was adept at listening critically to the students, thinking on his feet about their ideas, and deciding which direction would be most beneficial for those students.

However, even if the speculations are not correct, there are certain features that are nevertheless evident. In the seven minutes that Shuji-TA interacted with the students in the first interaction, he did nothing but ask students what their answers were, if they agreed with each other, and to explain their reasoning. For the fourteen minutes that he spent in the second interaction, he again mostly just asked for answers to questions on the worksheets, if students agreed with each other, and open questions related to what the students told him. He did *not* teach the students what Newton's law is, what "net force" means, and he did not answer S4's question about what T looks like, all of which might have led to him being positioned as an authority figure. Even when students started becoming sympathetic to the right answer in the end, he never confirmed one way or another that the box on the right was the correct one. And more subtly, he passed up opportunities to change the way the students were thinking, for example about what they intuited would happen if the rope force continued to be larger or if it suddenly became less. Instead he delved farther into the Tutorial, asking various questions, before choosing with intention the intervention he would deploy.

Shuji-TA's actions conveyed messages that students can utilize their own ideas instead of memorized laws, that it is important to think conceptually, and that inconsistencies should not just be accepted, but rather one should strive for reconciliation.

These messages were picked up on and accepted by the students: they stayed willing to continue thinking for themselves, be forthcoming with their own ideas, and discuss with each other. Even when the Tutorial asked them what Newton's law would say, S2 and Tadao did not reply so much by attempting to quote a rule as explaining what they think is canonically correct. These students consistently thought conceptually during the class and they were not satisfied with solutions that were inconsistent with physical reality. For example, they recognized that "the T's cancel and Timmy cannot be saved" was not an acceptable solution. Furthermore, this stance towards sensemaking and reliance on one's own ideas was robust enough to withstand temporary shifts of authoritative balance.

3. The educators were united

Thus far, this chapter has discussed the messages sent by the in-class activities, the assessments, and the educators. Although I have already done a little bit of this in the above, I will devote the remainder of this chapter to show consistency across these messages. From that, I will argue that students were not receiving mixed epistemological messages from various places in the class. First, I will show that the messages sent by the multiple educators were alike in that sense-making (instead of memorization), conceptual reasoning (instead of using formulas for calculations), and valuing and reconciling one's own personal experiences and ideas (instead of just accepting knowledge that doesn't make sense) were emphasized.

a) The strongest apparent challenge to the claim of teacher's pedagogical unity

Educators were, for the most part, eye-to-eye when it came to how the class should be taught. One of the greatest disagreements that existed between TA's and the instructor was about whether or not it would be better to have answers available to students for certain parts of the Tutorials. The episode took place in the TA debriefing after the fifth Tutorial. That week, the class had had a visitor, a teacher from a nearby high school. The visitor also joined the debriefing session.

As usual, the TA's were taking turns recounting various difficulties that they had had with the class that day (for example, what things students didn't read carefully and what things they had misinterpreted). The visitor asked if the students are freshmen and Hayate-TA explained that although they are second year students, there isn't much difference between them and first-year students. There was some talk about college entrance exams. Then, Mizuki-TA made the statement that begins the transcript in Appendix C.3: students had asked her to be given the "answer key" to the Tutorials.

It was not surprising to any of the educators that students were requesting answers to the Tutorial worksheets. Hayate-TA's assessment (40:54) reflected that students were not finishing the Tutorials, and that students had seemed anxious about that. Mizuki-TA seconded this (40:54) by saying that students are sincerely desiring to figure out the material. Hayate-TA continued to sympathize with the students (40:57): they run out of time without understanding what's going on, and they know that they likely won't get a chance to revisit it next week. Shuji-TA explained that the students won't be satisfied unless they get the correct answers (41:06).

Hayate-TA was the first and only TA to explicitly support that they satisfy the request of the students and grant access to the answers (41:13). The idea created a bit of chaos in the room, with a side conversation sprouting up between Mizuki-TA and Akiko-TA. Even the visitor suggested a way that students could get access to the solutions – using an internet site that they could access after that day's class (42:07)

It is clear that Professor Uematsu was never comfortable with this idea. Her skepticism when Hayate-TA first proposed the idea, her frowning, brow furrowing, and sighing are all indicators of being ill at ease. Perhaps in response to this, Hayate-TA specified that he isn't proposing having answers to *everything* on the worksheets – just things like interpretations and Free Body Diagrams, questions that, basically, *do* have a "correct" answer (42:24). At last, after listening to the various ideas and opinions, Professor Uematsu made a decision for the group. They would not give the students answers; rather, it is her goal to have students learn to relieve their academic curiosity themselves, without dependence upon authority (43:04).

This decision was immediately respected by Mizuki-TA, and the TA gave an additional justification for it (43:14): by having students suffer through initial confusion, they will more likely feel an epiphany by the correct results that they come to. Hayate-TA continued to express skepticism, however, when he again said that students just don't have the time necessary (44:04). However, when Professor Uematsu repeated her decision with the justification of going against the grain of student expectations that answers will come out quickly form authority when they need them (44:11), Hayate-TA amiably backed off his suggestion (44:18).

As per this agreement, the TGU TA's were never observed to be giving students answers like this. It is unknown whether this exchange was really enough to make Hayate-TA and the others change their minds about whether it would have been better or not to provide solutions to the students. Thus, we do not know whether the cause for TA's not giving answer sheets to students is because of their eventual conviction that that would not be a productive way to teach, or if it was because the idea of going against their professor (who was also their academic advisor and often appeared in the classroom with them and would easily notice) was unthinkable. However, not only did TA's restrain themselves from sneaking cheat sheets to the students, TA's seldom answered student questions at all.

It is not argued that there were no differences in opinions in how to best teach students and keep student morale high; the argument is that these differences were subtle. The TA's were arguing only about giving students the answers as a last resort, at the end of class. They were in accord regarding the bigger point, which is having a space for students to figure things out themselves (during class). In the data available, this anecdote was the strongest apparent challenge to the instructional consensus of how to teach these tutorials, and even here, there was unity regarding the benefit of constructivist teaching. Furthermore, arguments such as this were resolved in open discussion during TA training or post-class debriefing, and TA's resolutely followed the decisions of the group.

Whether Hayate-TA ever really believed in the value of withholding answers from students or not is not a question this dissertation attempts to answer. However, his statement to the five observers above in section C.1 is evidence that he could at least justify the decision himself.

b) Positive examples of how the educators were united

The Tutorial video clips analyzed above and other observations of recorded videos as well as field notes show trends in TA behavior. Miwa-TA told the five observers that she had learned that teaching does not mean always answering the questions students ask, and indeed, as Katashi-TA and Shuji-TA demonstrated, TA's rarely answered student questions directly if at all. Katashi-TA walking away after giving a hint about what could prove a productive approach to the problem was not atypical; in fact, it was the norm. As the episode with Katashi-TA demonstrated, TA's were judicious about when to talk to students at all and when to avoid interrupting their discussions. This is perfectly in-line with instructor guidelines written for TA's at Maryland who facilitate these Tutorials. (Edward F. Redish)

When TA's were engaging with students, like Shuji-TA did, TA's generally took pains to hear from everybody, especially students who seemed like they weren't actively participating in the group conversation. This did take a variety of forms, however, ranging from Shuji-TA and Akiko-TA, who were quite systematic in asking every student directly for answers, to Hayate-TA, who said at the debriefing of Tutorial 4 that if all students are nodding their heads in agreement, he will let it suffice to just ask "do you all agree?"

Note that checking in with every student was most commonly done when students reached a checkpoint in the Tutorial, signifying that they should check in with a TA before continuing. When Shuji-TA was first called over in the above episode, the students had reached such a checkpoint. So Katashi-TA, who did not ensure that every student was participating equally in the episode above, was perhaps lax in this regard because he was not entering conversations at such a checkpoint. The first of the three interactions above was him reacting to a specific conversation point that the students were having. The second and third times were students calling him over to ask a specific question. He may have been more systematic with other groups, especially if talking with them at checkpoints.

The majority of TA-student interactions took the form of TA's asking questions. The second-most common type of interaction, as both Katashi-TA and Shuji-TA demonstrated, was having students clarify their reasoning. This exemplifies Mizuki-TA's advice of making clear to students that TA's are interested in what the student is really thinking.

All these actions reinforce what Hayate-TA explained to the five visitors as being the point of Tutorials. Although it may come at the expense of students having confidence and accuracy in the knowledge they take away from the class, the goal was to have students reason about the physics content themselves, with their own ideas and intuitions. For such a thing to be possible, the students needed to be scaffolded in having these discussions, and the TA's provided this by calling on the students, asking them to elaborate their reasoning, and giving them space to have discussions. Note that this is completely consistent with the TA guidelines, which emphasize that goals of OSTs include "getting the students to build their physics intuition by making connections to their everyday experience" and "helping the students reconcile their misconceptions of how things work physically without undermining their trust in their intuitions". (Edward F. Redish) The consistency of the educators with the curriculum intent is explored more fully below.

Lastly, as Shuji-TA demonstrated, the TA's were careful and intentional with the words they said to the students, and debriefing sessions would often involve recounting stories of lines of Socratic questioning or more open questions that had been tried to help students who needed some guidance. This is completely consistent with Hayate-TA's tennis coaching example that he gave to the five visitors: you can't help a student by just telling them what to do. You need to first think about the situation from their point of view so you can carefully choose an intervention that will make sense for them.

D. Other aspects of the course aligned with the instructors' vision

Above I showed that although there were many educators of the course who interacted with students, the vision of the educators was largely a united one, both in ideology and in practice. Thus, it was not likely that students received a very different epistemological message from one instructor than from another instructor. In this section, we now evaluate the likelihood of students perceiving mixed messages from other aspects of the course.

It is possible that students may have felt a disconnect between the epistemological message being sent in the lecture and that through the Tutorial worksheets. After all, one activity is passively listening to the instructor, the source of knowledge, whereas the other is drawing on ideas of one's own and one's peers. However, the lecture component was typically kept very short, around ten minutes, and it was almost always framed as an introduction or conclusion to that day's Tutorial. The main points of the Tutorial would be reviewed, not only the conceptual, but epistemological as well. Several times, especially towards the beginning of the semester, the lecture motivated and explained the rationale for spending the remainder of the 90-minute class working in groups. In other words, a chief goal of the lecture component was to make the worksheets more accessible to students, to put an authoritative voice in support of the constructivist activity.

It would be more likely for students to find a disconnect between the class contents (worksheets and lectures) and the homework assignments, or more likely still, between the class contents and exams. In class, there was no reward for getting the correct answers, and the point was explicitly to discuss your ideas with your group mates, without worry of whether they are right or not. On exams, however, this was not the case. As mentioned above, there were no problems where students were rewarded for memorizing the correct equation, substituting values, and performing algebra. In other words, although the stakes varied, and although the emphasis on correctness varied, the value given to reasoning itself was a constant.

1. The educators were consistent with worksheets

a) Educators are not always consistent with the curriculum intents

Goertzen documented that, although OSTs may place emphasis on using one's own ideas as a source of knowledge in the physics classroom, professors and teaching assistants implementing OSTs do not always reinforce this message. (Goertzen 2010) Goertzen gives the example of Oscar, who, though in support of some aspects fostered by OSTs, did not "buy in" to having students use everyday experiences and intuition in the process of learning physics. Consistent with this view that he espoused in an interview setting, he denigrated the Newton's Third Law Tutorial's elicitation of a "common sense answer" by telling his students to just write down some guess that they shouldn't take too seriously. This action went against the Tutorial, which was designed with the intent of students reconciling this intuitive answer with Newton's Third Law.

If TA's readily give students answers to problems that the worksheets intend for them to figure out themselves, or instruct students to skip parts of the Tutorials that ask them about their "feelings", students will receive a mixed pedagogical message about what is really important in learning physics. (Goertzen 2010; A. Elby 2001)

Open Source Tutorials were not created with the restriction that no deviations from the curriculum be made. Rather, the OSTs DVD was created and disseminated so that instructors could piece together Tutorials as their teaching situations allowed, and, indeed, many researchers and teachers have made changes to the curriculum. (Yerdelen-Damar, S.) At the same time, however, one important characteristic of the material is a constructivist spirit, and deviating from this as Oscar did goes against the curriculum.

In addition to being a senior staff member of the above research project, for a number of years, Edward Redish was a professor of Physics 121 and Physics 122, introductory physics courses at the University of Maryland, and employed OSTs consistently. He wrote guidelines for his TA's to follow when facilitating OSTs. (Edward F. Redish) In addition to reemphasizing that goals of OSTs include "getting the students to build their physics intuition by making connections to their everyday experience" and "helping the students reconcile their misconceptions of how things work physically without undermining their trust in their intuitions", the guide lays out what TA behavior is effective to make these goals attainable, providing additional insight into the nature of the curriculum and hence the messages it will give to students.

Generally, the role of a TA "is NOT to explain the material in the tutorial to the students. Mostly you should be listening in to what's going on at the different tables, not talking." The guide specifies that TA's should listen carefully to students, eliciting their thinking or confusion; encourage them to compare answers with each other; letting students debate with each other, to figure out who is right and who is wrong on their own; occasionally point out factors that they may have ignored that led them in the wrong direction if needed; and have them keep moving if they seem to be taking the material lightly.

The list of what not to do reinforces the above list. TA's should not talk too much or lecture and they should not interrupt productive discussions. The list also includes that TA's should be cautious about telling students that they are right too quickly, since a goal is to have students learn how to judge for themselves whether they are right or not instead of deferring to authority.

b) TGU educators were consistent with the curriculum intents

The Gakugei TA's were not expert Tutorial facilitators. In fact, they were doing their first TA-ship with OSTs and had limited (or no) teaching experience before the class. In debriefing sessions, they would admit where they were stuck and confess mistakes they felt they had made. Many teachers may feel that Shuji-TA was sub-optimal by not teaching the students what Newton's 2nd law is, especially since the

Tutorial creators themselves assumed that students would come into the Tutorial knowing that (at least at the level of rote memorization).

More importantly, there were times in which the OST creators themselves might have disagreed with the actions of the TA's. Yui and S2 barely spoke at all during episodes with Katashi-TA (and this was true when the students were not interacting with a TA as well), and one can find fault in Katashi-TA not asking the two of them how they feel about the irrigation canal model, for example.

Although there may not have been 100% consistency between the messages sent by the educators and those sent by the worksheets, it is nevertheless striking the degree to which the two were in agreement. Hayate-TA described the goal of Tutorials as getting students to productively make use of their own ideas in understanding physics. This is very similar to the description given by the Tutorial authors: "getting the students to build their physics intuition by making connections to their everyday experience" and the actions of the TA's in the above episodes and in other videos exemplified this goal.

Hayate-TA's description of "refining intuitions" also is very similar to the words of the authors: "helping the students reconcile their misconceptions of how things work physically without undermining their trust in their intuitions". As far as specific steps to take to make these things happen, the TA guidelines by Redish specify that the role of a TA "is NOT to explain the material in the tutorial to the students. Mostly you should be listening in to what's going on at the different tables, not talking." Mizuki-TA and Miwa-TA seem to have built upon this in their strategies described above: it's important not just to listen while refraining from teaching, but to make it clear to the students that that is the game being played. Shuji-TA and Katashi-TA demonstrated how seriously the TA's took the charge of listening and not explaining.

Another guideline is to be cautious about telling students that they are right too quickly, since a goal is to have students learn how to judge for themselves whether they are right or not instead of deferring to authority. This is consistent with the pedagogical move Shuji-TA described to the five visitors of having students who are stumped evaluate arguments made by "another group" and also by his own actions of continuing the conversation even after S4 and others began to be sympathetic to the idea that the box on the right is the correct answer.

Thus, in my analysis of messages sent by the in-class worksheets and lectures, the homework, quizzes, and exams, and the educators, I find common threads of constructivism. This can be seen in evidence of what messages students actually received from these sources as well.

From every aspect of the class, students heard that physics can be approached conceptually (and not just with formulaic calculations), and that it is important to strive to have the material personally make sense (instead of just memorizing it) by finding a way to make your own ideas and experiences reconciled with the physics formalism.

E. Students did not complain about inconsistency (i.e., my account of consistency is meta-consistent with student account)

As described in Appendix E, 24 of the 28 interviewees provided some complaint about Physics Exercises. None of the 24 students, however, mentioned, for example, the complaint of "Tutorial doesn't help me with the homework/exams, so I don't understand why we do it" that is so often heard by Tutorial facilitators in other institutions. Gakugei students did not even contest the portions of Tutorials that ask students to be introspective and talk about their intuitions with each other (which students at the University of Maryland often see as especially irrelevant). This serves as additional evidence that students did not see a disconnect between the pedagogical messages being sent by the worksheets and those sent by the assessments. This evidence is suggestive, but not decisive. Obviously the best data would be in the form of students saying that there is consistency – not in students *not* saying that there *isn't*.

F. Survey results

There is data that can speak to this question of whether students really perceived the components of the course to be sending united epistemological messages or not. Although the 2011 students were not given this survey, 42 students from the 2012 class completed three survey questions to get at exactly this issue.

The first question was "During Tutorial, if I ask 'what is the answer to this part?', some TA's won't tell me, but other TA's will." The majority of students either said that it "does not apply" (14 students) or that it "doesn't really apply" (13 students). However, a larger number of students than I was expecting said that it "more or less applies" (7 students) or "applies well" (1 student).

From my own observations and from the descriptions given by the five students who helped validate the survey (see Chapter 3, section D), I would not have expected so many students to feel that some TA's are just giving answers. Although there is no way to know for certain, my suspicion is that these students were still picking up on how there is a range in how far TA's will probe (which was discussed by the 5 survey validators), even after the wording was changed on the prompt.

From the last two prompts of the survey ("How satisfied are you with your grade in Physics Exercises?" and "Even if you really understand what is written on the Tutorial worksheets, it is not enough to get good grades on the exams and quizzes in Physics Exercises"), I did not count students who said that they were dissatisfied with their grades and that the exams and quizzes are unfair. The rationale was that the student might not have been making an unbiased judgment of whether the exams were fair or not. Similarly, I disregarded students who were satisfied with their grades and felt the exams were fair. Five students were dissatisfied with their grades but still disagreed with the statement. Four students were satisfied with their grades, but agreed with the statement. Again, from my own perspective of how the worksheets stress the same kind of reasoning that is evaluated on assessments, this was a surprising result.

I suspect that many of the students who felt that the assessments were unfair were thinking that because they covered material that had not been addressed on the worksheets. Indeed, this was the rationale given by the survey validators who agreed with the prompt. I had wanted to evaluate whether or not the exams stress the same kind of reasoning and the process of sensemaking as the worksheets do. In hindsight, I'm not sure what prompt would have gotten at that more directly than the one I attempted.

G. Concluding remarks

It is interesting that the survey results agree only loosely with the qualitative data that I collected and presented in this chapter. Several explanations are possible.

It may be that students really did not perceive a consistent epistemological message from across the class aspects. However, this explanation is difficult to reconcile with the observations of students behaving as though they were clearly receiving the pedagogical message that the educators claimed they were trying to send (and, as the case studies of Katashi-TA and Shuji-TA illustrate, genuinely tried to send in the classroom).

It would be more likely that, in the classroom, students perceived an almost intangible feeling of "togetherness" from the instructors and classroom components that supported the new epistemology about physics learning that they were taking up; out of the classroom, however, they were more prone to see differences that existed. If, in the classroom, students felt that the "landscape" of the classroom pedagogy is "flat", outside of the classroom, at least when asked the prompt about the TA's, they may have been cued into zooming in too closely, and noticing that there are, in fact, "trees poking up in various places".

The argument that I have made in this chapter is that the various aspects of the Physics Exercises course were mutually supporting in conveying the epistemological messages that, in learning physics, one should:

- sensemake (and not memorize)
- reason conceptually (and not rely on formulas for calculations) and
- value and reconcile one's own personal experiences and ideas (and not just accept knowledge that doesn't make sense).

This feature likely served as a scaffold for helping students change their view about what it means to learn physics, and what the nature of physics knowledge is.

One of the contributions of this dissertation is to provide an example of a methodology for gleaning insights from foreign classrooms. Rather than looking at superficial features, I advocate looking more deeply and holistically for underlying mechanisms of learning. It is not a novel idea that a consistent pedagogy from across aspects of a course is important for effective student learning, and the intent of this chapter is not to make this point. Rather, I have presented analysis that is represent of what I mean by "look at deeper, underlying mechanisms" so as to illustrate the approach. Sometimes, as in the case of this chapter, the mechanisms uncovered will not be surprising ones. Sometimes, however, like in the case of students finding Physics Exercises reminiscent of primary school, surprises will be found.

IX. Discussion

Education researchers who have compared populations of students across countries have found differences not only in academic ability, but it beliefs about academia as well. These beliefs about learning have been argued to be an important piece that makes up the whole of successful learning in a country's classrooms. It hence follows that even were an American teacher to implement the same curriculum and teaching style that a Japanese teacher employs, because the beliefs of the students are different, that important piece would be lacking, and the learning experience cannot be guaranteed of success.

For teachers who expect students to take the knowledge provided without influence by their dispositions towards learning, this argument is of vital importance. It has been compellingly shown that students do not enter the classroom as a blank slate; rather their prior experiences play an important role in what and how they learn. Hence, the dangerous practice of implementing a curriculum or pedagogy that worked in a foreign classroom with expectations that it will achieve the same results in one's own classroom can be abated.

At the same time, however, this description of student beliefs, while poignant and compelling, has simplistically treated students as having fixed and rigid (unitary) beliefs about learning and about the nature of the subject being learned.

In light of data that has been gathered from education researchers in America, it seems clear that, in actuality, student beliefs have the potential to be quite fluid, shifting from context to context.

The roots of the cultural script construct allow for context-dependency, the notion of cultural scripts is similar to other constructs used that allow for context-dependency, and that even the definition of cultural scripts as "generalized knowledge about the event that resides in the heads of participants which guides behavior and tells participants what to expect" can allow for context-dependency.

I argue, therefore, that it would not be difficult to reconceptualize cultural scripts as something that can allow and expect context-dependency, and that cross-cultural education researchers should do this. This would make the construct not only consistent with recent findings from education researchers in America, but with the international results that I presented in this dissertation.

The behavior of the students I observed at Tokyo Gakugei University was utterly inconsistent with the idea of students having a "cultural script" in the sense that education researchers use the construct currently. Stigler and Hiebert, Biggs, Chappell, Isabelle, Holland, and others have explained that, from growing up in a given culture, their students of study grew up with beliefs about what learning should look like. They brought these beliefs into a learning environment that was inconsistent with those beliefs and had difficulty adapting to the new style. They "cannot handle [the different learning environment]… and withdraw"(Biggs 1994) or they continue "to play their traditional roles"(J.W. Stigler and Hiebert 1998).

They are “perplexed”(Holland 2008) and maybe even go through “a grieving process”(Chappell 2006). Similarly, the cultural script of the Japanese students about learning, or about college learning, or about learning physics, would be that the student will sit quietly in the classroom and absorb knowledge from the lecturing teacher. Since the curriculum we introduced utterly violated that script, it would be predicted that the Japanese students would similarly face difficulty in adapting.

This prediction would be incorrect - the Gakugei students in fact adapted very easily to the new style of learning.

Explanations that students give for why it was so easy to adapt include that they have had other experiences in academia that the new style of physics learning reminds them of. It seems that although they developed an epistemological stance towards physics in high school and/ or college, they actually had at least one other stance that they had previously constructed in elementary school. Although this latter stance was dormant when they first entered Physics Exercises, it was easily awakened.

This account, while inconsistent with the prevalent treatment of cultural scripts, is fully consistent with work that has been done within theoretical frameworks that treat students as having fluid beliefs, such as the resources framework.

I thus conclude that cross-cultural education researchers should expect student beliefs to be context-dependent.

Having argued that the current motivation for *not* copying and pasting from Japanese classrooms has a serious flaw, I do not wish educators to walk away thinking that I condone such copying and pasting. This dissertation thus simultaneously serves as an example of an alternative approach in getting teaching inspiration by observing foreign classrooms.

A. The unpredictability of cutting and pasting from Japanese classrooms is explained by cultural scripts

1. The gap in standardized exam scores prompted observations of foreign classrooms

As was described in the literature review chapter, K-12 students in the US come up short when compared to Japan and other countries in standardized exams of mathematics and science.(James W. Stigler and Hiebert 1999; Judson and Nishimori 2005; Judson 2012; Nichols III 2008; Silver 1998; Lapointe and others 1989; Lapointe and others 1992; McKnight and others 1987; HW Stevenson and Stigler 1992; Organisation for Economic Co-Operation and Development 2012)

To gain insight into what could be causing these discrepancies, international education researchers have studied what goes on inside the classroom, via surveys as well as video recordings. (Silver 1998; McKnight and others 1987; J.W. Stigler and Hiebert 1998; James W. Stigler and Hiebert 1999; Judson and Nishimori 2005;

Roth and Garnier 2006) Most of the research has been on the 8th grade and has made the following findings about Japan:

- Mathematics students delve into key points rather than breaking a topic up into needlessly small segments. (Silver 1998)
- Math teachers cover algebra, geometry, and measurement (McKnight and others 1987)
- Mathematics classes often feature problems situated in a real-world context (James W. Stigler and Hiebert 1999)
- Math students invent their own solutions to problems and then reflect on and discuss other students' solutions (J.W. Stigler and Hiebert 1998)
- Science students perform experiments preceded and followed by discussions that connect their results to key science ideas (Roth and Garnier 2006)
- Teachers are given time to individually and collaboratively prepare lessons, improve their teaching, and consider how to implement reformed curriculum (James W. Stigler and Hiebert 1999; Alvine et al. 2007)

2. Reforms have been enacted that make American classrooms look more like Japanese ones: some worked, but others didn't

There have been many proposed and enacted state and nation-wide reforms in response to these observations.(Silver 1998; McKnight and others 1987; Burton et al. 2002; Henry 2001; Nichols III 2008; Nichols 2007) There are many success stories of implementing Japan-like reforms.(Burton et al. 2002; Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999; Chappell 2006; Nichols 2007; Qin, Johnson, and Johnson 1995) At the same time, however, there have also been many failed implementations that matched the above list in appearance by:

- focusing on underlying principles(Education 1975)
- having more challenging curriculum at earlier grades (Education 1975)
- emphasizing higher-order thinking (Burton et al. 2002; Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999; Qin, Johnson, and Johnson 1995; Education 1975; J.W. Stigler and Hiebert 1998)
- emphasizing on student interaction (Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999; Qin, Johnson, and Johnson 1995; Education 1975)
- giving teachers opportunities to meet with each other and discuss curriculum(Saxe, Gearhart, and Nasir 2001; Gearhart et al. 1999)

One of the common causes for this failure lies in the teacher. It is well-documented that many teachers, while thinking that they are implementing reforms, are doing so only superficially, and are not being true to the intent behind the reforms.(James W. Stigler and Hiebert 1999)

3. Stigler uses cultural scripts to explain why we shouldn't expect copying and pasting to work

Mounting evidence suggests that applying reforms that match Japanese classrooms in superficial ways is not reliable. In addition to teachers failing to put into practice the "spirit" of the reform, differences in out-of-classroom factors that may correlate to performance have also been identified (James W. Stigler and Hiebert 1999; Judson and Nishimori 2005; Lapointe and others 1989; Lapointe and others 1992; HW Stevenson and Stigler 1992; Judson 2012; Organisation for Economic Co-Operation and Development 2012; McKnight and others 1987; Saeki, Ujiie, and Tsukihashi 2001; Ogawa and Shimode 2004; Schleicher 2012; Ogawa 2006), This is the backdrop for Stigler's cultural scripts to enter the scene.

Stigler has used the differences in culture observed across countries as an explanation for why copying and pasting shouldn't be expected to work. There is a disconnect between the ***cultural script*** of the students and what they are encountering in the classroom. Writing about when it does work, Stigler and Hiebert commented "One of the reasons that classrooms run as smoothly as they do is because students and teachers have the same script in their heads; they know what to expect and what roles to play." (J.W. Stigler and Hiebert 1998) On the other hand, if that script were to not be matched by the teacher, then the classroom would not run so smoothly. In this way, the failed attempts of teachers to implement Japan-looking features can be and has been explained.

This construct has not ended with Stigler and his studies of K-8th graders. Other education researchers and teachers have used the idea of cultural scripts to explain resistance of their college students at the undergraduate (Isabelle and de Groot 2008; Chappell 2006) and graduate (Holland 2008) levels. Furthermore, this idea is not limited to the verbiage of "cultural script" within the cross-cultural education research community. Biggs, for example, has described something similar in terms of a "cultural framework". (Biggs 1994)

B. Reconsidering the construct of cultural scripts

The definition of a cultural script given by Stigler and Hiebert is that it is "generalized knowledge about the event that resides in the heads of participants which guides behavior and tells participants what to expect".(J.W. Stigler and Hiebert 1998) Although education researchers have in effect interpreted and used cultural scripts as unitary, nowhere in this definition does it say that participants can only have *one* script about a given activity.

And, in fact, results from research in cognitive science, sociology, and education research suggest that the "generalized knowledge about the event" can, in fact, be quite fluid and flexible, driven not only by past experiences, but by subtle shifts in context as well. A manifold framework has explanatory power not only for situations where student views (for example, about what constitutes appropriate learning) shift fluidly from moment to moment, but when there is a more permanent shift in "belief" as well.

1. Motivation to change

a) In defense of Stigler and others

I have frequently referred to Stigler and Hiebert's article "Teaching is a Cultural Activity" to make the case that they would predict that the Gakugei students would react as the anecdotal fourth graders did – they would continue to play their "traditional roles" associated with their single, unitary cultural script. Perhaps I have overgeneralized the sentiment of the authors. Here is the full quote:

> *"A more recent and personal illustration of the stability of systems of teaching occurred when one of us was participating with a group of American teachers analyzing videotapes of Japanese mathematics instruction. A fourth-grade teacher decided to shift from his traditional approach to more of a problem-solving approach as shown in t he Japanese lessons. Instead of asking short-answer questions, he began his next lesson by presenting a problem and asking students to spend ten minutes working on a solution. Although the teacher changed his behavior to correspond with the teacher in the videotape, the students,* ***not having watched the video and not having thought about their own participation*** [emphasis mine]*, failed to respond like the students on the tape. They played their traditional roles and waited to be shown how to solve the problem. The lesson did not succeed. Even students are part of the system."(J.W. Stigler and Hiebert 1998)*

Inherent here is the idea that, had students watched the video and/or thought about their own participation in the classroom, they might have responded differently. They might not have been so bound by their cultural script; their beliefs about what learning looks like might not be so rigid after all.

Consider again the quote from Holland's anecdote about Paula, the teaching assistant:

> *"Paula's perplexity stemmed from a belief system about students and the classroom environment acquired from years of cultural orientation that dictated attitudes and behaviors. Behaviors, then, were the result of what Stigler and Hiebert (1998) referred to as a 'cultural script, generalized knowledge about the event that resides in the heads of the participants'…The participants brought their originary cultures of learning with them to the site institution." (pg. 182 of (Holland 2008)).*

This, like Stigler's fourth graders, is arguably phenomenological (and not theoretical) in nature. Holland is not saying that every foreign TA is perplexed, or even that every TA in the class being studied was perplexed. Rather, Paula was perplexed, and the reason for it is that her view about learning was clashing with what she was experiencing in the new learning environment. Where does such a view come from? Well, the fact that Paula grew in classrooms that were taught with a different ethos likely had a big role in it.

Overall, none of the researchers I have cited have said explicitly that "students have a belief system that is absolutely context-independent. They have a very rigid view of what learning should look like, and the classroom must perfectly fit that image or else the student will not be able to function." So, what, really, is the issue here? What, really, is the point of this dissertation?

b) What is lost by generalizing

I am relieved that researchers like Biggs and Stigler do not actually make claims explicitly like "students can only have one epistemology in their minds at a time. No matter where they are or what activity they are doing, their epistemology is exactly the same." I am nevertheless bothered that that is the general feeling that a reader of their work walks away with, if he thinks to consider the question at all.

When one reads "One of the reasons that classrooms run as smoothly as they do is because students and teachers have the same script in their heads; they know what to expect and what roles to play" (J.W. Stigler and Hiebert 1998) or "Seventy percent of the teachers even claimed to be implementing such ideas… But our data suggest that these changes have not affected the deeper cultural scripts from which teachers work"(James W. Stigler and Hiebert 1997) they are left with the impression that, basically, generally speaking, students and teachers have just one script about what learning should look like. When one reads "CHC students will be moving from an academic culture based on a set of values and expectations that are congruent with their general socialization to an environment lacking familiar support structures"(Biggs 1994), they are left with a similar impression: "basically, generally speaking, people in CHC countries believe x,y, and z, and that is different than what Americans believe". True, Paula is just an example, but it is an example that will likely leave the reader thinking "I have TA's from foreign countries… I wonder if their (unitary) beliefs are matching the teaching environment here." And when one sees that these believes are determined from surveys, how can one assume anything other than a context-independence of these beliefs. Implicitly, if the person believed it while taking the survey, they believe it in the classroom too – basically, generally speaking.

Basically, generally speaking, that might all be true. The phenomena of "pedagogy that works in Japan doesn't always work in America" that has been frequently observed *can* often be explained in terms of epistemology on a coarse grain size. Under a framework where these epistemologies are seen as stable beliefs, it is certainly easy to understand student resistance to reformed curriculum. Students have expectations about what should go on in the classroom, and if something else happens, they are uncomfortable, possibly even immobilized.

There are problems with this generalizing, however. Suppose I thought that my students, basically, think learning physics means listening to me lecture and memorizing what I say whether it makes sense or not. It follows that I would not consider that the context of the learning environment (whether the students sit in groups devising their own experiments or sit facing and listening to me in a lecture hall, for example) could influence that belief. It then follows that I would not attend to the idea that they could perceive "learning physics" in different ways depending on that context. And, if I were not thinking about how their framing of the learning physics activity can change, I would not carefully pay attention to how they are perceiving the event from moment to moment. "They are basically viewing it the way they always do – as a time to memorize what I say whether it makes sense or not." Hutchison and others have argued that such inattention is a pitfall for science teaching. It has been found that there *is* fluidity in student framing in a classroom, and "it is at least plausible" that without conscious attention to, reinforcement of, and accommodation for moments of productive framing, that students come to see that "the key to success in a science class is mastering a set of answer-producing algorithms or memorizing definitions"(Hutchison and Hammer 2009).

If I am not looking for variability in student reasoning and attitude towards learning, I might see Hutchison's students as "playing the classroom game" and assume that that is their cultural script and that's all there is to that. Rather, I want teachers to know that students are fluid, also able to treat the learning process as something where they use their own sense of what's reasonable as criteria for accruing knowledge. Without that knowledge, teachers might abort their attempt at teaching reformed curriculum as a result of prematurely concluding that their students' beliefs just don't work with the new teaching style, or they might adopt a Spartan attitude of "this course will change your beliefs even if it kills you!" and plow through the reformed curriculum without thought of how contextually shifting student attitudes (for example, by having explicit conversations of why the class is being taught in that style) could make the process much more palatable.

There is also a theoretical problem with generalizing that students basically have one set of beliefs about learning. A unitary framework on student beliefs is deeply challenged by data where student fluidity is important for the success of the lesson, such as with Hutchison's students, the students of Miss Kagey reasoning mechanistically (Louca et al. 2004), or Louis transforming his approach to physics. (David Hammer et al. 2005) My dissertation builds to this store of data by presenting a particularly vexing situation for a unitary rendition of cultural scripts: the unitary beliefs that Japanese students would have been labeled with were directly violated by the learning environment but nobody seemed to mind.

2. Cultural scripts come from and resemble fluid constructs

The theoretical construct of cultural scripts as described and made popular by Stigler is not in perfect accord with the construct of framing. "Teaching is a Cultural Activity" cites cultural scripts as deriving from the work of Gallimore. Gallimore, like Stigler, does not refer to the intellectual tradition of framing. Whereas Gallimore and other socioculturalists discuss emergent phenomena in a classroom at the level of the system, Goffman, for example, describes a frame as being something that resides in the head of an interactee.

However, the constructs are more similar than different. In both the socioculturalist and framing camps is the central idea that the individual participating in the event interprets meaning. A monkey's bite can be interpreted in different ways, depending on whether the bitten monkey is framing the activity as a fight or play. Reading a passage of text can be interpreted in different ways, depending on whether the reader is relaxing, learning, or on "a sacred path to heaven."(pg. 232 of (Grossen and Perret-Clermont 1994)).

Despite this striking resemblance, the ongoing, nuanced, and explicit debate about whether or not these interpretations are context-dependent and fluid that some cognitive scientists (those who use the idea of framing) take on seems to not be taking place in the Gallimore camp. Certainly by the time that Stigler took up the notion of cultural scripts, the idea of context-dependency had disappeared from the scene without explanation of why.

I argue for bringing considerations of context-dependency into the construct of cultural scripts. I argue that the same kind of debate that utilizes the framing literature can apply to thinking about cultural scripts, and indeed, *must* apply in order to understand data like I have presented in this dissertation.

3. What this change might look like

Although there are various ways to reconceptualize cultural scripts, it should be noted that frames with epistemological (as well as behavioral, etc.) components strongly resemble cultural scripts. I argue therefore that a cultural script for school can be described as a framing -- a set of expectations and associated way of acting, all associated with a view of "what's going on here" -- with an epistemological component (e.g., an epistemological stance associated with those expectations). With that in mind, we might say that Louis (David Hammer et al. 2005) had *at least two* cultural scripts, and the experiences he called upon determined which one he activated. Alternatively, we could continue to highlight how cultural scripts differ across cultures by thinking of a cultural script as a frame with a particularly sociocultural origin.

C. Data from Gakugei further justifies this reconceptualization

The literature review section of this dissertation examines much data speaking to the context-dependency of student epistemology. However, this research cited has taken place in the field of sociology, cognitive science, and education research – mostly in America. A cross-cultural education researcher could ask what relevance such findings has for looking at differences in how different cultures engage with learning activities? My dissertation answers this call, reaching directly out to the cross-cultural education research community by implementing reformed American curriculum in Japan.

Stigler's conceptualization of cultural scripts as unitary would predict that students would be surprised by Tutorials and that the curriculum would violate their expectations of what physics learning is (namely, rote memorization). The students would either fail to adapt (and would just wait for the answers to the worksheets from the instructor) or would undergo a grieving process in their adjustment (like Chappell's students).

This hypothesis would by no means be unreasonable. It is not the case that the curriculum used was so accommodating that no student could possibly resist it. Although "grieving" might not be a common reaction, it is in fact not uncommon for Western students to resist Tutorials and similar curricula (Cruz et al. 2010; Mauk and Hingley 2005; Finkelstein and Pollock 2005; Villasenor and Etkina 2007). Redish was called into the Chair's office as a result of one student's parents complaining about the class. (Edward F. Redish and Hammer 2009) This resistance is in total accord with Stigler's account of unitary scripts. Students come from a culture where physics is taught didactically, and they come to believe that it should be that way. When Tutorials force students into a learning environment inconsistent with this, there is sometimes tension. The students at Gakugei were coming from similar learning experiences as these American counterparts. In both high school and the prior year's college physics course, the students had learned physics by absorbing lectures and doing drills.

In this dissertation, I have shown that although this first prediction (students being surprised) is correct, the second (students failing to adapt) is not.

D. Students changed even when I wasn't there to guide

It was suggested by some that perhaps the reason why Physics Exercises was able to so seamlessly introduce Open Source Tutorials to students was because I was there orchestrating the implementation. I had taught OSTs numerous times and had even led TA training at the University of Maryland. Without my presence there, an alternative prediction that Stigler might have made would be that the Japanese educators would use the new curriculum in a superficial way without being true to the spirit of the curriculum. Goertzen found this to be a problem with TA's at the University of Maryland for example. (Goertzen 2010)

It is impossible to say what would have happened had I not been present for that initial implementation. However, it is noteworthy that, even with new TA's the following year who were never trained by me, the class was just as successful and well-received by students. In other words, it was not the case that students fought against the new style of teaching and the TA's the first semester were only able to overcome that resistance with my backing. It was sufficiently easy for the students to learn in this way that the class was able to stand independent of any active influence from me.

E. Why students say they were able to adapt

Informed by the research of Stigler and others, we undertook this research endeavor under the hypothesis that students would have had experiences in primary school that would play a role in how they responded to the new style of learning physics. For that reason, interviews were designed in part with the goal of getting information about students' primary school experiences. Prompts were also built in to see how readily students would see similarity between Tutorials and their primary school learning.

Unsurprisingly, these interviews showed more student connections between Physics Exercises and primary school than anything else they had experienced.

At this point, it would be easy to challenge that my research findings are skewed.

In my defense, we designed the interview protocols intentionally to begin as open-ended as possible and only become narrowly focused on Tutorial-primary school connections as a last resort. In this dissertation, I have been careful to separately describe how many students made these connections at which level of pointedness in the interview. Although there were interviews that reached the point of students saying "Uh, yeah I guess" when asked if Physics Exercises is similar to primary school, a far larger number of students provided such a response much more freely.

That being said, I generally agree with the criticism. Had the interviews included more probes into experiences that the students had had interacting with small children, it is likely that they would have found more connections between Physics Exercises and those interactions with children.

I do not think that the Gakugei students walk around thinking consciously about how Physics Exercises is similar to primary school. I think the connection was something that was drawn out in the context of the interview. But the fact that it was so relatively easy for so many students to draw out this connection is evidence that the connection was there.

And, again, I do not doubt that there are other things that would likely remind the students of Physics Exercises in different contexts. For that matter, I do not doubt that there are likely other factors responsible for the student ease of accepting the new style of learning physics. The three factors that I identified in this dissertation are not claimed to be the only factors. It is claimed that seeing the similarity of Physics Exercises to primary school was *one* factor, however. Although it was not true for all students, data supports the idea that, for a significant fraction of the students, elementary school experience tied closely in their minds to what they experienced in Tutorials.

More importantly, whatever the factors at play, my chief argument – that students were fluid in their epistemology – remains intact.

F. The Gakugei sort of fluidity has already been documented by education researchers

Although we were originally hypothesizing that we would see moment-to-moment shifts in student epistemology, I was surprised to find it stable: students seemed to consistently act as though they believed physics knowledge to be something that is personally constructed and where one's own ideas and experiences are relevant. Observations suggest that the shift was basically a one-time ordeal - students shifted from one epistemological stance to another in a very short amount of time, at the very beginning of the course.

This kind of shift is very similar to what happened to Louis. (David Hammer et al. 2005) Hammer's advice of "When you study, try to explain it to a ten-year old" acted as a trigger for Louis to shift from a view of physics knowledge being something to be memorized from flash cards to a view of it being useful to build on what you already know. In much the same way, Gakugei students seeing the similarity of the Physics Exercises curriculum to their primary school learning served as a trigger to shift their epistemology.

1. What would an attempt to describe the Gakugei phenomenon with a unitary framework look like?

It is not the case that unitary frameworks cannot explain the kind of shifting observed in Louis and at Gakugei. However, such frameworks were not designed to explain fluid phenomena, and they become cumbersome when applied to such cases.

In many ways, it seems as though the Gakugei students transferred something they had learned previously in elementary school into their Physics Exercises classroom. Hammer described how a unitary framework would discuss transfer in the case of Louis, which I am arguing is analogous to what happened at Gakugei. Just as the Gakugei students may have transferred their epistemology from their primary school days, so Louis might have transferred his epistemological frame from his experiences being a tutor and an older brother.

Whether analyzed from a unitary perspective or a manifold one, a simple story of "the TGU students have a belief about the role of knowledge in physics class" clearly cannot explain the data that I have shown in this dissertation. A more sophisticated, but still unitary, story of transfer could do the job, however. In more detail, perhaps something like this could begin the explanation:

> *Students at Gakugei were raised in a culture that emphasizes constructivist experiences in elementary and, to a degree, middle school as well. Hence, they have a cultural script for elementary (and perhaps some middle school) classes. They will think for themselves, make connections between the course material and their own ideas, and discuss their solutions with their classmates. The teacher will serve as a facilitator of discussions and, when needed, ultimate source of knowledge. Simultaneously, Gakugei students were raised in a culture that emphasizes preparation for entrance exams for college via rote learning in high school. Thus, they have a cultural script for high school classes. They will write down what the teacher says and writes on the board, will ask any questions after class, and will memorize the material. Whether the content makes sense or is personally meaningful is secondary in importance.*

Note that it is no more problematic to have a script for elementary school and a script for high school than it is to have a script for family dinner and a script for a fast food restaurant.

The story necessarily becomes more complicated once we realize that Physics Exercises *surprised* students, however. The Gakugei students were raised in a culture where physics is thought to be difficult, formal, stiff, and full of difficult mathematical questions. Many of them, after a semester in high school, decided it was not for them and wanted to avoid it as much as possible. Many of the Gakugei students who did take a second semester of physics in high school found it to be similar to the first. Almost all students took physics at Gakugei prior to Physics Exercises, and almost all students asked reported that it had been very similar to their high school physics classes, very similar to what they had been expecting. There is NOTHING in their culture that would support them having the idea that Physics Exercises would be anything different from their prior physics experiences. And, indeed, they reported that the class surprised them, that it violated their expectations. How could a framework of unitary epistemologies explain how, nevertheless, Gakugei students were able to adapt so quickly and easily to this radically different style of physics class? How can it be that the students' script of what it means to "learn physics" or even "learn physics at Gakugei" could have undergone a Piagetian process of accommodation in such a short time span? Perhaps something like this:

> *Gakugei students (and presumably other Japanese college students) continue to carry with them both their elementary school script and their high school scripts regarding "what learning in school should look like." Perhaps they are able to utilize either script, when appropriate, in any given classroom.*

2. Why such an explanation fails

The challenge that one can raise to this, however, is that, what's to say that they only have two scripts? Surely they have had experiences not only of utilizing their own ideas to solve challenging problems and passively listening to the teacher. Many Gakugei students reported prior academic experiences of looking up information in outside references, doing hands-on activities, and going on field trips.

Would it not be reasonable to think that, given proper scaffolding, they could apply those other "scripts about school learning" to affect their specific attitude about physics? Is it not likely that, in other classrooms, those experiences could be tapped into to leave students with an impression that physics is about getting knowledge from the authority of the research community? That physics is about doing experiments and recording the results? That physics is about exploring the world around you? Or some combination of these things?

We have embarked upon a slippery slope; we have begun to conceptualize previous experiences not as a concert of influences leading to a single attitude, but rather as creators of myriad lenses with which a student can view his experience (of, for example learning physics). We are noting that these lenses can be exchanged in a very short time span. We have inadvertently slipped into the world of manifold epistemologies. This conclusion is similar to that reached by Louca et al. (Louca et al. 2004) when considering how a beliefs advocate could respond to such findings that subjects have variable epistemology across contexts within a given discipline:

> *"… the beliefs advocate might say that beliefs can vary, not only between disciplines but also between different contexts within a given discipline.*

This line of reasoning is consistent with the resources framework, and we need to emphasize its implications: If a student can have three or four contradictory context-dependent beliefs about the structure of physics knowledge, for example, then a "belief" we attribute in one context would not necessarily apply in another. Nor would we expect students in a given context to be articulately aware of their beliefs that apply in other contexts. In effect, this response is to adopt a resources framework, except for the terminology."

Again, regarding the success of Miss Kagey's cookie intervention:

> *"A beliefs advocate could frame the teacher's cookie intervention as helping students 'remember' their more sophisticated epistemological beliefs about the mechanistic nature of knowledge, in which case students' subsequent explanations could become more sophisticated. But this line of reasoning, relying on the coexistence of teleological and mechanistic epistemological beliefs that are remembered or forgotten depending on context, fits more naturally into a resources framework. "*

And, without going down the path of accepting that student attitudes towards physics were fluid (in the sense of taking the shape of the context container they inhabit), we cannot explain Gakugei students' readiness to accept a curriculum that so dramatically violated their expectations of what physics is and how it is meant to be learned. A manifold epistemologies model, on the other hand, can do this work.

A researcher using a traditional unitary epistemology lens might give students a survey, prior to entering Physics Exercises, asking them questions such as "What do you think is the best way to learn physics?" and expect those students, upon entering Physics Exercises, to flounder and fail to participate in the "Tutorial game". It might be expected that they would react as the children in the 4th grade math class of Stigler's colleague. However, using a manifold epistemology framework, we can explain that students had not one way of framing their physics class, but at least two: they were able to draw upon the frame previously constructed (for example, in elementary school) that it is appropriate to use your own ideas and experiences to make sense of material learned during school. We have seen at the University of Maryland and other institutions that, given sufficient support, students can be led to frame the activity of participating in a physics classroom as a time to sense make. That is, the common stance of "this class is going to be about sitting quietly and taking notes to memorize" is not a rigid one.

G. Summary of the main argument

The way that Stigler and others use the construct of cultural scripts would lead to a prediction that the students entering the Physics Exercises classroom would have a difficult time adjusting. A survey, like those used by Stigler and others to determine student beliefs, might be given to the Japanese students prior to their entering the classroom, and it would code them as believing that learning physics means sitting in front of the lecturer and absorbing that authoritative knowledge. This would be part of their cultural script. Then, in the classroom, the students and curriculum would not have the same cultural script in mind, and the class would not progress as smoothly.(J.W. Stigler and Hiebert 1998)

In this dissertation, however, I have shown that although Gakugei students had their expectations violated, there was no resistance to the new approach. I have shown that the predictions of unitary scripts would be incorrect, and so I have shown the limitation of a unitary view of cultural scripts.

This dissertation identified three factors that may have served as important scaffolds for the Gakugei students shifting from one epistemology of what learning in the physics classroom entails to an alternative framing. In identifying these plausible scaffolds and, more generally, documenting the readiness with which students shifted their expectations in the context of these scaffolds, this dissertation thus justifies the expansion of frameworks of manifold epistemologies into the field of cross-cultural education research.

One way to do this is to reconceptualize cultural scripts. If we conceptualize scripts as something that a student can have in manifold, then we can say that students had both a high school and a primary school script of physics learning. If such a modification is not acceptable, then I argue that the cross-cultural education research field should adopt a different framework other than cultural scripts. In any case, my argument is that **cross-cultural education researchers should (i) expect a student's beliefs to vary across contexts and (ii) not be so quick to label a population of students as having *a* belief.**

H. Could a manifold framework help us understand other data from the cross-cultural education research field?

This is not the first cross-cultural research study to discover complex student attitudes. In addition to the Amit and Fried studies described in the Literature Review, the ROSE survey has also found complex results. For example, although Japanese girls surveyed were generally not interested in science and technology, they were interested in learning about the physics of cell phones. (Ogawa and Shimode 2004) In light of this complex data, it is a wonder that researchers have persisted in attributing to students unitarity, as opposed to treating their interests and attitudes as context-dependent.

Surveys like the ROSE result in a picture of students carrying around an attitude towards science such that they are interested if the topic is cell phone physics but not interested otherwise (below figure 11, on the left).

The argument that I have laid out in this dissertation paves the way for considering a framework where the student's interest or lack thereof is something that can be constructed or destructed in the moment by putting together smaller cognitive pieces (figure 11, right). Surely these girls will not be interested in all lessons addressing the physics of cell phones, and there are likely other areas that would interest them as well. It is intuitive that their interest would vary from day to day by what constraints are placed on them by other classes, how much sleep they got the previous night, etc. Treating student attitudes as though they are stable objects, however, ignores such variability.

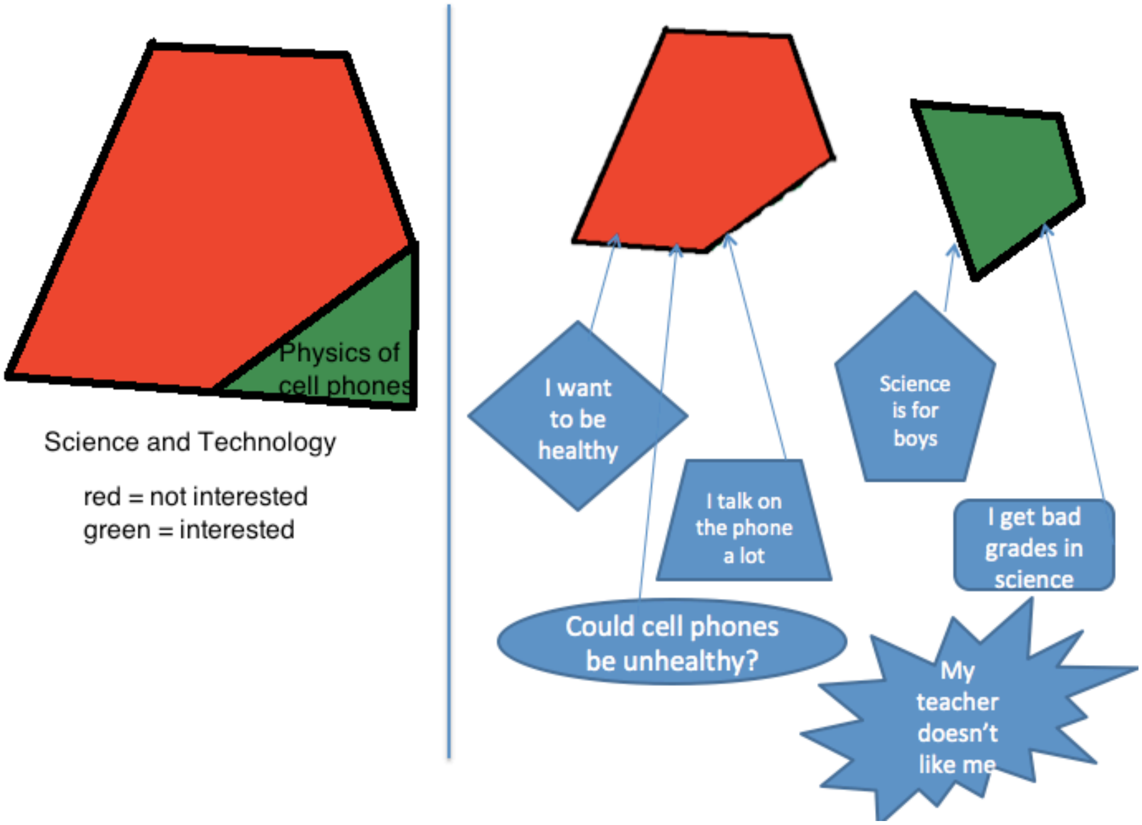


Figure 11. (Left): a unitary account of how, overall, a student is not interested in science and technology, but is interested in a small facet of it. (Right): a manifold lens can account for the same phenomena with more versatility.

Similarly, consider the findings of Amit and Fried (Amit and Fried 2005) regarding the complex relationships students have with authoritative figures. I argue that it is possible that this hierarchy of conditions that they found might not hold in contexts that they did not observe, for example, if the class would be taught in a novel way. One can think of students as carrying a complex hierarchical attitude about mathematical authority, such that the guidance of the teacher is sought when certain conditions are met (figure 12). After a point, however, it may become both more elegant (D. M. Hammer and Elby 2002) and accurate to utilize a framework where a student's notion of mathematical authority is one that is determined in the moment by activation of smaller cognitive elements that include, but need not at all be limited to, proximity of the teacher and how difficult the question is. (figure 13)

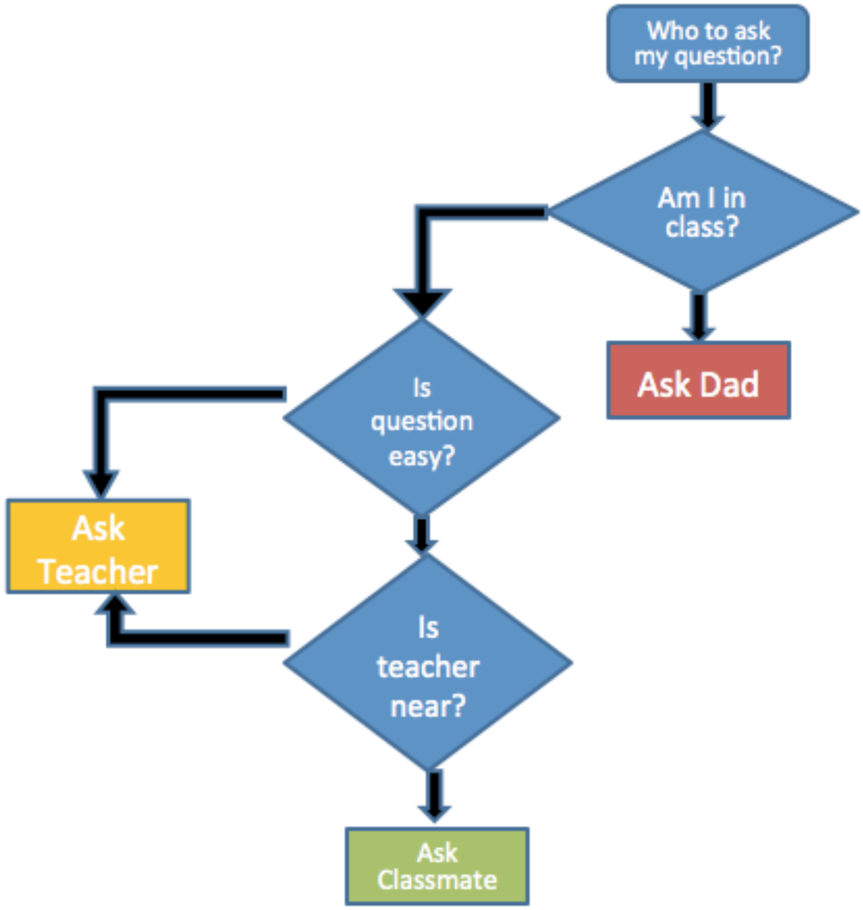


Figure 12. A complicated unitary attitude about who has authority in mathematics

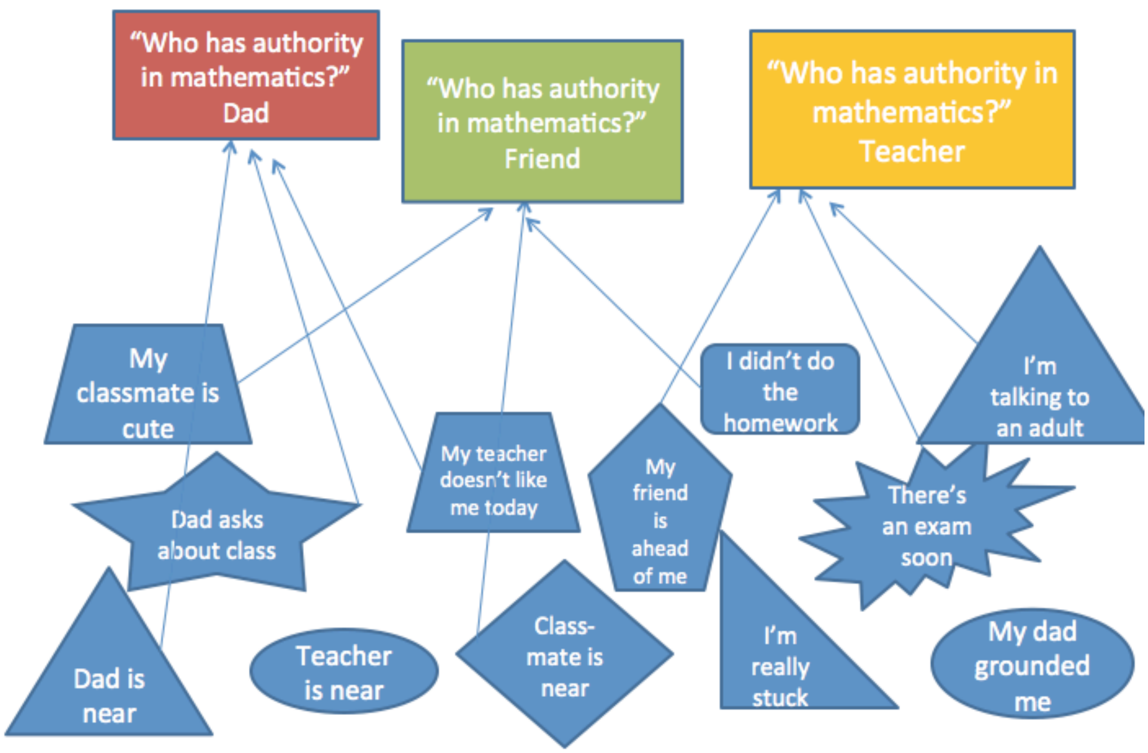


Figure 13. A manifold lens would see a student's notion of mathematical authority being determined in the moment by coherent activation of smaller cognitive elements.

Amit and Fried provided for the most part a phenomenological account: they did not comment on the fluidity of student beliefs. They did not make any claims or suggest that students have a rigid belief system, but they also did not explicitly describe beliefs as being fluid. Since I do not have their data, I will not attempt to analyze it, with a resources framework or otherwise. However, I encourage them to consider a manifold lens of manifold in looking at their data themselves. It is likely that there are some scaffolds provided by the classroom they studied that supported the epistemologies observed in the students.

I. The second contribution of my dissertation: How to learn from foreign classrooms

My main point in this dissertation is that students are more fluid in their beliefs than they are often credited for and so it's premature to restrict curriculum based on supposed "cultural scripts". This may seem to stand against the work and advice that Stigler, Hiebert, and others have offered.

In actuality, I am in full support of an important idea of Stigler's and I wish to repeat his sentiment of warning: "don't expect that taking a feature that works in a successful classroom and plugging it into your own classroom will make your classroom more successful. These features act together in concert – you must look at the level of the system." Or, as Biggs put it:

> *"In this ['pedagogical flow' of a country's schools], based on mutual interaction between all components, one factor, such as class size, cannot be isolated from the other components and be expected to work in a different system the same way as it works in its own… What is true of the cuddly English bunny when transported to Australia, where it wreaked havoc, applies to education ecosystems."(Biggs 1998)*

I do not wish for this sentiment to get lost; in fact, I wish to build on this sentiment to propose an alternative method for teachers to gain insight from foreign classrooms.

1. A popular suggestion of what teachers should do

Before I present my own proposal of how to productively gain insight from foreign lessons, let me discuss what Stigler and other cross-cultural education researchers have advocated.

Generally speaking, the cross-cultural education community recommends proceeding cautiously and starting small with education reforms. Levin and O'Donnell concluded "When it comes to recommending or prescribing educational, clinical, and social interventions based on 'research,' standards of evidence credibility must occupy a position of preeminence."(pg. 67 of(Levin and O'Donnell 1999)) The authors described such credibility coming about from an education knowledge base and recognized that researchers must first agree upon what kind of research can produce knowledge that will be usable for the large-scale reform desired.

Hiebert et al considered what such a knowledge base could look like and how it could be created. The authors described how results of crop yields from experimental corn fields are recorded in a database that is available to other farmers who can then decide whether they will similarly try the innovation or not, and who then in turn add their results to the database. They recommended collaboration between researchers and educators where sometimes teachers try out practices implemented by colleagues, and sometimes they try ideas generated by researchers. (Hiebert, Gallimore, and Stigler 2002) Stigler and Thompson, building off this idea, anticipated that researchers will play a larger role in suggesting innovations during the first stage of the collaboration, but that it is teachers "who must eventually be the ones to figure out how to adapt a new idea to the particularities of the classroom and to the social and policy contexts that have so much impact on education processes." (James W. Stigler and Thompson 2009)

This pedagogical knowledge created in concert between researchers and educators would need to be shareable with others in the field. (James W. Stigler and Thompson 2009) The collective knowledge could then be passed on to the next generation of teachers via professional development that provides educators "a repertoire of strategies and knowledge that will enable them to more effectively respond [to the challenges of the classroom]."(McKnight and others 1987)

But what is the starting point for such progressions that can lead to this education knowledge base? From where do teachers and educators, looking at better-performing foreign classrooms, draw their inspiration for new ideas? As the default, they would be drawn from seemingly superficial features of successful classrooms. Although a methodology of "copy and paste" may serve as a seed from which a tree of communal education knowledge can grow, it is a higher risk for those seedling classrooms. For the sake of the students like those in the 4th grade math class of Stigler's colleague, and for the sake of the tree growing from unstable seeds, it would be nice if there were a safer, more insightful starting point than this "copy and paste" methodology.

2. My proposal for what teachers should do

My contribution through this dissertation is a suggestion of where to get that initial inspiration for those first reform attempts in the classroom. Rather than looking and seeing "oh, they make students talk to each other in groups, I'll try that", instead look at the overall interaction that is going on and find underlying mechanisms of learning. Then, bring about these mechanisms in your own classroom. Bear in mind that the specific incarnation of these mechanisms may look very different than the original instantiation. My dissertation uncovered three mechanisms that are probable explanations for why students quickly and stably approached learning in the new desired style. Students

- saw the learning experience as similar to a prior one
- easily saw the relevance of the class to their future goals
- received consistent messages from the educators and curriculum on how they were to go about learning the material.

It follows, then, that a teacher wanting to reproduce these mechanisms in her own classroom should

- Get students to connect curriculum to prior experiences
- Make class relevant to future goals of students
- Have a consistent message coming from the educators and curriculum

In finding these three underlying mechanisms of Physics Exercises's success, my dissertation, then, serves as an example of the new approach I propose.

a) Two caveats to this approach

Often, as was the case at Gakugei, these mechanisms uncovered will be familiar ones. It is not surprising that a consistent pedagogical message or connections found between the curriculum and future goals helped the class progress effectively. However, sometimes surprising features will surface as well. It is not surprising that having an experience similar to the unusual class format made it easier for students to adjust; It *was* surprising to hear students freely offer that even an experience as distant as elementary school made it easy for them to accept the reformed physics class.

Admittedly, the approach that I have demonstrated is not always possible. For reasons of either financial constraints or other commitments (like needing to teach one's own class), it is not always possible to duck out and immerse oneself in observations about another classroom for six months. But where such opportunities do present themselves, I advocate looking at depth more than width. If it becomes a choice of surveying many classrooms superficially or a few successful classrooms carefully, I propose the latter. Furthermore, I propose, in general, looking at such classrooms from a perspective not of "what is it that is different in this classroom that seems successful?" but rather "how can I describe the overall interaction taking place in this classroom? How can I recreate that in my own classroom?" Rather than trying to copy surface features of having TA's that are in PER, hands-on activities, very brief lectures, or any of the myriad other differences that Physics Exercises might have from your own classroom, I advocate looking at what these pieces did collectively, as an assembled interaction.

b) This proposal is really not novel

This contribution from my dissertation is really not very interesting to science education researchers, as it is already well-known that if one is to try to transfer pedagogy from one context to another that one must look at the deep structure of what is really going on in the classroom. In fact, Biggs pointed out that this has been familiar to cross-cultural researchers since Triandis's work in 1971. (Biggs 1998) He described the "emic-etic issue" and described emic factors as being "culturally evolved techniques and practices, generalizable within the given system" and etic factors as being "universals, such as learning processes." Identifying the system at a higher level of abstraction corresponds to identifying etic factors. He concluded that "Level 1 [the lowest level of abstraction] components cannot be interchanged from one system to another; their meaning derives from how they function within their given system" but that "cross-cultural innovations [like PBL, coming from Canada originally] work because the focus is on engaging the appropriate level of learning process, not on importing the technique per se."(Biggs 1998)

This dissertation thus brings nothing new to this theoretical conversation; the true intellectual contribution is to the unitary/ manifold discussion of student beliefs. Nevertheless, with this dissertation I illustrate previously known techniques and insights so as to demonstrate the value in foreign case studies like that of Physics Exercises. I am also demonstrating these insights to reinforce the message to teachers that they shouldn't import a "bunny" into their classroom, expecting it to function as it did in the Japanese counterpart.

Just as Stigler, Gallimore, and many others do, I promote thinking of the classroom as a complex system that is more than the sum of the parts. I think that such systems should be studied in all their complexity as a means of gaining inspiration from successful Japanese (and other!) classrooms.

J. Popular criticism of my work

1. Does elementary school in Japan really have more group discussion based on student ideas than in America?

As discussed in the literature review, findings by Stigler and others indicate that Japanese primary schools, particularly in math and science classes, have more time devoted to considering student ideas and working in groups. However, this finding is not consistent with results found from Tosa's studies of inquiry in science classrooms.

> *"group work is generally incorporated in about the same frequency in US and Japanese science lessons at the elementary level. In fact, more group discussion based on student own ideas happens in the US lessons. The difference is the rigorousness of the content and the process of reaching the scientific concepts under the discussion." (Tosa, personal e-mail)*

Tosa cited Roth et al. 2006 for showing that TIMSS 1999 revealed that only 17% of US 8th grade science lessons used inquiry whereas 57% of Japanese lessons did.(Tosa 2011) Critically, however, Tosa found that American teachers who claimed to use inquiry exhibited greater student self-directedness than in Japanese classrooms that reported using inquiry.

"Students wrote down their explanations… based on the result they got in the experiment… In contrast, in one of the Japanese lessons… [the teacher] simply stated the correct answer… [and] proceeded to follow textbook and lesson material rather than attempting to explain the different answers that were presented by students."(Tosa 2011)

However, US teachers did not connect student explanations to scientific explanations; in fact, "scientific concepts under the classroom discussion were not clearly identified in many of the U.S. lessons." This is perhaps consistent with the findings of Roth and Garnier (Roth and Garnier 2006) that although US 8th grade science classrooms did have hands-on opportunities, US science teachers "did not typically use these various activities to support the development of content ideas in ways that were coherent and challenging." (Roth and Garnier 2006) In other words, it could be that the reason Japanese lessons have been reported as having more inquiry was because the concept of "inquiry" in the minds of American teachers "did not count" on the criteria used by Roth et al.

In another publication, Tosa reported that, of 26 Japanese primary school science lessons, 20 included group activities and 7 included student-to-student discussions. Of 19 US primary school science lessons, 13 included group discussion and 10 included student-to-student discussion.(Sachiko Tosa)

On my end, I can only acknowledge that there are mixed findings regarding differences in educational experiences between American and Japanese students. Nevertheless, regarding this dissertation, I will point out that, regardless of whether there is more or less group work in elementary schools in America, and, in fact, regardless of whether or not there is much group work in elementary schools in Japan, the students that I interviewed and observed at Gakugei recalled having done group work in elementary school, and there is evidence that, for many, these experiences helped them in Physics Exercises.

2. Maybe Japanese students are different from American students in that they don't resist unfamiliar curriculum?

The argument that I have made in this dissertation is that Japanese students (like American students and everyone else) form their perceptions of the world from their past experiences, and these perceptions play an important world in how they react to new experiences. The point where my argument diverges from Stigler's, however, is in saying that these experiences don't leave students with a single concerted view on the way learning should take place. Rather, it leaves them with myriad lenses through which to interact with the classroom. One variant of the claim "Maybe Japanese are more receptive to new curriculum" (which is very similar to Kaede's sentiment about how Japanese are very flexible people) would be in complete accord with my argument: maybe Japanese have had more varied experiences in the past on which they can draw to not be in shock when something new happens (like an interactive physics class being introduced). I don't think there is strong data to support such a claim, so I will not address that here. I will only note that, if that were true, it could indeed lead to Japanese being more receptive of new curricula than American counterparts.

There are other flavors of this argument, however. "Maybe the Japanese students were resisting but were just too polite to show it?" This argument has been addressed in Chapter 5: if you are swallowing medicine just because you have to, your face is going to leave a hint of your discomfort. Even the TA's felt that students adapted quickly and smoothly.

One argument that has been laid out in literature is that CHC students are good at "cue-seeking"(Biggs 1998; Biggs 1994), which is quickly discerning what kind of game is being played in the classroom and then playing it themselves. This comes about from preparing for entrance exams. Hess and Azuma(Hess and Azuma 1991) have similarly argued that "adaptive dispositions" are brought about from key experiences in early childhood, including parents disciplining children by emphasizing empathy ("think about the pain the farmer who grew this carrot would feel if that carrot were not eaten"), and by early teaching practices including repetition and sticky-probing ("taking time on the same topic, looking at it from varied perspectives and in a variety of conceptual frameworks").

Note that this argument subtly differs from my own. I have argued that *sometimes* Japanese students think learning is memorizing from the teacher and *sometimes* they think learning means creating knowledge yourself from your own ideas and experiences. One contributor to this flexibility is having had previous experiences that are similar to either learning style such that the student can say "Oh, OK, this is kind of like primary school, where we … " The argument of Biggs, Hess, and Azuma, on the other hand, is that Japanese students are *always* adaptable in nature. They have a rigid unitary disposition that they acquire in their early years, and this allows them to "play the game without necessarily being corrupted by it."(Biggs 1994)

I think it is totally plausible that training in seeking cues is one reason why Gakugei students were able to respond as productively as they did to the Tutorials.[28] This does not, however, discredit the argument that I have made – that finding relevance in the curriculum to future goals, receiving a unified pedagogical message, and seeing similarity to a past experience – were also likely relevant features. Furthermore, since students reported that their image of physics and physics learning had changed as a result of the class, it does not seem likely that "they played the game without being corrupted by it".

Regarding my main point, which is that the idea of cultural scripts as it is used in the cross-cultural education community is over-simplified, the concept of cue-seeking

[28] Although, actually, there is some evidence to discredit this. TA's often complained that various parts of the tutorial worksheets would grab student attention and students would insist on continuing to work even when TA's instructed the students to move on. Student willingness to comply was also seen to be limited when students occasionally refused to stop their discussions even when Professor Uematsu resumed lecturing.

seems to be a challenge. "Perhaps students have a cultural script which says 'do whatever the teacher wants'." I argue that this is not a "cultural script" in the sense that it has been prevalently used. Whereas cultural scripts effectively includes the idea of "I have expectations about how this class should go that tells me when to speak and what role different types of knowledge play. If those expectations aren't met, there's going to be trouble," cue-seeking suggests "whatever the teacher tells me to do, I'll do, regardless of my expectations about what classroom learning looks like." In other words, cue-seeking is inherently too fluid to be the type of "cultural script" that is commonly described in cross-cultural education literature and that this dissertation argues against.

a) Evidence that Japanese students can resist reformed curriculum

Evidence that Japanese students can resist reformed curriculum is notably lacking. I asked my colleagues in physics education research in Japan if there is "some documentation of student complaints accompanying a teacher's impression that the class was not received well by students" but efforts were to no avail. Jun-ichiro Yasuda, who implemented Open Source Tutorials in his own classroom at Meijo University, replied: "I have looked for such documentation during this three years, but I can't find it... I think usually people want to write successful result in Japan." (personal correspondence, Oct. 10th, 2012)[29]

However, it is noteworthy that some of the students in Physics Exercises resisted the curriculum exactly as Stigler's anecdotal fourth graders did. This was reported by Shuji-TA (in chapter 5).

[29] There is, however, literature describing public resistance to new curriculum (specifically, the Integrated Curriculum and yutori education).(L. MacDonald 2005; L. MacDonald 2006; L. J. MacDonald 2006)

X. Conclusion

A. Methodological contribution: look for underlying mechanisms

Videos of classrooms in America and in Japan, like those in the TIMSS video studies, document salient differences between classrooms in different countries. Furthermore, standardized international exams have demonstrated Japanese superiority in diverse mathematics and science tests. It has been largely assumed by educators interested in getting "Japan-like" results themselves that it is these differences observed by video that, in some way or another, are responsible for the different outcomes. There have not been systematic studies in Japan showing that group work produces better results if everything else is kept constant; rather, it has been an educated guess that one characteristic is a causal reason for the other, that what is observed in the videos is actually leading to the differences in results.

Many have assumed that bits and pieces of these plausibly helping attributes can be imitated in American classrooms and that better student learning will result. Stigler and others have shown that this is not a reliable method for reforming curriculum, and they have argued against wide-spread reform based upon this approach. However, they are not, in principle, against trying out a feature observed in a video in an experimental classroom, like an early Iowa farmer trying out hybrid corn.

Because implementing such superficial features is unreliable even for a given class, I, on the other hand, recommend against even *testing* a feature seen in a video at the individual classroom level. Instead, in this dissertation, I demonstrate a method that I believe is more reliable. What may appear at first to be an isolated classroom characteristic is, I (and others) argue, a piece integrated into a whole. That piece has its own shape, and is restricted in what other pieces it can fit with. There are limitations in what other contexts it can suitably be used in. We cannot assume apriori that it can easily be tailored to different situations than that in which it was first found. But, if the dynamics of the classroom can be understood in a more abstract sense, then that abstraction can be more easily converted to new situations. Rather than copying and pasting superficial features of a classroom (such as what curriculum is used), I advocate discerning underlying mechanisms of learning in successful classrooms, and thinking how one can recreate those mechanisms at home.

B. The familiar experiences mechanism

Preliminary evidence suggests that an important reason why Tutorials were successful at Gakugei was that students were able to relate the class to prior experiences that they found to be similar. However, considering how students specifically mentioned primary school (instead of, for example, playing outside with their friends), it seems likely that the fact that these prior experiences occurred in academia contributed significantly to their ability to connect them to Tutorials.

It is premature to make a conclusion like "constructivist elementary schools lead to greater student adaptability to reformed physics curriculum in college." However, I think this dissertation can serve as motivation for future studies that will look at this idea more thoroughly, with controlled studies. Controlled, large-N studies may very well confirm that students are more likely to develop an expert epistemology about physics despite traditional learning in high school if they have constructivist elementary schools providing scaffolding for the shift. If they do, I think education policy makers in both America and Japan would be very interested.

However, the mechanism that I am identifying is not bound to this style of physics class. We might imagine that, if the goal was to have students buy in to a lecture-based class, then having primary school classes where students are working in groups would NOT help, and could, in fact, hinder a student from aptly keeping still and absorbing the teacher's knowledge. The point thus is not that the prior experiences were constructivist, but that they were similar to the class at hand.

I repeat that the mechanism is not even limited to prior experiences occurring in academia; the main point is that, for whatever reason, students were able to make connections between their new class and those prior experiences. At UMD and other schools, for example, educators have found that student buy-in to the new style of physics learning is assisted by explicitly telling students to imagine that they are not in school, that they are explaining to a child, for example, or "playing on the playground."

C. The main argument of this dissertation

Students at Gakugei entered with the typical view that learning physics means listening to and memorizing knowledge from the teacher's lecture and solving lots of problems by rote. However, they quickly changed their view to instead think that physics can and should be learned with reference to intuition and one's own experiences. They came to see the importance of conceptual reasoning, and of making sense of material for themselves. I argue that they were able to make and then maintain this shift because of scaffolds present in the course.

As mentioned above, one mechanism for the change was students seeing the class as similar to what they had previously experienced. I argue that this sense of familiarity acted as a trigger for their change. Once they shifted, being able to see the relevance of the learning style to their future goals motivated them to persevere in the style – this mechanism was a stabilizer of their new stance. Finally, an additional stabilizer came in the form of the TA's and curriculum delivering a relatively uniform epistemological message: instead of being told by the worksheets that it's important to refine their intuitions but being told by the TA's to disregard parts that ask about intuition, these students were consistently encouraged in their new epistemology.

Through scaffolds such as these, students at Gakugei, UMD, and elsewhere have changed their framing of the physics classroom. Although many students do go through a "grieving process" like Chappell described, many other students do not. Thus, although the student stance of "this class is going to be about sitting quietly and taking notes to memorize" may be commonly found and *may* be rigid, it is not necessarily so. This dissertation described three characteristics about a classroom environment that were quite plausibly consequential to students being able to easily shift their framing at Gakugei without significant resistance. In identifying these plausible scaffolds and, more generally, documenting the readiness with which students shifted their expectations in the context of these scaffolds, this dissertation thus justifies the expansion of frameworks of manifold epistemologies (where attitudes are fluid) into the field of cross-cultural education research.

XI. Future Research

This dissertation has focused on one school utilizing one reformed curriculum: Open Source Tutorials at Tokyo Gakugei University. I have argued that, in this case study, the students did not have rigid unitary cultural scripts dictating to them what kind of behavior is appropriate for learning. I have argued for some of the scaffolds that helped students change their approach as fluidly as they did (for example, that they had experienced similar learning in primary school). Candidates for future research questions that would be inspired from this finding could include:

- How fluid are students at changing their learning approach when given different types of reformed curriculum?
- How fluid are students at other schools in shifting their approach to learning when faced with Open Source Tutorials?
- For each of the two above, what mechanisms are at play when students shift their epistemology?

These lines of research would be a natural expansion from this N=1 study, and could uncover systematic trends in how students change their epistemology about physics learning.

These findings would also help confirm or refute the claims that I've made in this dissertation. For example, a popular alternative explanation for why students at Gakugei were able to adapt to the new learning style is that the educators interested in improved instruction methods, and that the students were pre-service teachers. Maybe it's really not about prior experiences in academia at all.

Although the data that I uncovered and presented in this dissertation suggests that this was not the case, one way to evaluate such a claim is to see if the familiarity mechanism is still a factor for student ease of adaptation at other schools, where the teachers and students are less interested in reformed pedagogy. To some degree, this has already been done, and it seems that students adapt easily whether they are pre-service teachers or not.

A. Japanese students adapt readily to the Tutorial-style of learning at other schools (Meijo and Fukui)

Following the semester that Open Source Tutorials were introduced to Gakugei University, Dr. Junichiro Yasuda, after observing the class and getting information from the TA's and Professor Uematsu, implemented Tutorials in his own classroom in the fall semester of 2011. The classes were not videotaped, because of concern that filming might make the students nervous. In a personal correspondence on November 14th, Dr. Yasuda wrote the following (in English):

> *At first, the students were nervous, since most of them were shy and were not used to discuss. However, in the 2nd or 3rd lessons, they became used to discuss and they looked so fun in the discussion… I think*

> *the students ENTERING Meijo (engineering class, advanced class) are not less open-minded about conversing with each other.* (comparing to TGU students)"

At the beginning and end of the class, Dr. Yasuda administered the FCI. He reported that although his class size was small, the FCI gain was quite high. (<g>=0.54 for N=10) In comparison, average <g> in Hake's study for traditional classes is 0.20. Generally, the only classes that show a <g> as high as 0.54 are very high impact classes such as extensive active engagement with a PER-based text or Workshop Physics. Professor Redish confessed to having not yet beaten a <g> of 0.50. At Gakugei, Professor Uematsu achieved a <g> of 0.24 on the 30-question FCI, and a <g> of 0.37 on a 15-question selection of the FCI that was covered by the class (the content of the other 15 questions was not addressed in Physics Exercises). (Uematsu 2011)

On a separate survey given at the end of class, Dr. Yasuda asked (on a Likert scale) the following questions (followed by the most common student response):

- In physics, "solving a problem" is basically finding the appropriate law or formula, substituting in numbers, and getting an answer. (I think so)
- I don't really think about connecting things occurring in the real world with physics laws. (I don't think so)
- How was the degree of difficulty in Physics Exercises? (Just right)
- Did you feel that Tutorial was important? (I felt that somewhat)
- Did you feel that Tutorial will be useful to you in the future? (I felt that somewhat)
- After taking Tutorial, do you feel that you have grown? (I felt that somewhat)
- Do you want your younger classmates to take Tutorial next year? (I do think that way somewhat)

Dr. Yasuda concluded (on January 23rd, 2012, in Japanese):

> *This means that also for students in the science and engineering department at a local private school, Tutorial was perhaps generally effective, was it not, I think… That they could experience discussion, it seems that there were a lot of students finding out the significance of scholarly activity coming from the perspective of understanding physics concepts.*

Dr. Yoshihide Yamada at Fukui University implemented Tutorials in Introductory Physics from the University of Washington with success. In a private e-mail sent on July 1st, 2012, he described a teacher-training course that he was team-teaching with his colleague Dr. Kyoko Ishii on rotation with five other instructors. During the weeks that Dr. Yamada and Dr. Ishii were co-teaching the course, they implemented a translated Tutorial on basic circuits. Although Dr. Yamada felt that there was not as much preparation for implementing the curriculum as he would have liked, he was nevertheless "surprised at the outcome." The following is from a private e-mail (in English):

They were so active that they could continue to talk 180 minutes. I could never imagine my students became so active. To tell the truth, I had been thinking that the outcome of Gakugei University, which you wrote in your article, was because it was Gakugei University - much higher GPA than Fukui... Now I can appreciate what you wrote in your article. Tutorial (or can I say "interactive-engagement technique"?) is great.

Dr. Ishii presented findings from the implementation at the World Conference on Physics Education 2012 in Turkey.

1. Investigating the factors at these other schools

a) We can look at what factors were present that may have led to the student gains.

I have shown in this dissertation that a significant number of students adapted readily to the new style of learning physics that they found through Tutorials. I have offered evidence that, for a significant number of these students, this adaptation was aided by three characteristics of the learning environment: that students found the new learning style to be similar to what they did in primary school, that the students were motivated to learn in this way because they saw the style as relevant to their future goals, and that they received consistent messages throughout the course about the appropriate way to learn the material.

Assuming that these factors did in fact help, one can ask "were these three scaffolds only effective because they were working in concert with each other? From the 24 students on the 2012 survey who reported a change in their physics epistemology, the majority of these students (13) were also classified as picking up on all three characteristics of the learning system. Ten of the remaining 11 students received two of the three mechanisms (for example, they saw the course as relevant for their futures and had past constructivist experiences). This suggests that the possibility that, without a sufficient number of factors present / picked up on by the student, change would not occur.

Along those lines, we can ask which factors resonate with which other factors? For example, if those students with the experiences they had in elementary school would not be planning on becoming elementary school teachers, would those primary school experiences still become helpful for adjusting to Tutorials?" Clearly, looking at other classrooms where not all three factors are present can help to answer this question.

From Meijo, for example, Dr. Yasuda informed me in a private e-mail (in English) on December 4th that

"I asked my students whether they remember they did group work in their elementary school. Among the 11 students, 3 students answered yes. And, though this is my impression, 2 of the 3 students are the most excellent students concerning with the discussion skill in my class."

Since Dr. Yasuda's students are not pre-service teachers, this small anecdotal experiment supports an argument that the "prior experiences" aspect need not also have the "future goals" aspect to become activated and contribute to student adjustment.

Similarly, there are undeniably other contributing factors that can help students adjust to an unusual physics classroom in addition to the three identified here. What else was present at Meijo that helped its students adjust, if only 3 students recalled group work in elementary school and none of the students are pre-service teachers?

b) And we can look at what factors were absent that might account for smaller gains

A similar question surfaces in the opposite direction when we observe that the evidence available actually suggests that Tutorials at Meijo may have been less effective than at Gakugei.

Dr. Yasuda scanned and sent the 10 survey responses that also included the questions (as suggested originally by me) "How would you answer if someone who doesn't really know physics asked you 'What is physics?' " and "Did Tutorial change your opinion regarding 'what is physics?' "

Whereas almost all of the 2011 Gakugei interviewees who were asked similar questions responded that they had changed their attitude about what physics is, and 24 out of 42 students on the 2012 survey responded that they had changed their attitudes towards physics, only two of the ten students at Meijo answered "yes", for reasons similar to students discussed at Gakugei. I do not deliberate on this data here because the Meijo students did not sign consent forms to have their data reported in publications.

It could be that students at Meijo did not change their approach to physics learning because, upon entering the class, they already had the views that the Gakugei students developed through Tutorials. However, there is data to suggest that students at Meijo may have resisted the new curriculum more than students at Gakugei did.

In correspondence with Professor Uematsu that Dr. Yasuda later shared with me (with Professor Uematsu's consent), there is data in the form of field notes from the first Meijo Tutorial. Immediately after the first Tutorial, Dr. Yasuda sent the following note on Oct. 6th, 2011 (in Japanese):

> *I was able to think that there appears to be a gap between groups that can discuss and groups that cannot. In groups with a lot of kids who originally have a bright personality, they were excitedly discussing while encouraging each other, but in groups that were not that way, they would solve the problems separately, and I could see that silence appeared to continue for a long time. Since it is still the first time, I hope that from here on it will go and improve…*

We took the FCI in the previous class. There are a lot of students with high scores, but there are variations. In the atmosphere that I saw today, I could think that students with a high score on the FCI appeared to have more active discussions. For students with low FCI scores, more than the discussion being skillful or poor, discussing was passive, and they could not discover the reason for the discussion– there were students who appeared that way.

My class is an advanced class and there are a lot of students who are skilled at solving calculation problems, but, unsurprisingly, that appeared to plague their heads in Tutorial's problems. I really felt the significance of doing Tutorial.

Tutorial 1 was divided between the first two weeks of class. After the second week, Dr. Yasuda reported on Oct. 13th (in Japanese):

Students in groups that are having active discussions are increasingly becoming skilled in discussion and I am nothing but happy to be hearing that, but students who are not able to participate in discussions in groups where discussions are stuck have dark expressions and I am thinking if there is not some way to help them.

Similar to the question of "what unique factors did Meijo and Fukui have that allowed students to adapt to the new class style?" is the question "what DIDN'T Meijo have that made Tutorials 'not work as well'?" In response to Dr. Yasuda's first e-mail, Professor Uematsu suggested that one difference might be the number of female students:

10/7/2011 (Professor Uematsu's response, in Japanese)

The relationship to the FCI [that students with high FCI scores appear to have more active discussions] is also really interesting, isn't it? Certainly I could feel that there was a trend for groups with students who do well to be more likely to have discussions that could be thought to "be meaningful". However, I get the feeling that the number of groups who were chatting quite happily "ah, isn't it? Like this isn't it?" about their differing ideas was not few. (If I look back at the videos Mike took, I also feel frustrated about why the discussions flowed the way they did - Students had been very close to the way to the right answers. However, only one or a few words of a member made the flow of conversation deflect and they missed the right way.) It's only an impression, but I feel like groups of girls in particular have a tendency to be chatting quite happily - there might be a gender difference.

Dr. Yasuda replied to this observation by pointing out that there is on average one girl in each group of four, but that, indeed, she is often a conversation leader for the group. It might be interesting to investigate the role of having more females in a classroom (for example) on ease with which students buy in to the new way of doing physics.

B. Other Interesting possibilities for future research

1. What was the process by which students negotiated a shared framing?

Conlin's dissertation research focused on how groups of college students, when faced with Open Source Tutorials for the first time, come to establish a shared understanding of the activity in which they are engaging. (Conlin 2012) Through such means as using humor to save the face of group members and mend strains on the shared framing, students are able to reach an agreement on the unspoken rules of what it is that they will be doing together for the next hour. Similar research has been done with Japanese students, for example, by Sawako Watanabe (Watanabe 1993), who observed the priority of establishing the relative hierarchical positions of the group members followed by turn-taking that somewhat follows that hierarchy (it is more common for the youngest member to give their opinion first, because they have the least respect to lose).

As described earlier in this dissertation, due to concerns about Japanese students being camera shy and equipment limitations on sound recording ability in the face of a room crammed full of students, there is very limited data on how Japanese students reached an agreement on the rules that would govern their interactions in the classroom. However, were it to be possible to have sufficient sound-recording abilities as early as the first moments that students form groups and are first given the worksheets, it would be fascinating to observe the period of adaptation in Japanese students to Tutorials to look at obstacles Japanese students run into and how quickly/ in what manner they are able to overcome those obstacles.

2. Going beyond plausibility that the three mechanisms actually helped students adapt.

This dissertation emphasized that Tutorials were successful in the sense that the Gakugei students were able to change their views about the nature of physics, and it showed three features of the learning environment that plausibly acted as mechanisms for this success. However, this remained a plausibility argument. In other words, I did not establish a strong case that the three characteristics of the learning environment in the Gakugei classroom were actually *causes* of the class's success.

It would be great to do more testing to try and observe these factors actively helping students. For example, it would be interesting to observe students in interviews or in the classroom who are stuck trying to remember some formal knowledge from a previous physics class or getting lost in mathematical equations, and telling that student "pretend like you are in elementary school. How would you go about this in that case?" and seeing that student shift to a sense-making approach. Although I unfortunately did not observe this in this study, there were not many times in which

I saw students stuck in this way, and such a pedagogical intervention was almost never used when students were stuck. To get at this, one could give students prompts that would be more likely to encourage them to seek memorized knowledge, and instructors could be advised to more readily use the prompt of "how would you explain it to an elementary school student?"

3. Going beyond plausibility about the student initial state

It would also be interesting to solidify the claims I made about the initial state of students when they entered Physics Exercises. In other words, an ethnographic study that begins at looking at students in their first year at Gakugei and follows them into and through Physics Exercises could create a stronger case that Tutorials really did change them. Alternatively, if students could be found to be fluctuating between the new attitude towards physics that they demonstrate and the old attitude towards physics that they claim to have had – that would also be evidence of their prior state being what they claim it to be.

4. Can facilitating Tutorials change the instructors themselves?

Lastly, this dissertation focused on the perspective of the students – how they changed as a result of the class. It would be interesting to look from the perspective of the educator - what effect does being a TA in Tutorial have on the *educator*? This would be a question of interest to those concerned with teacher training. In a personal correspondence from Professor Uematsu sent 2/8/2012 (in English):

> *It was great that TA's made much progress in the course of the class. They learned themselves that physics can make sense, actually saw the misconceptions which they learn in textbooks of PER and got better and better at facilitating students' discussion. We found Tutorial very effective also in education of graduate students in Gakugei.*

She later echoed this sentiment in a correspondence to Dr. Yasuda during the first few weeks of his Tutorial class at Meijo, where she commented that Gakugei TA's themselves shifted from treating physics as "plug and chug" to "sense-making". Evidence to support Professor Uematsu's claim is how Akiko-TA explained to the five observers that although there were some things that she hadn't liked about the experience, she had not previously realized that intuition can be used with physics, and she was glad to have been able to develop that attitude.

XII. Appendix

A. Methodology

1. Consent form

Informed consent. 2010-2011: Improving students' mathematical sense-making in engineering

This is a research project being conducted by Andrew Elby at the University of Maryland, College Park. We are inviting you to participate in this research project because you are a student taking undergraduate physics. The purpose of this research project is to study how students use mathematics in physics and engineering courses and to evaluate if changes to the prerequisite physics courses may help students use math more effectively in their later engineering courses.

The procedures involve allowing us to collect your grades, test scores and written coursework, answering written coursework, answering written survey questions, and (for those of you who volunteer) getting audio- or video-taped while solving problem sin class or during interviews outside of class.

The survey and interview will each take about an hour. The research will take place on the Tokyo Gakugei University campus for six months.

We will do our best to keep your personal information confidential. To help protect your confidentiality, copies of written work, grades, and scores, and videotapes and audiotapes will be stored in a locked filing cabinet in a locked office. Digitized data will be stored on an external hard drive in that cabinet. If we write a report or article about the research project, your identity will be protected to the maximum extent possible; all data will be reported anonymously. Videotapes will be shown only in meetings and publications aimed at education researchers. Your information may be shared with representatives of Tokyo Gakugei University or governmental authorities if you or someone else is in danger or if we are required to do so by law.

There may be some risks from participating in this research study, specifically the risk of embarrassment. Your survey/ interview responses or grades or written work could "leak" into the public sphere. Someone to whom we show the video may recognize you.
If you are in a physics course, you may benefit because your survey and interview responses could inform changes in how the course is taught.

Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop

participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify.
This research is being conducted by Andrew Elby at the University of Maryland, College Park. If you have any questions about the research study itself, please contact Andrew Elby at 2226 Benjamin Bldg., ., College Park, MD, 20742, USA 301-405-3161, elby@umd.edu or Hideo Nitta at 日本, 東京都小金井市貫井北町４丁目１－１；042-329-7111、hi_nitta@u-gakugei.ac.jp . If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742, USA; irb@deans.umd.edu; 301-405-0678.
This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.

Your signature indicates that:
You are at least 18 years of age:,
The research has been explained to you;
Your questions have been fully answered; and
You freely and voluntarily choose to participate in this research project.

Name of Subject
Signature of Subject
Date:

2. Speech before handing out consent forms

はじめまして、2 週間前に植松先生か紹介がありましたマイク・ハルです。

こちらは(name deleted)です。私の説明が適切かどうかを確認するために来ています。

私は、よりよい授業を実現するために、この授業を研究する研究メンバーの一人です。　研究は授業の録画を使います。　この同意書は研究用目的の録画についてのものです。　学芸大付属高校で、すでに録画の経験があると思います。　そのとき同意書にサインをした覚えがありますか。　アメリカの教育研究では倫理規制法があって、おそらく日本を含めてどの国よりも厳しくなっています。　この研究は、皆さんが高校で経験した録画を使った研究と類似したものですが、アメリカの団体が資金提供しているので、録画の用途の説明と、皆さんの同意が必要になります。

まず初めに、録画を見るのは、私たちのグループだけで、先生も TA も、他の誰もが見ることはありません。

つぎに、この録画は、学会発表と論文に使用できたらと考えています。宿題も使用するかもしれません。　この同意書はそういう約束事についてです。　この授業の成績が確定するまで、誰が同意したかどうかはわからないようになってい

ます。　そして、同意書にサインするかどうかは成績に影響しません。　物理教育研究の学会で使用される録画は、録画に出てくる学生の部分が修正されます。サインしなかった学生については、本人とはわからないように顔や声をぼかします。　サインした人学生については、別名に変えます。　学会で録画に映っているのがあなただと分かるようなことはほとんどありません。　絶対に YouTube には出てこないので安心してください。もう一度言いますが、録画の使用は学会に限定します。　授業が終わるまで録画はアメリカの研究グループ以外の人間が見ることは絶対ありません。　というわけで、サインをしても何らかの影響が及ぶことはありません。1　サインすることの本当の意味は、表情や声がはっきりしていると、学生の態度がよりはっきり分かるので、研究が格段にやりやすくなるということです。　今後の授業の改善のために、皆さんにサインをお願いします。

同意書には、インタビュー(面接)についても書かれてありますかそれは無視してください。サインした後で、気が変わったり、疑問に思うことがあれば、いつでも気軽に聞いてください。メールアドレスは mhull12@umd.edu です。　質問はありませんか。

3. Speech to invite students to participate in an interview

皆(mina)さん、こんにちは！
マイク・ハルです。
米国(beikoku)のメリーランド大学(daigaku)物理(butsuri)学科(gakka)の「物理(butsuri)教育(kyoiku)研究(kenkyu)」グループのメンバーです。
「物理教育の研究」では、どうすれば物理をより深(fuka)く理解(rikai)してもらえるか、どうすれば良い物理授業(jugyou)を実現できるかを研究(kenkyu)します。
「物理教育研究」では、授業で教え(oshie)られる様々(samazama)な物理の概念(gainen)、コンセプト、について、学生(gakusei)の皆(mina)さんがどのように理解(rikai)し、考えているかを調査(cho-sa)します。
そして、皆さんが、授業についてどのように考えているかを調べます。

今日(kyo)のお願い(onegai)は、インタビューに応募（Ōbo)して下さいと言うことです。皆さんが授業についてどう思っているか、そして、物理についてどう思っているかを聞かせてもらうために、個別(kobetsu)の、つまり 1(ichi)対(tai)1(ichi)の、インタビューをさせていただきたいのです。
このインタビューは、日本語(nihongo)で言えば面接(mensetsu)ですね。ただし、この面接は就職(syusyoku)活動(katsudo)などの面接とは違(chiga)って、皆さんをテストするものではありません。試験(shiken)ではないのです。このインタビューは、皆さんが考えていること、思(omo)っていることを率直(sottyoku)に聞かせてもらうことが目的です。
　私が訪ねたいことは、授業(jugyo-)についてどのように考えているか、物理一般（ippan）についてどう考えているか、ということです。そして私の希望(kibou)としては、皆さん全員とインタビューさせていただきたいのです。

このインタビューでは、私は、学生さんが宿題(syukudai)や試験(shiken)にどのように取り組んでいるのか聞かせてもらいます。また、自分の勉学(bengaku)の中で物理や数学(suugaku)がどんな風(fuu)に役立(yakuda)っているのかとか、そのようなことを聞かせてもらうつもりです。

インタビューはビデオに録画(rokuga)させてもらいます。ただし、授業のビデオと同じ(onaji)で、このビデオは、この科目(kamoku)の成績(seiseki)をつける人々(hitobito)には見せません。だから、インタビューで何を言おうが成績には全く(mattaku)関係（kankei）しません。

ビデオは私と私の共同(kyodo)研究者(kenkyusya)が見ます。そして、この学期が終わった後で、ビデオの一部(ichibu)を「物理教育研究」の研究会（kenkyuukai）や学会（gakkai）で見せる可能性(kanousei)があります。

インタビューは一人(hitori)二回(nikai)までできます。

一回(ikkai)のインタビューは 1 時間(jikan)です。そしてこの一時間に対する謝礼(syarei)は二千円(nisen’en)です。

私のこれまでの経験(keiken)では、このインタビューを受けることで学生さんは物理が少し良くわかるようになります。そして、学生さんはたいていこのインタビューを楽しみ(tanoshimi)ます。それは、自分の言いたいことを言うことができ、それを相手(aite)が熱心(nessin)に聞いてくれるからです。

皆さんはこのインタビューに応募(oubo)する義務(gimu)はありません。応募しないことによって不利(furi)になることは全く(mattaku)ありません。講義(kougi)をされる(植松 uematsu)先生も、TA（ティーエー）さん達も、誰(dare)が応募したのか、応募しなかったのか、全く知(shi)らされません。だから、成績には全く影響(eikyou)がないのです。

皆さんの中には、わけがあってインタビューを受けたくない人もいるかも知れませんね。この中に有名(yuumei)なテレビ・タレントの人がいたら、仕事でないビデオを撮(to)らせるとマネージャー(manager)にしかられるかも知れないですね。

でも、本当にインタビューを受けたくない理由があるのでなければ、私としては、ぜひ、皆さんに応募していただきたいのです。
だって、物理について、授業(jugyo)について、言いたいことが言えて、それを熱心(nessin)に聞いてもらって、それで 2000 円もらえるのですよ！悪い話ではないでしょう？

そして、まじめな話、授業の内容(naiyo)にどう取り組んでいるか、また、物理一般についてどう思っているかについてのあなた方の意見は、日本の物理教育にとってとても役に立つ重要（juuyou）なことなのです。そして、その研究(kenkyu)結果(kekka)がこれからの物理教育をより良くする上でとても役に立つのです。

私たちはあなたがたが本当にどう考えているのか知りたいのです。あなた方のそれぞれがいろいろな考え(kangae)を持っているはずです。そして私たちはそれを知りたいのです。

私はできるだけたくさんの学生さんとインタビューをするつもりです。全部(zenbu)で何人(nannin)できるかまだわかりませんが、インタビューのための時間(jikan)枠(waku)はたっぷりあります。だからどうか応募(oubo)して下さい！

4. Technical details

a)

I offered 2,000 yen ($24 at the time) for about one hour of meeting with me.

b)

The reward that the survey validators received for their labor was 1,000 yen ($12) given to them by Miwa-TA[30] (all TA names are pseudonyms), and having their name entered twice into a 4,000 yen lottery that one student would win. I explained to them and the rest of the 2012 class that the first 50 participants in the survey would get 1,000 yen, and every participant would be entered into the lottery for 4,000 yen. I added the 1,000 yen reward as an extra incentive since virtually no students had voiced interest in participating in the survey. Prior to that, the 2011 class had been invited to partake in the survey for the reward of being entered into the 4,000 yen survey. Only two students responded, and they were at last e-mailed the survey to complete. Only one of the two did so, and he was entered into the 4,000 yen lottery, but was not rewarded 1,000 yen. Adding the 1,000 yen reward succeeded in getting a sufficient number of student responses.

c)

The morning of June 21st, Y asked if it would be possible for him to participate immediately, and he explained that he would be filling out the survey and taking part in the interview via his i-Phone. The survey was mailed to him (the final survey and draft 1 of the survey are available in the appendix), but he did not fill it out until that evening. Meanwhile, I Skyped K on his computer the evening of the 21st and had an interview consisting of him thinking out loud while he completed the survey and I took notes and followed along with the survey myself. Following the survey, I asked questions about his responses to the survey.

d)

Once the survey to be filled out by the first 50 students was completed but before it was sent out to the students, it was copied in Survey Monkey and modified slightly

[30] I wired the funds Miwa-TA would need to her bank account and e-mailed her the list of students, and gave them her contact information. She then arranged to compensate every student individually.

for the creation of the survey to be filled out by any students accessing the website later than the 50th student. Specifically, all mention of 1,000 yen was removed from this second survey, although the incentive of the 4,000 yen lottery was left in.

The survey for the first fifty students was opened and an e-mail collector created. The settings of this collector were as follows:

Recipients =me AND the school e-mail address of every student enrolled in Physics Exercises 2012 EXCEPT for the five survey validators

Message = Subject: Survey concerning Physics Exercises

Body: *Everyone,*

Hello! The survey has been completed, so, if you would, please fill it out starting now. From the people who fill it out, one person will be chosen by the lottery and will receive 4,000 yen. Furthermore, the first 50 students who fill out the survey for me will not only be entered in the lottery, but will absolutely receive 1,000 yen. (From the 51st participant, at the beginning of the survey, you will be informed that you will not receive 1,000 yen. If you still fill it out, you will still be entered into the 4,000 yen lottery.) The person chosen by the lottery will receive 4,000 yen from Professor Nitta, but the 50 people who fill out the survey early will receive 1,000 yen by post from me. (In the last question of the survey I ask your e-mail address. I will contact via that e-mail address and ask your mailing address. Once you tell me your address, I will mail 1,000 yen.)

The survey is here: [each student got a different link]

It should not take 30 minutes to fill out the survey. There is absolutely no obligation to fill out the survey, but it will really help the research, so it will also help the improvement of physics education. Therefore, everyone, I ask you to fill it out.

From Mike

In the event that you absolutely do not want to fill out the survey, please go here: [each student got a different link]

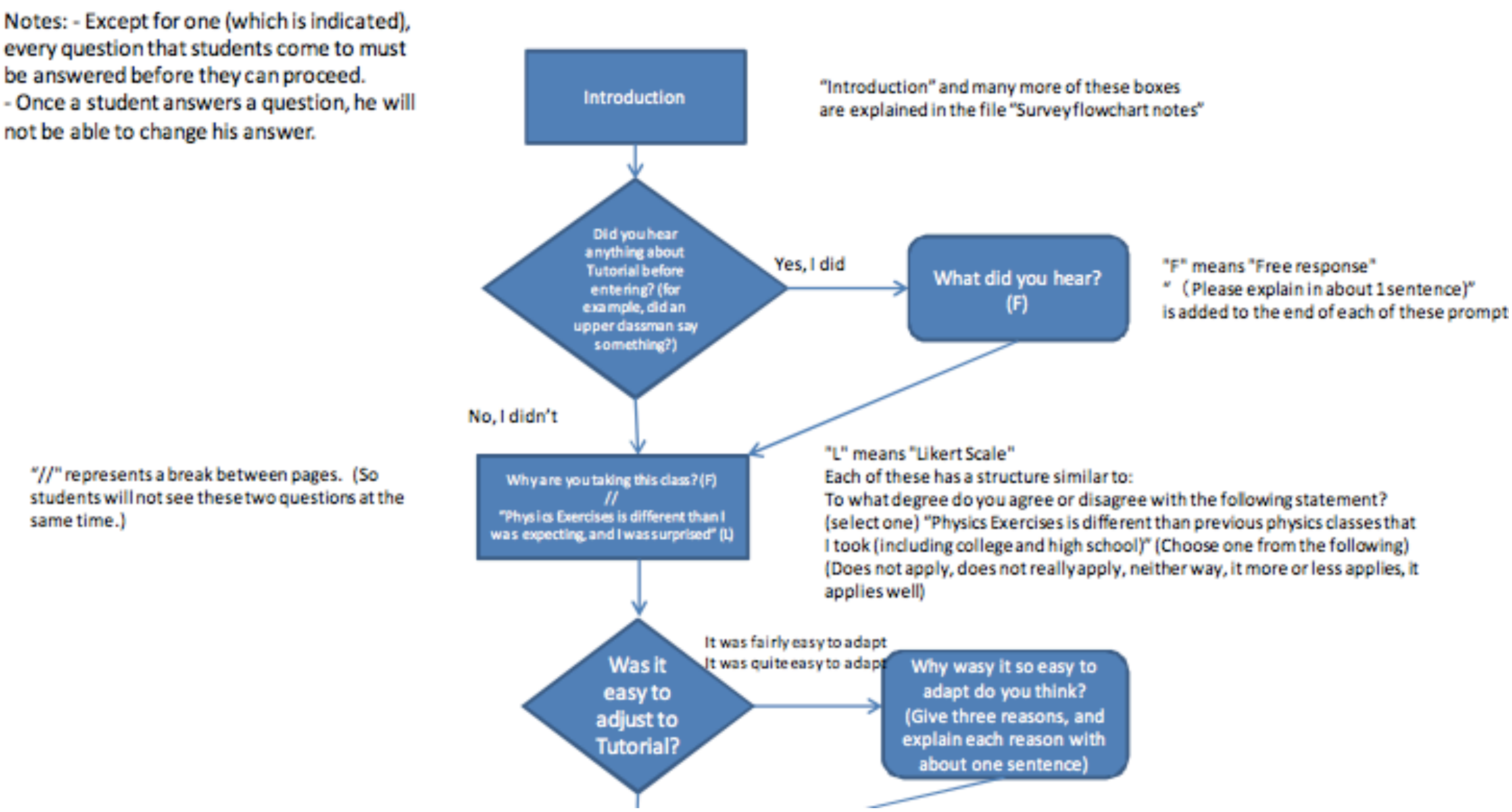
Change Settings: Allow responses to be edited = No

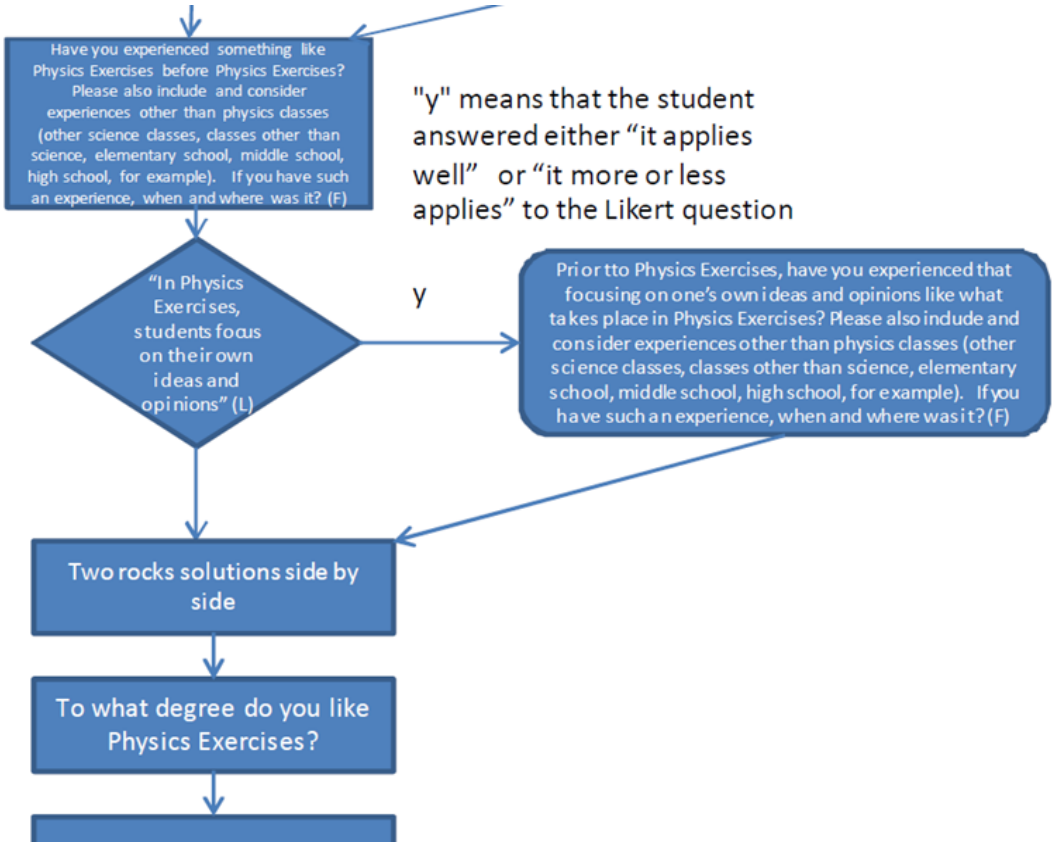
Change Restrictions: Set a Max Response Count = 46 (I completed the survey as well as a test, so that 45 students would be able to access it via this collector. The five survey validators were counted as the first five students in the 50 student sample pool): In the Closed message, students were redirected to the survey that was not restricted to 50 students but where they would not get 1,000 yen.

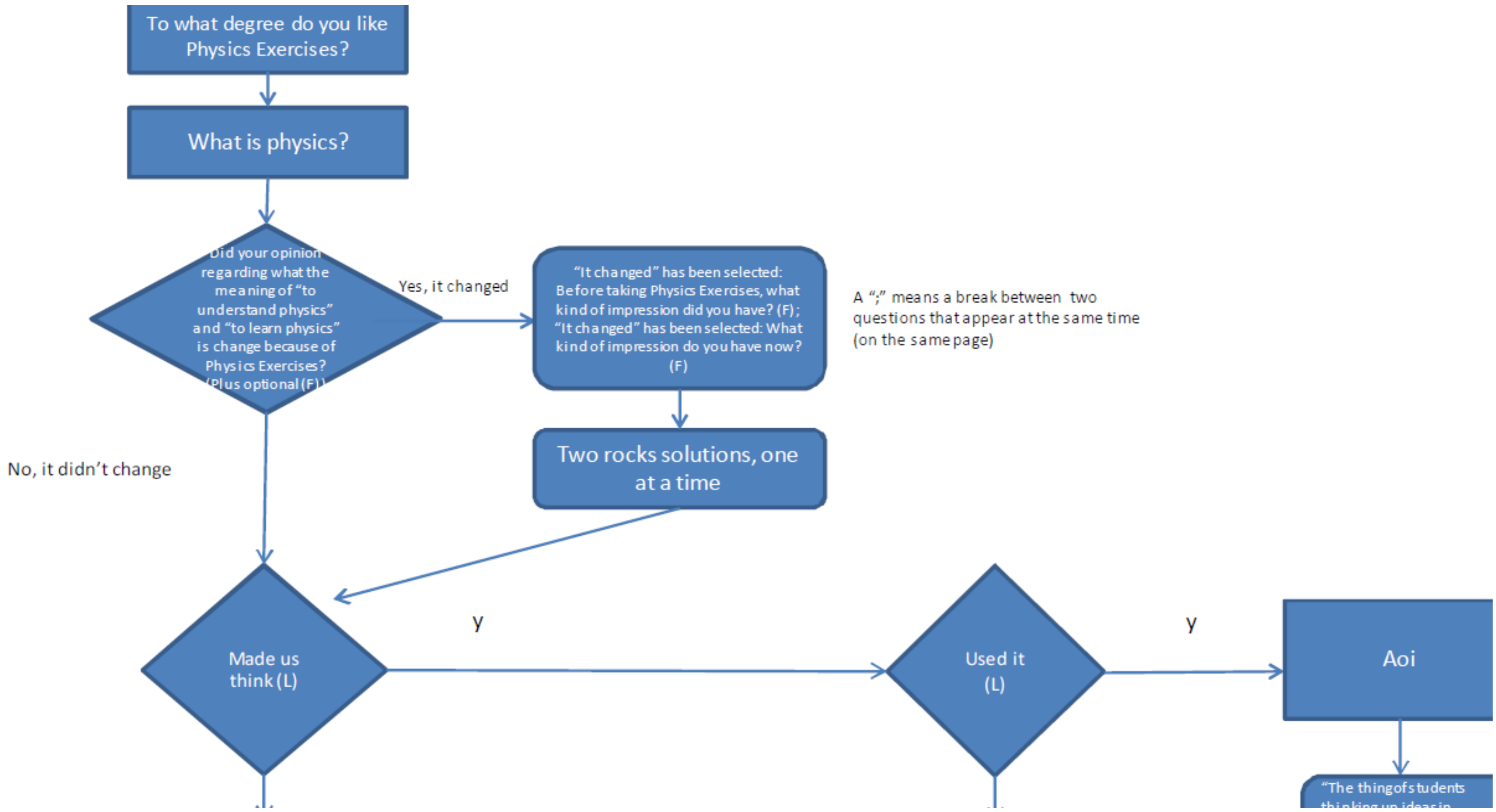
The URL of the over-fifty survey was e-mailed directly to the two 2011 students who replied to my e-mail. The responses of these two were kept separate from the 2012 group of students (they were reporting on a different class with different TA's, etc.

than the 2012 group, so it is necessary to be careful not to combine their survey responses).

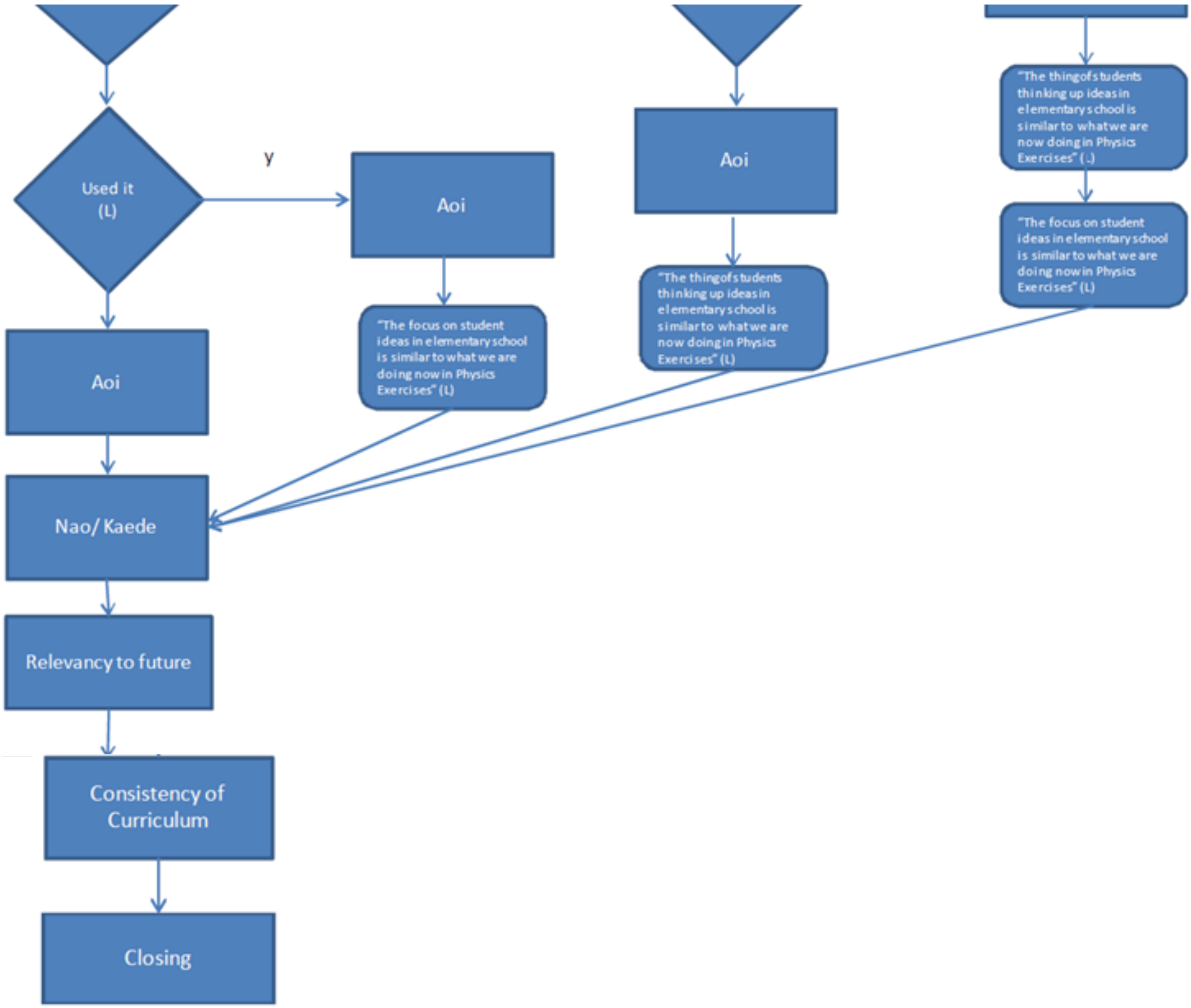
5. Survey Final Draft – Skip Logic Flowchart




Have you experienced something like Physics Exercises before Physics Exercises? Please also include and consider experiences other than physics classes (other science classes, classes other than science, elementary school, middle school, high school, for example). If you have such an experience, when and where was it? (F)
"y" means that the student answered either "it applies well" or "it more or less applies" to the Likert question
"In Physics Exercises, students focus on their own ideas and opinions" (L)
y
Prior tto Physics Exercises, have you experienced that focusing on one's own ideas and opinions like what takes place in Physics Exercises? Please also include and consider experiences other than physics classes (other science classes, classes other than science, elementary school, middle school, high school, for example). If you have such an experience, when and where was it? (F)
Two rocks solutions side by side
To what degree do you like Physics Exercises?



To what degree do you like Physics Exercises?
What is physics?
Did your opinion regarding what the meaning of "to understand physics" and "to learn physics" is change because of Physics Exercises? (Plus optional (F))
Yes, it changed
"It changed" has been selected: Before taking Physics Exercises, what kind of impression did you have? (F); "It changed" has been selected: What kind of impression do you have now? (F)
A ";" means a break between two questions that appear at the same time (on the same page)
Two rocks solutions, one at a time
No, it didn't change
Made us think (L)
y
Used it (L)
y
Aoi
"The thing of students



Used it (L)
y
Aoi
"The focus on student ideas in elementary school is similar to what we are doing now in Physics Exercises" (L)
Aoi
"The thing of students thinking up ideas in elementary school is similar to what we are now doing in Physics Exercises" (L)
"The thing of students thinking up ideas in elementary school is similar to what we are now doing in Physics Exercises" (L)
"The focus on student ideas in elementary school is similar to what we are doing now in Physics Exercises" (L)
Aoi
Nao/ Kaede
Relevancy to future
Consistency of Curriculum
Closing

6. Survey Final Draft – Survey Flowchart Notes

"//" means a separation between pages of questions. ";" means separation between two questions on the same page (visible at same time)

"L" means "Likert scale" – this format is used: To what degree do you agree or disagree with the following statement? (Select one) "Physics Exercises is different than prior physics classes I took (include college and high school)." (Choose one of the following) (does not apply, does not apply well, neither way, it more or elss applies, it applies well)

Introduction	Consent form // Name ; major ; prior physics experience (see pg 3) //) "Physics Exercises is different than prior physics classes I took (include college and high school)." (L)
Was it easy to adjust to Tutorial?	Two years ago, a Japanese physics teacher came to observe a course using Tutorials at the University of Maryland. Although he had an interest in that class, he decided that it would be trouble to try implementing that way of teaching in his own class in Japan. The reason why is that since Japanese students are not trained to think about one's own ideas during class and to make those nearby listen, even if you write "Think about this question and have a discussion with those around you" on the worksheets, he predicted it would amount to nothing more than students just quietly waiting for the answer from the teacher. During Tutorial, do you think of your own ideas and opinions and tell them to the students around you? If so, to what degree was it easy to adapt to that way of learning? (Choose one from the following) (I don't really think up my own ideas and opinions and tell them to those around me, it was not easy to adapt, it was not really easy to adapt, neither way, it was fairly easy to adapt, it was quite easy to adapt, other (explain in about one sentence)
To what degree do you like Physics Exercises?	To what degree do you like Physics Exercises? (Choose one of the following) (I do not like Physics Exercises, I do not much like Physics Exercises, neither one, I more or less like Physics Exercises, I really like Physics Exercises)
What is physics?	What does it mean to "understand" physics? (F) // According to some students, "to learn physics" means to learn the ways of using equations so as to solve problems. According to other students, it is to learn why various phenomena occur in the form they do. Other students have other impressions. What is it "to learn physics" to you? (F)

"F" means "Free response";"(Please explain in about one sentence)" is added to the end of each of these prompts

Made us think	We are interested in what Japanese education is like. In the following questions, rather than your own opinions, tell us what was going on at your school. Talk about your school itself. To what degree do you agree or disagree with the following statement? "As a general impression, at my elementary school, the teacher often made students think up ideas themselves" (L)
Used it	"As an overall impression, at my elementary school, the teacher often used the ideas that students thought themselves." (L)

Aoi	According to a student from last year's Gakugei Physics Exercises class (Aoi), "(In elementary school), rather than 'answer the problem', there were a lot of questions about how we solved it, and you think yourself how you could solve it, that is different from person to person, so I think that being able to say your own thinking was emphasized" What degree do you agree or disagree with the following statement? (Choose one) "As a general impression, my elementary school was also that kind of feeling" (L)
Nao/ Kaede	According to a student from last year's Gakugei Physics Exercises class (Nao), "Unsurprisingly, during the time of elementary school, you chat, and talk, and solve problems all together. Because we have that experience, even though so many years passed in high school and we are taking classes where the teacher is teaching uni-directionally, we were able to quickly adapt to Physics Exercises I think. Because we already experienced this experience around elementary school." What degree do you agree or disagree with the following statement? (Choose one) "I think like Nao." (L) // According to a student from last year's Gakugei Physics Exercises class (Kaede), "In elementary school, it wasn't a style of the teaching always teaching, and it was a class style of students talking amongst themselves, and everyone has come having taken that kind of class about once, so I don't think there are many kids who think "Huh, is this thing a CLASS?" Therefore, I think it was easy to take in." To what degree do you agree or disagree with the following statement? (Choose one) "I think like Kaede" (L)
Relevancy to future	"I think that Physics Exercises is helpful for my future job" (L) ; Once you graduate, what kind of work do you wnt to do? ; If you think it's not helpful, why do you think it won't help? in the case that you think it's helpful, in what way do you think Physics Exercises will help with that? (F)
Consistency of curriculum	"While doing Tutorial in Physics Exercises, if I ask "what is the answer to this part?", some TA's won't tell me but other TA's will." (L) // Which of the following applies the best? (I am not satisfied with the grades I am getting now in Physics Exercises, I am not very satisfied with the grades I am getting now in Physics Exercises ,neither way , I am rather satisfied with the grades I am getting now in Physics Exercises, I am satisfied with the grades I am getting now in Physics Exercises) // It is not fair that the content covered by exams and quizzes in some classes is different than the content learned during class. I want to ask to what degree exams and quizzes in Physics Exercises coincide with Tutorial. To what degree do you agree or disagree with the following statement:"Even if you properly understand what is written on the Tutorial worksheets, it is not enough to get good grades on exams and quizzes in Physics Exercises"(L)
Closing	So that I can send you the 1,000 yen by post, I want to ask your mailing address. Also, if you are chosen in the 4,000 yen lottery, I will inform you by e-mail. Which e-mail address can you take messages from? // This is the end of the survey. Good job!

＊1. インフォームドコンセント（正しい情報を得た上での同意）、2012:
工学,物理分野における数学のsense-making（意味形成）の向上、改善

これはMaryland大学、カレッジパーク校、Andrew Elbyによって管理されている研究プロジェクトです。物理学科の学部生に対してこの研究プロジェクトへの参画を招待させていただきます。この研究プロジェクトの目的は、どのように学生が物理、または工学コースにおいて数学を使用しているか、またもし必須課目である物理コースの内容を変えた場合、将来の工学コースにどのような影響をもたらすか、を調べるものです。

この研究内容には、あなたのこのアンケートに回答することを我々が収集することも含まれています。そして授業とこのアンケートに対する一対一のインタビューの録画も含まれています。このインタビューは約30分程度かかります。

我々はあなたの個人情報を出来るだけ厳守するよう努力します。あなたの個人情報を守るために、収集したこのアンケートに回答することとビデオ等は鍵のかかる米国にあるオフィスに保管されます。デジタル化されたデータは外部パスワードで守られているハードドライブに保存されます。

もしこの研究プロジェクトに対して我々が論文やレポートを作成した際には、あなたの身元は匿名とし、個人情報は厳守されます。録画したビデオテープは教育研究者に対する学会やミーティングにおいてのみ紹介されます。もし、東京学芸大学または政府の公共機関の代表者が、法律の元にあなたの情報を要求してきた場合、それは掲示されるかもしれません。この研究への参画にあたりいくつかのリスクが伴うことをあらかじめ言及させていただきます。あなたのインタビュー、またはこのアンケートに回答することを見た誰かがあなたを認識する可能性もそのリスクには含まれています。
しかし、裏を返せば、あなたのインタビューやアンケートに基づいて、あなたの受講している物理コースが直接改善される可能性も含まれています。

あなたのこの研究プロジェクトへの参画は、すべてあなたの自由意志に基づきます。たとえあなたがこの研究プロジェクトへの参加を決意した場合においても、途中からの中断はいつでも可能となります。もしあなたが不参加、もしくは途中中断を決定した場合においても、評価や成績などには何の影響もありません。

この研究はMaryland大学、カレッジパーク校、Andrew Elbyによって管理されています。もしこの研究に対して質問等がございましたら、2226 Benjamin Bldg., College Park, MD, 20742, USA 301-405-3161, elby@umd.eduまたは、Hideo Nitta, 日本, 東京都小金井市貫井北町4丁目1−1；042-329-7111, hi_nitta@u-gakugei.ac.jp までご連絡ください。
もしあなたの人権、あるいは研究に関する損害などの報告がございましたら、Institutional Review Board Office, University of Maryland, College Park, Maryland, 20742, USA; irb@deans.umd.edu; 301-405-0678までご連絡ください。この研究はUniversity of Maryland, College Park IRB procedures for research involving human subjects において評論されました。

このアンケートに回答することは以下のことを意味します。
* あなたが18歳以上であること。
* この研究内容をあなたは完全に理解していること。
* あなたの疑問はすべて解答されたこと。
* あなたのこの研究プロジェクトに対する参画はすべてあなたの自由意志であること。

○ 同意します（進むために、このボタンをクリックして、"Next"をクリックしてください）

There is absolutely no obligation to fill out this survey. Your filling in this survey signifies your consent for the the Physics Education Research Group at the University of Maryland free use. However, your name will be changed.

If you fill out this survey to the end, you will receive 1,000 yen. In addition, you will be entered into a 4,000 yen lottery. If you do not proceed to the end, there is a chance that you will not receive 1,000 yen and will not be entered into the 4,000 yen lottery, so please be careful.

If you click the "Next" button and go to the next page, your answers will be saved just like that and you will not be able to change them (even if you go back and fill in a new answer, it will not be saved).

By filling this out, you swear that you are the following person (write your name below)

What is your major?

In high school, which physics classes did you take? (Physics 1, Physics 2, for example)

Two rocks solutions side by side

Please consider the following problem (the correct answer is already written immediately the problem, and you don't need to derive an answer yourself)

* * *

We have the equation v = v0 + at 、v is velocity, v0 is initial velocity, a is acceleration, t is time. You are standing on the fourth floor balcony, holding two rocks. Let one go naturally. You throw the other one downward with a speed of 2 m/s. After 5 seconds, how are the speeds of the two rocks different? Is the second rock still faster than the first rock by 2 m/s, just like that? Is it faster than 2 m/s? Is it slower than 2 m/s? (Gravitational acceleration is 10 m/s^2)

* * *

Please consider two solutions to the problem at the same time.

* * *

One student's answer (way of solving 1)

"First of all, the one you freely drop: being freely dropped means that nothing but gravity is working, so acceleration is a = g, equal to gravitational acceleration. And, this is v = v0 + at、a = g. therefore it becomes v = v0 + gt . And, now v0 was 0, so 0. g is 10 they write, so 10. In other words, this one is, after t seconds, v = 10 t . And, if it's after 5 seconds, 10 times 5, and this one is 50 m/s. This time, the second one, first of all, nothing but gravity is acting, so, a is g. Til here it's the same, but v0 is this time, it says that you will throw, so the initial velocity becomes 2 and, g is made 10, so v = 10t + 2. If you do that, if it's 5 seconds, 10 times 5 plus 2 is 52 m/s. 52 m/s minus 50 m/s ＝2 so, the first one is 2 m/s faster – just like that.

Another student's answer (way of solving 2)

The "at" part of v = v0 + at is the amount of change of the speed. And, for both, the accelerations are the same, so this one's acceleration, and this one's acceleration are both identical. Since the time of accelerating is also identical, at is also identical, so the amount of change to the speeds are the same. In other words, both rocks change their speeds exactly the same, so the difference in speeds doesn't change. If there is a difference in speeds at the beginning, and if both change in the same way, the difference in the end is the same as the difference in the beginning. Therefore, the difference in speeds is still 2m/s, just like that.

Please compare these two ways of solving. do you prefer one answer more than the other? If so, please explain why. If not, please explain why not. (F)

Two rocks solutions, one at a time

This time, please consider problem solution 1:

* * *

We have the equation $v = v0 + at$ 、v is velocity, v0 is initial velocity, a is acceleration, t is time. You are standing on the fourth floor balcony, holding two rocks. Let one go naturally. You throw the other one downward with a speed of 2 m/s. After 5 seconds, how are the speeds of the two rocks different? Is the second rock still faster than the first rock by 2 m/s, just like that? Is it faster than 2 m/s? Is it slower than 2 m/s? (Gravitational acceleration is 10 m/s^2)

* * *

"First of all, the one you freely drop: being freely dropped means that nothing but gravity is working, so acceleration is $a = g$, equal to gravitational acceleration. And, this is $v = v0 + at$、$a = g$, therefore it becomes $v = v0 + gt$. And, now v0 was 0, so 0. g is 10 they write, so 10. In other words, this one is, after t seconds, $v = 10\,t$. And, if it's after 5 seconds, 10 times 5, and this one is 50 m/s. This time, the second one, first of all, nothing but gravity is acting, so a is g. Til here it's the same, but v0 is this time, it says that you will throw, so the initial velocity becomes 2 and, g is made 10, so $v = 10t + 2$. If you do that, if it's 5 seconds, 10 times 5 plus 2 is 52 m/s. 52 m/s minus 50 m/s = 2 so, the first one is 2 m/s faster – just like that.

Is the way of thinking of this approach close to your image before entering Physics Exercises? Or, is it close to your current way of thinking about physics? Or, is it not close to either?

(F)

//

This time, please consider problem solution 2:

* * *

We have the equation $v = v0 + at$ 、v is velocity, v0 is initial velocity, a is acceleration, t is time. You are standing on the fourth floor balcony, holding two rocks. Let one go naturally. You throw the other one downward with a speed of 2 m/s. After 5 seconds, how are the speeds of the two rocks different? Is the second rock still faster than the first rock by 2 m/s, just like that? Is it faster than 2 m/s? Is it slower than 2 m/s? (Gravitational acceleration is 10 m/s^2)

* * *

The "at" part of $v = v0 + at$ is the amount of change of the speed. And, for both, the accelerations are the same, so this one's acceleration, and this one's acceleration are both identical. Since the time of accelerating is also identical, at is also identical, so the amount of change to the speeds are the same. In other words, both rocks change their speeds exactly the same, so the difference in speeds doesn't change. If there is a difference in speeds at the beginning, and if both change in the same way, the difference in the end is the same as the difference in the beginning. Therefore, the difference in speeds is still 2m/s, just like that.

Is the way of thinking of this approach close to your image before entering Physics Exercises? Or, is it close to your current way of thinking about physics? Or, is it not close to either?

(F)

7. Survey Draft 1 (in Japanese)

同意します （進むために、このボタンをクリックして、”Ｎｅｘｔ”をクリックしてください）

2. このアンケートに回答する義務は全くありません。
アンケートの終わりまでに回答してくださったら、1000円をもらいます。それに4000円くじに入り
ます。終わりまで進まなかったら、1000円をもらえなくてくじに入らない可能性がありますから、
注意してください。
”Ｎｅｘｔ”というボタンをクリックして、次のページに行ったら、そのまま答えが保存されて変
えることは出来ません（戻って新しい答えを回答しても、保存されないということです）。
このアンケートに回答することはメーリランド大学の物理教育研究グループの自由な使用に同意
することを意味します。ただし、あなたの名前は仮名にします。
回答すると、あなたは(名前を下に書いてください) 本人であることを誓います。

3. あなたの専攻 / 撰修は何ですか？

4. 高校では、どの物理授業を受けましたか？（物理 I、物理 II、とか）

5. 次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでください）
「物理学演習は以前に受けた物理の授業とは違います。」（次から一つ選んでください）

6. 物理学演習に入る前に、チュートリアルについて何か聞いたことがありますか。（例え
ば，先輩が何か伝えましたか。）次から一つ選んでください。

7. それはどんなことですか。（一文ぐらいで説明してください）

8. どうしてこの授業を受けることにしたのですか？（一文ぐらいで説明してください）

9. 次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでください）
「物理学演習は授業に入る前の予想とは違って、びっくりしました。」（次から一つ選んでくだ
さい）

10. 多くの学習者によると、チュートリアルを使用する授業（物理学演習を含む）は以前に受
けた物理の授業とはとても違って、チュートリアルを使用する授業に入ったらびっくりしたようで

す。それでも、あるチュートリアルを使用する授業では、学習者は新しい授業のスタイルに慣れ
やすいらしいです。同じチュートリアルを使用しても，授業が学習者にとって受け入れにくいこと
もあります。あなたは、物理学演習のスタイルがどの程度受け入れやすいですか？（次から一
つ選んでください）

11.「受け入れやすい」と選ばれたら、どうして 受け入れやすい、あるいは「受け入れにく
い」と選ばれたら、どうして受け入れにくいですか？（理由 3 つをつけて、すべての理由を一文
ぐらいで説明してください）

12. 物理学演習の前に、物理学演習のようなことを経験したことがありますか？ 物理の授業以
外の経験（他の理科の授業、理科以外の授業、小学校、中学校、高校、など）も含んで考え
てください。あったら、いつとかどこありましたか？（一文ぐらいで説明してください）

13. どの程度物理学演習が好きですか？（次から一つ選んでください）

14. 次の問題を検討してください（正しい答えは問題のすぐ後に既に書いてあり、自分で答え
を導かなくてもいいです）。
＊＊＊
v = v0 + at という方程式があり、v が速度、v0 が初期速度、a が加速度、t が時間です。
あなたは四階のバルコニーに立っていて、石を二つ持っている。一つは自然落下させて。もう
ひとつは下に向かって2 m/s の速度で投げます。5 秒後に、2つの石の早さはどれだけ違うでし
ょう。二つ目の石はまだ一つ目の石よりも2 m/s 速いまま？ 2 m/s より速い？ 2 m/s ほど速くな
い？（重力加速度は10 m/s^2）
＊＊＊
問題の解き方二つ同時検討してください。
＊＊＊
ある学習者の答え（解き方１）
「まず、自然落下させた方: 自然落下ということは、重力しか働いていないから、加速度はa =
g、重力加速度と等しい。で、これは、v = v0 + at、a = g，だから、v = v0 + gt になる。で、

今v0っていうのは0だったから、0。gは、10って書いてあるから10。つまり、こっちが、t秒後
には、v = 10 tだ。で、5秒後だったら、10かける5で、こっちは、50 m/s。こんど、二つ目、
とりあえず力は重力しか働いていないから、aはgです。ここまでは一緒だけど、v0は今回、
投げるって言われているから、初速度は2になって、gは10ってされているからv = 10 t + 2。そ
うすると、5秒だと、10かける5プラス2は52 m/s。52 m/sひく50 m/s ＝2だから、一つ目より2
m/ｓ だけ速いまま。」
他の学習者の答え（解き方２）
「v = v0 + atのatという部分は速度の変化量。で、どちも、加速度一緒だから、こっちの加
速度も、こっちの加速度も等しい。加速している時間も等しいから、atも等しいから、速度の
変化量も等しい。つまり、石二つも同じだけ速度が変化するから、速さの差は変わらない。最
初に差があったら、二つも同じように変えたら、最後の差は最初の差と一緒。だから、速度の
差はまだ2 m/s速いまま。」
この解き方を比べてください。ある答えがもう片方の答えより好きですか？そうなら、どうしてか
説明してください。そうではなかったら、説明してください。（一文ぐらいで説明してください）

15. 物理を「理解する」ということはどういうことですか？（一文ぐらいで説明してください）

16. ある学習者によると、「物理を学ぶ」という意味は問題を解くために数式の使い方を学
ぶということです。他の学習者によると、さまざまな現象が，なぜそのような形で起きるのかを
学ぶということです。他の学習者は他の印象を持っています。あなたにとって、「物理を学ぶ」
という意味は何ですか？（一文ぐらいで説明してください）

17. 「「物理を理解する」、「物理を学ぶ」とはどういう意味か？」ということについて、物
理学演習はあなたの意見を変えましたか？（次から一つ選んでください）

18. 「「物理を理解する」、「物理を学ぶ」とはどういう意味か？」ということについて、物理
学演習はあなたの意見を変えましたか？（一文ぐらいで説明してください）

19.「変えました」と回答されました：物理学演習を受ける前には、どのような印象を持って
いましたか？（一文ぐらいで説明してください）

20.「変えました」と回答されました。今現在、どのような印象を持っていますか？（一文ぐ
らいで説明してください）

21. 今度は、問題の解き方 1 を検討してください：
＊＊＊
v = v0 + at という方程式があり、v が速度、v0 が初期速度、a が加速度、t が時間です。
あなたは四階のバルコニーに立っていて、石を二つ持っている。一つは自然落下させて。もう
ひとつは下に向かって2 m/s の速度で投げます。5 秒後に、2つの石の早さはどれだけ違うでし
ょう。二つ目の石はまだ一つ目の石よりも2 m/s 速いまま？ 2 m/s より速い？ 2 m/s ほど速くな
い？（重力加速度は10 m/s^2）
＊＊＊
「まず、自然落下させた方: 自然落下ということは、重力しか働いていないから、加速度はa =
g、重力加速度と等しい。で、これは、v = v0 + at、a = g，だから、v = v0 + gt になる。で、
今v0 っていうのは0 だったから、0。g は、10って書いてあるから10。つまり、こっちが、t 秒後
には、v = 10 t だ。で、5 秒後だったら、10 かける5 で、こっちは、50 m/s。こんど、二つ目、
とりあえず力は重力しか働いていないから、a はg です。ここまでは一緒だけど、v0 は今回、投
げるって言われているから、初速度は2になって、g は10ってされているからv = 10t + 2。そうす
ると、5 秒だと、10 かける5 プラス2 は52 m/s。52 m/s ひく50 m/s ＝2 だから、一つ目より2 m/
s だけ速いまま。」
このアプローチの考え方はあなたの物理学演習に入る前のイメージと近いですか？ または、今
現在の物理に対する考え方と近いですか？ または、どちとも近くないですか？（一文ぐらいで説
明してください）

22. 今度は、問題の解き方 2 を検討してください：
＊＊＊

v = v0 + at という方程式があり、v が速度、v0 が初期速度、a が加速度、t が時間です。
あなたは四階のバルコニーに立っていて、石を二つ持っている。一つは自然落下させて。もう
ひとつは下に向かって2 m/s の速度で投げます。5 秒後に、2つの石の早さはどれだけ違うでし
ょう。二つ目の石はまだ一つ目の石よりも2 m/s 速いまま？ 2 m/s より速い？ 2 m/s ほど速くな
い？ （重力加速度は10 m/s^2）
＊＊＊
「v = v0 + at のat という部分は速度の変化量。で、どちも、加速度一緒だから、こっちの加
速度も、こっちの加速度も等しい。加速している時間も等しいから、at も等しいから、速度の
変化量も等しい。つまり、石二つも同じだけ速度が変化するから、速さの差は変わらない。最
初に差があったら、二つも同じように変えたら、最後の差は最初の差と一緒。だから、速度の
差はまだ2 m/s 速いまま。」
このアプローチの考え方はあなたの物理学演習に入る前のイメージと近いですか？ または、今
現在の物理に対する考え方と近いですか？ または、どちとも近くないですか？ （一文ぐらいで説
明してください）

23. 私達は、日本の学校教育がどういう物かに興味があります。次の質問には、自分の意見
ではなくて、学校では、何が起きていたかを教えてください。あなたの学校自体について答えて
ください。次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでくだ
さい）
「一般的な印象として、私の小学校では、学ぶプロセスのために、先生はよく生徒の自分のア
イデアを生徒に考え出させたり、注目させたりしていました。」（次から一つ選んでください）

24. 去年の学芸大学の物理学演習の授業の学習者（アオイ）によると、「（小学校では）
問題の答っていうんじゃなくて，どうやったら求められるかっていう質問が多くて，自分でどうやっ

たら求められるか考えるし，それは人によって違うから，そういうのは自分の考えを言えること
が重要視されていたと思います」。
次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでください）
「一般的な印象として、私の小学校もそう いう感じでした。」（次から一つ選んでください）

25. 次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでくださ
い）
「小学校で自分のアイデアに注目することは今物理学演習でやっていることと似てます。」（次
から一つ選んでください）

26. 去年の学芸大学の物理学演習の授業の学習者（アオイ）によると、「（小学校では）
問題の答っていうんじゃなくて，どうやったら求められるかっていう質問が多くて，自分でどうやっ
たら求められるか考えるし，それは人によって違うから，そういうのは自分の考えを言えること
が重要視されていたと思います」。
次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでください）
「一般的な印象として、私の小学校もそう いう感じでした。」（次から一つ選んでください）

27. 去年の学芸大学の物理学演習の授業の学習者（ナオ）によると「やっぱり小学生の頃
にしゃべって，話して，皆で問題を解く経験があるので，中学･高校と何年も経って，先生から
一方的に教えてもらっている授業を受けていても，、物理学演習の授業にすぐ慣れたと思う。こ
ういう経験は小学校のころで既に経験していたから。」
次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでください）
「私はナオのように思う。」（次から一つ選んでください）

28. 去年の学芸大学の物理学演習の授業の学習者（カエデ）によると「小学校では，先生
が常に教えるスタイルじゃなくて，生徒同士で話し合う授業スタイルがあるし，皆一度ぐらいはそ
ういう授業を受けてきたことがあるから，それほど「え，これって授業なの」って思う子はあまり

いないかなって思います．だから，受け入れやすいと思います。」
次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでください）
「私はカエデのように思う。」（次から一つ選んでください）

29. 次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでくださ
い）
「物理学演習は私の将来の仕事に役立つと思う。」（次から一つ選んでください）

30. 卒業したら、どんな仕事がしたいですか？

31. 役立たないと思ったら、どうして助からないと思いますか？
役立つと思う場合なら、どのように物理学演習はそれに助かると思いますか？（一文ぐらいで説
明してください）

32. 次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでくださ
い）
「物理学演習でチュートリアルをする時には、あるTAは答えを教えないけど、他のTAは教え
る。」（次から一つ選んでください。）

33. 次の選択肢から、どれが一番当てはまりますか？（一つを選んでください）

34. 次の文章には，どの程度賛成，あるいはどの程度反対ですか。（一つを選んでくださ
い）
「物理学演習の試験や小テストはチュートリアルを通して何を学んでいるか測る。」（次から一
つ選んでください）

35. 1,000円を郵便で送るために、メールであなたの住所を聞きたいです。それに、もしくじで
4,000 円が当選したら、メールで案内します。どのメールアドレスで連絡とれますか？

これはアンケートの終わりです。お疲れ様でした！

B. Success of Open Source Tutorials at Gakugei

1. Rina

Interviewer: Is there something you would tell someone who is considering enrolling in Physics Exercises?[00:26:12.02] Rina: I took this same class last year, but I dropped it and so I'm taking it again. [00:26:19.01] The class is needed for me to get my license to teach middle and high school.[00:26:25.21] If we're talking about the style of last year's class... let's forget about whether the class is necessary for the student or not, if it's just someone saying "I'm interested in the class but...", [00:26:37.03] then I would tell him that, basically, if you don't study hard on your own, it will be difficult for the class content to seep in.[00:26:50.11] But if we're talking about this year, I think I would say something about how the class might be good because it will fix your way of thinking about your own ideas about physics.[00:27:08.20]   Interviewer: Can you say that again?   This year's class is... ?[00:27:14.18] Rina: I think I would say that this year's Physics Exercises could be a good experience because it gives a lot of opportunities to think about the concepts you carry about physics.[00:27:27.18] Interviewer: In other words, students have physics concepts, and there are opportunities to think about those individual concepts[00:27:40.19] Rina: Perhaps many Japanese students learning physics don't think deeply about concepts or why something is interpreted in such a way; [00:27:53.10] rather, I think they are taught the way to solve problems, so with things like why in certain situations you do a certain calculation, they don't really... [00:28:07.22] it doesn't mean that they really understand.   They are taught solutions, ways of solving problems.   [00:28:15.23] You just apply the equation; you decipher the context, you interpret the problem wording... I think it's common to solve by thinking "in times of this type of problem, you use that way of solving", [00:28:27.09] so it doesn't really mean that you understand the world of physics, you know what I mean?[00:28:43.05]   Interviewer: So, was last year's class like this: without understanding why you're calculating, if it’s this kind of problem, you apply this equation, and... was it that kind of class?[00:28:58.17] Rina: A problem would be given, students who knew how to solve it would do so and be done,[00:29:07.17] and as for students who didn't get it, the teacher would say that he was going to give an explanation about some basic knowledge relevant to the field.[00:29:22.14]   I would listen, but we would be taught equations and things really quickly, and as far as asking questions of why it turns out that way... [00:29:38.28] we have a lot of daily experiences and the like... even if I'd ask students who do physics, they would say something like "That way of thinking is just the way it's done in this world"[00:29:53.16]   Interviewer: When you say "world", you mean...?[00:29:56.16] Rina: They would say things like "In physics, this is just that kind of thing, so don't think too deeply".   In the end, without really getting it, I would think "well, maybe it's good to apply this equation" and I would set off to solve it that way,[00:30:12.20] but since the problems were difficult, I didn't know how to apply the equation, and eventually it didn't work out and ended there.[00:30:20.29]   That was the style of last year's class[00:30:30.05] Interviewer: This is the world of physics, so you don't need to think so much about the real world.   Just if it's this kind of problem, do the calculation like this.

[00:30:43.01] Rina: Yes, that's right[00:30:44.04] Interviewer: But Tutorial is different than that?Rina: Yes, it's different[00:30:53.10] Interviewer: Now is more... how is it different?[00:30:57.03] Rina: There were a lot of problems where we were made to think in certain ways, like there were a lot of things called "making interpretations", [00:31:12.10] and within those types of problems were included things like misconceptions from daily experiences that we had been thinking ourselves. [00:31:26.05] There were also opportunities to think about why those ideas were, after all, wrong, and so I thought it was really good.

[00:35:10.12] Interviewer: Why didn't you take physics in high school?[00:35:33.11] Rina: The first year of high school, everyone had to take chemistry, but in the second year, there was a choice between biology and physics. [00:35:45.08] It wasn't so much that I liked biology, it's just that I didn't think I could do physics. [00:35:57.11] At that time, it wasn't about whether or not I had an interest, but rather whether or not I could do it, whether or not I could understand it, and I didn't think I could.[00:36:15.27] Interviewer: Why not?Rina: Well, as expected, it's abstract, and really... like electricity or forces, it's things that you can't see with your eye, right? [00:36:26.16] Since I didn't really understand that... also, in middle school the chemistry/physics teacher at the time I took it happened to be a really awful teacher and I really didn't understand what he was saying. [00:36:49.23] When I thought that it would be that difficult thing, I decided it would be impossible.

[00:38:38.11] Interviewer: As a high school student... physics is atoms for example, there's a lot of abstraction, you can't see electricity, for example... you had that kind of impression. When you now think about physics, do you still have that impression? Or has your image towards physics changed since then?[00:39:07.24] Rina: Yeah, it's changed since then. I've come to believe that I can understand it. [00:39:24.25] but As expected, it is abstract, and so I think there are a lot of things that can't approach daily experiences like magnetism and E-M waves where [00:39:50.15] the teacher just tells you something and you don't have any idea why, you just have to accept it. [00:39:56.10] Since I can't quickly connect and be like "Oh, of course!", I think physics is difficult. But, even if it's a little fragmented, if there are areas that I can become able to understand, if I can come to understand little by little, I think that I can understand, and if I can understand, [00:40:23.05] the ideas of how forces that you can't see must be working... to me it's really interesting.[00:40:34.04] Interviewer: So, now what you're thinking is that there are still a lot of places where it's hard to make connections, but in some places, you have connected. Those connections are between physics concepts and... what?[00:41:03.02] Rina: Physics concepts and... huh. When they would say "a force is acting", I wouldn't really think that it was but I would just say "I see". [00:41:17.21] However, there was a place that really made sense where we showed that definitely if you go from the assumption that that kind of force is acting, everything that follows fits. [00:41:35.26] Even if it's about how complicated forces relate, if I go step by step, I think I can understand it.[00:41:53.10] Interviewer: Did you carry that attitude from last year, or did you come to think that way since Tutorial?Rina: Since Tutorial[00:43:10.19] How would you explain this equation to a class friend in college?[00:44:10.01] t is a unit of time at this moment, if you cut time into tiny little pieces, it indicates one moment... [00:44:30.03] a is, in the span of that moment, how much it got faster. It got just a little bit faster than the original speed. Just after this motion has occurred, in that small moment, how much it changed. [00:44:57.04] This (v0) is the original speed of that difference, so at the current moment in time... um, this object had an original speed and if you take as given that it has a motion that, after some number of seconds, makes it different - faster, and that in each moment, the speed increases...[00:45:23.10] that degree is decided and that is known in this condition... the degree that the speed is increasing is known, so if the moments accumulate, this equation will show you what the speed is at the present moment.[00:46:18.03] Interviewer: Is t the entire time, or is it just a tiny slice?Rina: It's the tiny slice of time.[00:46:32.16] If you take this to be v0 here at this time, speed increases by just this amount, it becomes the whole speed, v, [00:46:42.14] and this width, the gains just after it increases by this width every time are added up. It's like that.[00:47:07.07] Interviewer: The t in this equation is the time from this line to this line?Rina: Yes, that's rightInterviewer: So the time from start to finish is not shown in this equation?Rina: Um, no, this t is... if it's just one part, then it's this, but if... you can think about it as being one second, two seconds, three seconds, four seconds, five seconds, so this t depends on the change, and the ultimate speed can be found.[00:47:55.26] Interviewer: OK, so if t is 1, then it's up to here, but if it's 2, it's up to hereRina: Yes, yes[00:48:08.18] Imagine that you are an elementary school student and one of your friends asks for an explanation, what would you say?[00:49:10.18] Rina: Is it necessary for me to explain that this is speed?Interviewer: Can you repeat that?[00:49:25.23] Rina: In explaining this equation, is it not enough to explain just this way of thinking, or do should I also explain that v shows speed and a shows acceleration?Interviewer: Please decide yourself; what do you think? But for whatever reason the elementary school student is asking for an explanation of this equation[00:49:43.02] Rina: There's a cheetah and it's running at it's regular speed when it finds a gazelle.[00:50:45.23] At that time, it accelerates, meaning it gets faster, but that means that in the next moment it's even faster still, so it isn't going at the same speed. It gets faster and faster moment by moment.[00:51:22.20] During the time it takes for it to reach the food, how much speed did the cheetah reach?[00:51:37.05] When you want to think about that... firstly, during the time before finding the food, that running speed is v0 and t is a time increment that is much smaller than a secondand a is how much it got faster in that time increment that is much shorter than a second.[00:52:13.21] The best would be to have pictures. There's a cheetah, and it finds the food, and there are moment-by-moment pictures of the acceleration.[00:52:29.11] From the starting point, every second you'd see the tip of the nose... the separation from picture to picture would become wider and wider I think.[00:52:58.07] But, if you take it to be one second, after one second...If, for example, you decide this speed that it had originally, after one second, how many km/hr does it become? It gradually increases.[00:53:19.10] That kind of basic explanation is the best I guess.[00:53:26.28] I don't know the actual speed, but if you take the acceleration to be 1 km/sec, if it's one second, it increases by 1 km/s.[00:53:45.03] That's decided here. This is the original, normal running speed, but if it's 1 km, how many km does it become? If it's after two seconds, how many km/s does it become?[00:54:00.22] That's how the speed slowly increases, gradually getting faster.That's what the equation shows.

[00:54:40.27] Two balls problem[00:55:40.01] (she throws an imaginary rock)[00:56:04.13] I think the second ball will be less than 2 m/s faster than the first one.[00:56:22.22] The motion of the rocks follows gravitational acceleration and gradually become faster as they fall.[00:56:36.24] At first the other rock is thrown with a speed of 2 m/s; that's the initial speed, and that's included, but with the second rock too, gradually the 10 m...how do you read this?[00:57:00.01] Interviewer: /s s?Rina: it's OK to say 10 m/s s? That speed gradually becomes faster, so ... [00:57:16.02] the size of this (g) is pretty big, so the difference won't be 2 m I think[00:57:31.00] Interviewer: You're saying the 2 m/s difference will get bigger? Smaller?[00:57:33.23] Rina: It will get smaller[00:57:38.01] Interviewer: And that's because they are accelerating? With this large acceleration?[00:57:45.25] Rina: Gravitational acceleration is... with the one that just falls, after 1 second, it would be 10 m... [00:58:05.09] (gestures the force needed to throw the ball with 2 m/s) this force of 2 m is acting and it's pointing down I think, compared to the other one...[00:58:14.28] But, huh... after five seconds?[00:59:19.26] She calculates and finds that it is 2m/sRina: Huh, it's the same[00:59:27.27] (laughing) it's still 2 m/s fasterInterviewer: OK. Were you surprised?[00:59:38.13] Rina: YesI feel that something accelerating from gravity will just be so much faster[00:59:51.14] Interviewer: The thrown one, or the one you just drop?Rina: The one you just let go, and eventually the one that falls too will have the same difference, but when two things are falling with the first one having been thrown and they're going down I just don't have a feeling that the power of the two rocks will be different. Even if you say that there's a difference, it won't be as much as the difference that it started with. So I was thinking it would become smaller. But then if I do the calculation, it doesn't change, so I'm like "Huh?"[01:00:44.22] Interviewer: Do you believe this answer? Are you suspicious?[01:00:50.18] I was just now thinking why it is that from everyday experience I was thinking that the initial speed would not be conserved if you throw something down.[01:00:59.21] There's air, so if you throw something down, air resistance has an effect, so it's not just that speed when it actually falls. I'm thinking that the speed would decrease [01:01:17.13] so I was thinking to align more with those daily experiences,[01:01:23.29] but in the world of physics, the unwritten conditions... I think it's a feeling of first you need to just go ahead and solve itInterviewer: Sorry, that was complicated... can you repeat that?[01:01:32.01] Rina: When you solve a physics problem, conditions that aren't written here...(Language confusion)[01:01:51.19] you have to think about things that aren't there, and[01:02:00.27] if you aren't used to physics,[01:02:07.05] daily experiences are unfortunately a higher priority.[01:02:17.07] The stuff you learn in class is correct and our daily experiences are correct, so I think there is absolutely a way to get them to be consistent and I want to think that if we are made to align the content in class with daily experiences that we can understand, [01:02:43.09] so if daily experiences are different from the answer, I start unfortunately thinking that my own answer is wrong and[01:02:56.18] it makes me confused for a moment, but in the wording of this problem, about air,[01:03:05.29] I haven't studied this much and I don't know but there should be some kind of equation for air resistance or something. [01:03:16.11] The conditions to solve the problem aren't written here so if you think maybe it's dealing with something that isn't there...[01:03:27.21] in dealing with imagining this situation, this is a situation of throwing a rock from a fourth floor balcony, right?[01:03:33.06]   That's not imagining the everyday, it's actually like in outer space... well, that's not right, because you need to have gravity, but... it's not a normal fourth floor balcony that we exist around everyday; it's a much more special condition, you have to imagine a theoretical fourth floor balcony or else this doesn't apply.[01:04:01.09]   That's why people who study physics a lot say that things that are kind of impossible in reality are written.

[01:04:25.12] Interviewer: Do you have any questions?Rina: In the end, what was the answer to this question?[01:04:32.29] Interviewer: Do you think it's right?Rina: Other than this, I don't know a way to think about it, so I'm thinking it is 2 m/s[01:04:46.08] Interviewer: got it.   First of all, what I want to say is... wait a minute, you said that you can't think of another way to solve, but... just before now, you told me two ways of thinking, right?   One way was this calculation, the other [01:05:11.05] was close to everyday experiences, but without air... with that no air everyday way of thinking, could you answer?[01:05:24.02] Or was that explanation just to explain why the two ways of thinking weren't lining up?[01:05:35.24] Rina: That was, um... I was giving the reason for why the answer that I put here and the answer from my everyday experiences are different, as a summary. [01:05:46.20] But I put more value on daily experiences, or maybe it's just that I'm more used to it, and solving physics problems for me isn't really clear[01:05:58.27] Interviewer: You mean this way of solving here (plug and chug solution) is not very clear to you[01:06:00.16] Yes.   I don't have much confidence in my own work, so, in the end, I can't really say whether or not this is correct...[01:06:11.21]   Interviewer: Got it. More than that, another way of answering, perhaps a way of answering that can really satisfy... how about if I told you that?[01:06:27.28] You can perhaps really connect it to daily life; if I told you that way of answering, how would that be?[01:06:38.20] There is a way of answering other than this calculation, that other way of answering has much more of a connection to daily life, it is perhaps a way of answering that will be much more satisfying to you.   If you're interested, I will tell you, but...[01:06:53.21] Rina: I want you to tell meInterviewer: OK, sure[01:07:18.20] I explain the forms-based explanation, including that for rocks, air resistance is pretty negligible over that distance, but she can imagine the case of there being no air as well.[01:08:10.08] It's hard to explain and my Japanese is strange, but do you understand?**Note: my explanation was actually pretty much perfect, I was just being modest to see if I could get her to paraphraseRina: Yeah, I think I understand.[01:08:21.27] And, the other thing is, as I was just listening now, the thing I was thinking about how daily experiences don't match well is that the rock that you just let fall; it just falls from this starting point, right?   And the one that you throw down... the one that just falls is completely different in the first second.[01:08:57.28] Interviewer: Yes, the distance is totally differentRina: It's comparing the speeds of the two rocks here and here, right?[01:09:06.11]   But for some reason, when it said "after five seconds", what I imagined is not this, but after some distance, like at the ground, I imagined them reaching there at the same time.[01:09:28.19]   I had this feeling that unless they are side by side, you can't compare them.   If you compared when they were at this line, this one would be after x seconds, but this one would be some number bigger than x, right?[01:09:53.03]

And if you do that, the difference would become less than two, the difference in speed because the acceleration, this one would grow more.[01:10:15.29] Yeah, if you compared the speeds when the thrown ball and the dropped ball crossed this line, I have a feeling that the original speed when you threw it would not be conserved.[01:10:35.15] In reality I don't think it would be. So I was thinking it would be small. After those five seconds it's in air, I didn't think that they would be at completely different places[01:10:48.22] Interviewer: For example, here, if you take a timer and measure speed, this rock's speed would be... uh... it would be slower, right? And this would be... no, the opposite?[01:11:04.23] Rina: I don't know whether it would be faster or not,but you can't necessarily say that it would be 2 m/s faster. And I think it would be less than 2 m/s.[01:11:19.04] That's why I previously erroneously chose "less than 2 m/s"[01:11:28.25] Interviewer: Got it. What I said previously is "this explanation might satisfy you", but did it? That amount of change explanation?[01:11:39.25] Yeah, I think it's OK. I heard it and was perhaps able to understand that I wasn't thinking that they would be at different places in space at the same time.

[01:12:03.12] Interviewer: If you think about those two ways of solving - the utter calculation way and the forms-based way, which one do you basically prefer?[01:12:30.05] If it's a calculation, it comes out with numbers, right?[01:12:37.10] And, my way of understanding this problem is, once, just get it out, see that the answer is "doesn't change", and then once you understand that, think about why it doesn't change and then arrive at an explanation like yours.[01:13:05.07] So... if, from the start, you can understand this way of thinking, that's great, but that's probably pretty hard.[01:13:24.21] So, once, as expected, just memorize it, solve the problem, and compare with the initial speed, if it's faster or slower.[01:13:33.26] But it's not get out that answer, just write it and be done. Rather, look to see if it's different than what you were thinking initially and if so, think why - that will make it easier to understand.[01:13:51.22] In one shot, to reach that point... I have a feeling I can't do that. [01:14:02.00] Interviewer: Thank you for that explanation, but that's not quite what I was asking... for example, let's say that you are a teacher.[01:14:28.23] let's say you have two students - one just writes out this calculation and one just writes this paragraph - which would you give a higher score?[01:14:52.14] Rina: Do I have to give a better grade to one of them?Interviewer: You could give the same gradeRina: And I can't talk to them, just look at their homework?I: right[01:15:29.05] Rina: It depends on the situation, right? If it's just "solve this problem", then both would be full credit.[01:15:53.13] But if it's a problem where you have to use an equation,[01:16:17.01] in the end, if for some reason it's that kind of problem, like in preparation for an exam, where there aren't the kind of problem to explain your thinking...[01:16:40.28] if it's an assignment to lead up to an exam like that, then,[01:16:52.27] if it's "what happens when you apply this equation?", then it would be partial credit if it's not with an equation.[01:17:08.03] on the other hand, if it's...

[01:21:39.23] In last year's physics classes, If you think about these two solutions and Tutorial and last year's classes, which is closer?[01:22:13.04] Rina: This way of solving [plug and chug way] is close to last year's class[01:22:21.15] This year's class is more with words; there's a lot of "give an explanation"; last year, if you could solve the problem, it didn't matter

2. Madoka

[00:14:33.29] I: For example, suppose there's someone who is thinking about taking your class but wants to know what it's about before enrolling - what would you say?M: "Physics is hard isn't it" is what I'd say[00:14:42.05] I:Compared to other physics classes, this class is more diffiM: difficult[00:14:50.22] I:What part is difficult?[00:14:54.20] M: It isn't surprising, but up til now, I would think about things like calculations and phenomena and numbers, but[00:15:01.16] I'd just think quickly, like on intuition...[00:15:05.10] It's not surprising that when a contradiction or something would arise...[00:15:10.04] When a contradiction or something would arise, to think "wow, I wonder why?"...[00:15:14.21] really, until now, until now "this thing I had been thinking that is common and natural ... yeah, that seems to not match the physics" - thoughts like that, until now, I wasn't really doing that[00:15:30.22] So I feel it's hard

[00:15:41.23] I: I think I understand. In other words, physics classes that you've taken til now have been more about calculations, using numbers, for example, and[00:16:02.04] but, class now is not so much calculations and numbers, but more... well, something about contradictions you were saying, but... well, in place of those calculations, what are you doing? Can you explain that area again?M: In place of calculations, interpreting those phenomena is what it is, isn't it?

[00:16:26.12] I: Interpreting phenomena
M: Interpretations, with a contradiction, with a contradiction, if how you can fix it, if it matches physics or not, things like that
[00:16:48.23] I: How can you fix contradictions[00:16:58.09] And that kind of thing, inside of physics classrooms, you don't have that much experience, and it's hard to do[00:17:02.12] M: That's right[00:17:05.21] I: I see[00:17:17.19] I: And that is a bad point about the class now, right? Is there something good about the class?
M: A good point is that, if you sol…, can I say "solve a contradiction", the point where you understand is, unsurprisingly, it's that I guess you become more expert regarding physics, (???), everyday life's, the phenomena occurring in everyday life, there was a connection to physics… it's that point.
[00:17:54.02] I:If you can understand it, phenomena of everyday life with physics becomes connec…
M: connections were there, and, unsurprisingly, you understand better
[00:18:11.29] I: If you can make that connection, "now I understand better" is how you can feel, is that what you mean?
M: To summarize, it's that "physics is clear" is how you can feel
[00:18:30.20] I: Physics becomes clear
M: It becomes clear

[00:18:55.12]I: Did you take physics in high school too?M: YesI: What physics classes?M: 1 and 2[00:19:07.14] I: And what physics classes did you take last year? M: Last year was Physics Discussion and Basic Physics
[00:19:14.09]I: And, those high school classes and last year's physics classes and this year's other physics classes that you're taking are those kinds of classes? That kind of calculation, use numbers, don't fix contradictions, just calculations, for example. That kind of class was all that different from the class you're taking now?[00:19:39.10] M: You mean different than Tutorial?I: Right, right
M: First of all, the classes I took last year, it was a feeling of simply knowing (with emphasis) clear phenomena, "this phenomena exists", for example. The mechanics class I'm taking now is calculations and has a feeling of solving for answers. Unsurprisingly, they are different from Tutorial.
[00:20:09.23] I: And high school was closer to last year's classes of "this phenomena exists!" or was it closer to the class you're taking now of being just about calculations?M: BothI: There was both, I see[00:20:35.02] I: That kind of calculation, using numbers physics class, I understand that style, but last year's class, that "clear phenomena exist" type of style I don't know much about, how is that class different than your class now?
M: Phenomena, what I mean by phenomena, for example, is physics laws… it was at the level of introducing us to them. Somehow, if you talk about if they were a clear thing in the real world, that (???) didn't come.
I: What was that word?
M: Evidence, metaphors, it wasn't really…
M: examples…
[00:21:40.26] I: OK, I see, like current is like a flowing riverM: that's rightI: That kind of metaphor
[00:21:49.19] I: That was last year's classes that used metaphors?[00:21:57.07] Or was that more like Tutorial?[00:22:01.29] That style of using metaphors[00:22:07.29] M: That was Tutorial (after a long pause - how could it possibly be last year's classes?)I: I see. Tutorial uses metaphors
M: It's (or they are) easy to understand, right?
I:Metaphors that are easy to understand[00:22:18.19] I: But last year was...M: Last year was, well, laws, for example, laws would be given a small explanation. If I had to say so, even if there was an explanation, it really was not very clear. It was that kind of feeling.
[00:22:48.22] I: Sometimes there would be explanations, but they were hard to understandM: hard to understandI: But tutorial is more, for example, it uses metaphors, it uses easy to understand metaphors, and it's much easier to understand how it's connected to daily life[00:23:09.07] That's what you mean?M: YesI: I see

[00:23:33.26] In Tutorial, students are in groups and talk with each other and solve problems, right? Is that aspect different than high school physics classes, last year's physics classes, and this semester's other physics class? Or did you already have that kind of experience?[00:23:52.01] M: It absolutely was not there
[00:23:55.10] I: It absolutely was not there

M: In these classes we think individually
I: What were you doing individually?
M: Just taking notes and solving problems
I:You were solving problems during class?
M: Calculation problems, for example
I: Yeah, yeah, I see
[00:24:15.10] When you were taking notes, that was what the teacher had writtenM: Yes, that's rightI: That means, that's like, like what you previously said, kind of a one-directional teaching?M: Yes, that's right[00:24:34.12] I: The teacher's knowledge was written on the blackboard, and students took it sort of thing[00:24:41.13] I: That physics knowledge was from the teacherM: That's rightI: In Tutorial, that kind of knowledge comes from where? There's no lecture, and...
M: Unsurprisingly, things that we've learned up til now, or… how can I say this, right? Experiences. From experiences that we've had up til now. Everybody is talking together.
I: Ah, student experiences? Everyone's...M: Everyone's. Also, in intuition for example
I: I see
[00:24:22.13] When you were taking notes, you were writing from the teacher - knowledge was coming from him. Where does knowledge come from in Tutorial?[00:24:56.22] It's what we've learned so far, what we've experienced so far - we talk together... intuition, for example[00:25:41.23] I: When you entered Tutorial, were you surprised?
M: Yeah, I was, wasn't I?
[00:25:48.24] I: What was surprising?
M: It's called "Exercises", so, unsurprisingly, I was thinking it would just be solving lots of problems, and I thought "Wow, actually there's this way of doing it too". That's what it was.
I:And when you say "this way of doing it", you mean
M: I mean, everyone talking together, problems… or engaging with tasks given to us, rather
I: I wonder, did you have the reaction when you entered class of "This is utterly different than the style of physics I learned before, is this even physics?!"
M: (laughing) That was there a little bit in the beginning, wasn't it? I did think "is this really physics?" but the contents (???) and unsurprisingly, it is physics I thought
[00:26:46.24] I:If you remember that time, is there an opinion about what physics is?
M: What about physics?
I: That first moment, when you were thinking "is this physics?", did you have an opinion of what physics is?
M: An image of physics at that time
I: Right, an image of physics
M: Well, maybe it's just me, but physics is difficult, it's nothing but calculations and that makes it a difficult thing is what I thought (???), from a ruler, for example, with that kind of feeling

M: They had us enter from this area and, somehow, “oh, I wonder if this will be easy” is what I was thinking at the start
[00:27:47.28] I:Before the first day of Tutorial, your impression, opinion about physics was that it's hard and that there are a lot of calculations. And now, when you think about physics, what do you think "physics" is?
M: Will I say that it is difficult, but, unsurprisingly, it’s connected hand-in-hand with the everyday? It’s something clear, isn’t it?
[00:28:34.15] I: But before your opinion was that it wasn't particularly connected to everyday life?
M: It’s not that it was not connected, but, unsurprisingly, I could not feel that it was really clear
[00:29:01.03] I: I see. Now, you can feel more that you can understand physicsM: That's right[00:29:11.04] I: I understand

[00:36:13.18] Two rocks problem givenM: I should solve this?I: Feel free, yes, please do[00:36:26.23] M: In the case of no influence from air, for example, free fall is, if we take the (???) speed to be v, [00:36:40.25] 10 times... 2 seconds? 5 seconds, 50[00:36:51.05] and if the rock thrown with an initial speed of 2 m... 5... +2[00:37:08.23] so, this one, the (???) one [makes gesture of throwing a rock] is fast... I think.I: So the answer is "still 2 m/s faster"?M: 2 m... huh?I: Or is it more than 2 m/s?[00:37:30.08] M: it stays at that relative speed I thinkI: that relative speed, I understand[00:37:37.20] I: Where did you get this equation?M: That last equationI: Oh, it's the same as this?M: YesI: I see.[00:37:53.28] If I look at this way of answering, you put in numbers, did a calculation, 50 and 52, and if you subtract, it becomes 2M: Yes that's rightI: is that the way of answering?M: Yes[00:38:11.12] I: Is there another way to answer this problem?M: Another way to answerI: Yeah. Or with this problem, do you have to put in numbers and calculate?[00:38:40.27] M: the accelerated speed is the same, together at the time they are released, the difference is always the same, if you will, the difference... not the difference? This (???), what is it called is it?[00:39:06.05] Relative speed... they become together is what I mean[00:39:25.09] The relative speed becomes the same, so it remains 2 m/s is what it is, right? [00:39:41.03] I: Why is the relative speed always the same? Why is the difference always the same?M: If it comes to this, this might be wrong, but gravity is pulling on them the same, so it's just the start that determines the difference even if they are pulled[00:39:54.10] it doesn't decrease, that... both. It's just the initial difference that decides it, I think. If you do that, the relative speed is the same.I: Because the acting force is the same...M: That's right, gravitational[00:40:17.09] M: The force of gravity is the same, so only the initial speeds determine the difference in speeds, so it's still 2m/s, right?I: I understand the first thing that you're saying - the gravitational force is acting the same on both of them, I understand that. And I understand that in the end, the difference is the same as the beginning difference, I also understand that. But, how do you go from that "the same force is acting" place to that conclusion is kind of not yet understood, could you explain that a little more, what's in the middle?[00:41:14.16] M: The place in the middle?I: That Japanese was strange, wasn't it, I'm sorry. [takes paper and pen to draw a diagram of the starting assertion, a dashed line leading down the paper, and the final conclusion at the bottom]   For example, you said that the force is the same, right?   Gravity is the same.   And here, the conclusion is still 2m/s.   How did you get from here to here?[00:41:48.05] What's in the middle?M: Since the pulling force is the same, the acceleration is the same, so the change in speed is the same[00:42:00.00] I: Ah... the change to the speed is the same, because the accleration is the sameM: The speed too is the same.   If you do that, the other rock stays behind the other one the same amount, is what I was thinkingI: I understand. Because the change is the same, the final difference that they have is the same as the difference held at the beginningM: [with conviction] yes, that's right

[00:42:30.16] I: If you look at this way of answering, you put in numbers and do calculations, right?M: Right[00:42:37.13] I: This other way of answering is what kind of way of answering?M: You mean this one?I: Yes.   The one you just said, the force is the same, the acceleration is the same and... this is like a mathematical... ?[00:42:52.12] M: Yea, mathematicalI: Well, you do calculations, for example, that kind of way of answering.   This other way of answering is what kind of way of answering?M: I have never actually done it in the real world, but, not surprisingly, it's having an image, isn't it?When I was doing it, it was a (touch?) of "It would be like this, wouldn't it?"Yea, image-like; a simulation[00:43:22.03] I: When solving this kind of problem, which way of answering do you use more often?   That image-tekina way of answering, or the calculation style way of answering?M: (???) the mathematical way (???) came out [00:43:53.23] I: A little earlier, you explained that before you entered Tutorial, you had the opinion that physics is difficult and it's just calculations, but upon entering, it became easier to see how physics connects to daily experience, right?[00:44:25.19] If you look at the explanation of this velocity equation, for example, if you look at this explanation, which way of thinking about physics is closest to that?   Or is it a different way of thinking?[00:44:46.23] Maybe that was also hard to understand...[00:44:50.04] M: Um, yeah, this, during the explanation, I wasn't thinking about mathematical equations, just about speedWithout thinking about mathematical equations, if I just think about speed - I did that, butwith this, unsurprisingly, I (sense of regret) used mathematical equations and... how can I say this?[00:45:30.02]   I: This is hard to explain, sorry... M: Sorry, somehowI: No, hmm... with the equation explanation, you were basically thinking about velocity (writes "v" and circles it).   About equations, for example, well, about calculations - you weren't really thinkingM: I wasn't thinkingI: And when you were solving the problem, the previous, this way of solving was[00:46:01.00] about a calculationM: calculationI: you were thinking (writes "calculation" and circles it)[00:46:13.02] I: What you just said is that, when you think about physics (writes "physics")the way of thinking before Tutorial was just calculations[00:46:26.00] and (writes "calculation" and circles it), but now if you think about physics, the connections to daily life are much more present, M: Not just calculations[00:46:44.19]   I: Not just calculations, and everyday (writes "everyday")M: Not just calculations, but calculations are also important, aren't they?[00:46:49.00] I: Are also necessary, aren't they? (writes "calculation" and circles the two words together)[00:46:59.19] With this kind of time where you were explaining the equation, that way of thinking, that thinking about speed, is that close to this way of thinking[00:47:09.13] or was it close to this way of thinking or was it a different way of thinking?M: It's separate, isn't it?[00:47:18.05]I: It is separateM: It's close to an image[00:47:20.12]   I: It's close to an image.   Got it.   This is Tutorial, this is the opinion before Tutorial, and this is "image" (writes "image" and circles it)[00:47:35.09] And this is close to this (draws arrow from "v" circle to "image" circle)M: That should be "ji"I: "ji"?M: Oh, never mind, yes, that's rightI: This is right, OK, got it[00:47:52.04] And if you look at this initial way of solving, which is it closer to?M: "Calculation"[00:48:00.15]   I: That past, towards physicsM: Yea, that's right[00:48:08.06] I: I understand.   And if you look at that second way of solving, what is it close to?M: The second one is an image here isn't it? (points to the side of the "image" circle)[00:48:16.25]   I: But this (pointing to "image" circle) image... M: It's in the middle, this, it's not completely "image"This, if I actually did it, it might fit in "everyday", but I perhaps have not done itAnd if you do that, it (sense of regret) ends up in here I think[00:48:37.03]   I: I seeM: (??) experiment, in about this middle area[00:48:43.15]   I: I understand

[00:55:34.24] I: In Tutorial, it's not the teacher's knowledge, it's not a lecture; the stuff you're learning is from the group, the things you are thinking yourself, you use your own experiences and intuition to learn, is what you said before?   Have you had this experience, this through your own prior experiences and intuition, learning experience, have you had that, other than this class?[00:56:07.22] M: Unsurprisingly, not reallyI: OK.[00:56:33.20] You said that in high school, the teacher would basically teach unidirectionally - there would be a lot of lectures, but in elementary school, the feeling was more of a "let's all think together!", for example... that thinking and Tutorial's thinking for yourself - how are those different?   How are they similar?

M: The thing different from here is, unsurprisingly, doing (???) ourselves, deepening knowledge ourselves

I: TutorialM: RightI: And in elementary school, what you said is it's different than high school, let's all think together

M: Everyone does it, will I say (???)

[00:57:33.19]   I:That "let's all think together", that thinking for yourself and Tutorial's thinking for yourself - how are they different?[00:57:44.22] M: The difference?I: Yes

M: The difference is…

[00:57:48.06] I: Or how are they similar.   Please compare those two experiences

M: Unsurprisingly, the part of everyone’s opinion (???) is, unsurprisingly, similar I think

[00:58:09.19]   I: OK, but elementary school was not using experiences and intuition, in order to say that opinion, is that the difference?

M: Use intui… ?

I:Sorry, it became confusing!   The thing that's similar is that both Tutorial and elementary school is that everyone says their own opinions

M: (???)

[00:58:32.00]   I: And, what you just said is that in Tutorial, students use their own experiences and intuitionM: Oh![00:58:39.22] I: And, that experience was not in other places, is what you said?   So it's kind of hard for me to understand.   On the one hand, both elementary school and Tutorial have "everyone says their own

opinion" but on the other hand, Tutorial uses your own experiences and intuition and in other places, like elementary school, you didn't have that experience. Is that not a contradiction?[00:59:13.24] M: It is, isn't it?
If we're thinking about saying an opinion, unsurprisingly, in the case of elementary school, regarding that experiment, everyone altogether, you try it, or you look at the teacher's experiment, and you talk about what you did, and you deepend your understanding. Unsurprisingly, that experience is connected to the experience of Tutorial now I think.
[00:59:46.00] I: OK, I understand. You have solved the contradiction, thank you very much

3. Miu

16:53 (Please tell me about Tutorial)
M: Tutorial, right? No, really, somehow, it's like I've never before thought that physics could be this much fun. It's become an interesting, it's interesting. Within my awareness, I like biology more than physics, more than anything… this physics… I do that Tutorial… I've absolutely not been doing physics
[00:17:40.07] I: Oh, like in high school, last yearM: Right, right. Middle and high school were combined, and everything was completely done in middle school – it was that kind of curriculum, so in high school, it's a feeling of doing what you selected yourself, ah… during the first year of high school, I did a little, well, I did it but, basically, I'm not touching it, it's a feeling that I'm not doing it, and, unsurprisingly, my awareness of physics is something I don't like. It's like this, kind of I want to avoid it, it's that kind of feeling, right?
[00:18:12.25] I: That was because of the experience in middle school?
M: Um, yes, somehow, in middle school to actually, think like this, to think, somehow calculations, somehow calculations, the moment that physics became calculations was when I thought "this is impossible", yeah. Somehow, there are difficult equations for calculations, to have to use that and solve, when I thought that I can't solve, "This is, for me, *difficult*", is when it became hated. At that moment. But, from those mathematical equations, I also started to not touch mathematical equations, and, at that point, gradually I fell out. I do this Tutorial and, in actuality see this kind of collision or to draw water, to let it trickle out of a water container myself and see that, somehow, it's a feeling of first doing the funness of physics, yeah.
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. [00:23:55.24] I: Do you feel that what you're learning now makes sense? Or is what you're learning now simply something you need to memorize, even if it doesn't make sense?M: Ah, no, I think it's something I'm mastering
[00:24:03.25] This, somehow, just(???),[00:24:05.25] it's totally different from (???) classes, and, like,
[00:24:11.25] that thought is there, that
[00:24:14.10] like this of myself, what am I trying to say… like this,

[00:24:19.18] like this, if it were just memorize, it would just quickly fall out, right?
[00:24:26.09] That's my case.
[00:24:27.22] But, somehow, I thought "Ah!" (has a look of revelation as she hits her fist into her open palm)
[00:24:32.16] That understanding, if you will, making sense, my thought of "Ah!" (repeats the gesture), somehow[00:24:36.22] I won't forget it, and I don't want to forget it is what I think, I do.
[00:24:42.04] Because of that, "let's always feel that way", if you will, that, that
[00:24:49.20] thought, what is it called? Mmm, uh, it's not a thought, but …
[00:24:51.28] I think I want to think. Even in daily life – earlier I was talking a little with a friend… [00:24:58.08] Even climbing the stairs, four, while going from the first floor to the fourth floor [00:25:02.10] To that degree, like this, "if we're climbing this, thinking about (matching???) energy -
[00:25:06.08] I started thinking about that, you know" is what I'm saying and she says "Yeah, right? I think so too!" – it's that kind of feeling.
[00:25:12.13] (laughing)I: Is that right?M: Yeah[00:25:17.19] M:We were talking about that, yeah
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[00:28:18.06] I: Oh, first of all, sorry, you told me about physics in middle school, but did you take physics classes last year?[00:28:27.00] M: Yes I didI: What kind of feeling were those classes[00:28:29.05] M: Calculations… calculations, if you will, right?
I:Did you hate it?M:Somehow… but… I like watching calculations, and if I'm watching them it's good, but I don't want to solve them - [00:28:43.05] that's what I was thinking. (laughing very loudly). Pardon me, yes.
[00:28:48.13] I: Got it. In those classes, was it necessary to solve? Or could you get by just by watching?[00:28:55.02] M: I'd stare, and the answer would come out (???) and I'd think "Wow, amazing [00:28:59.11] But somehow, it became (???), when I'd come to not understand,
[00:29:04.16] I thought "I've had enough"
[00:29:09.07] I: Oh, in that previous class, you weren't able to understand was how you felt?M: Yes[00:29:13.21] M: Somehow… memorize (with emphasis) mathematical formulas is the feeling [00:29:15.09] I: Mathematical formulas, equations, for exampleM: Ah, equations for example[00:29:22.24] From there, somehow
[00:29:24.21] (Speaking in monotone), memorize, apply, get out an answer
[00:29:32.06] I: Right.
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[00:30:40.10] I: Did you have this reaction: "Huh?! This is utterly different than middle school's and last year's physics class - is this even physics?"
M: Ah, I thought it was utterly different. Completely. This, ah, but if we're thinking about *physics* then certainly it is that kind of thing I'm thinking. I guess it comes out from the everyday. I started wanting to know more about physics things, and that, to this degree, you can learn the same thing, but you can learn it even though the style is as different as this – that's what I thought.
[00:31:29.19] I: It's still physics that you're learningM: Yeah, yeahI: But the way of learning it is differentM: Different[00:31:32.17] The way of learning in Tutorial now is in groups, talking, and the previous class's way of learning was calculations, for example?
M: Calculations, for example, from some kind of mathematical equation," the mathematical equation goes like this, this, and this, and it holds true here!" kind of thing. The Earth is, what was it, the Earth's (???), well, (it didn't get that far?), but, somehow, to lead to that answer, in the understanding – there was an image of a kind of feeling that it's about mathematical equations, and somehow, from start to end it was nothing but that. It was mathematical equation (???) it couldn't come out, the answers wouldn't come out – there was that image, you know?
[00:32:29.02] I: In physics classes before Tutorial, if you would think about physics, your image towards physics was that it was mathematical formulas and from calculations, something comes out...
M: What am I trying to say… the answer if you will, laws, everything comes from mathematical equations, they are things derived, so, well, you have to understand equations, and you have to memorize them… what can I say, what… that was my personal image. Yeah.
[00:33:12.19] I: Laws come from calculations and equations
M: They do
I: It was that impressionM: Yes[00:33:16.10] I: And after entering Tutorial, that kind of physics knowledge, for example, laws, if not calculations, where does it come from, you know what I mean?
M: Calculations if you will, somehow, everyday's regular… sort of like, this kind of thing as well (moves bottle up and down and smiles)for example, "Oh, I see!"(lifts bottle again), for example, somehow, what is it (laughs). Like, it's a different street than the everyday, the most (???), mathematical equations, difficult mathematical equations, ev…, something like, since you don't use it in living a normal life, it's (???). But in the norm, this kind of movement you do yourself, if you will, even this kind of action (puts pen down in a different place), if you look at that for example, if you move for example, even just doing that, "that's physics too!" kind of thing.
[00:34:17.15] I: Everyday life, for exampleM: Yeah!I: In a day, even if you don't use an equation, you can still learn about physicsM: Yeah, yeahI: From your own experiences, for exampleM: Yes![00:34:35.14] I: Got it.
[00:34:51.07] I: In Tutorial, students are talking in groups, right?M: YeahI: Was there that feeling in previous physics classes too?
M: Ah, no there wasn't
I:There wasn't

[00:35:05.29] M:The teacher, regarding (???), students would (makes gesture of students writing notes maniacally)[00:35:08.26] kind of, like this, and, like writing, yeah. Write and understand… if you didn't understand, [00:35:17.12] after class, you would go to the teacher, for example, to ask your question – it was like that.
I: I got it. And, in that class, the teacher was writing on the board and students were taking notes... if that's the case, was the knowledge coming from the teacher? That teacher was writing his own knowledge on the board, and students were taking that knowledge, but in Tutorial, the teacher isn't lecturing, and there is no textbook, so where does it come from, physics knowledge?[00:35:57.18] M:Ah, I see. In the before ones, there is an image that it was coming from the teacher, but [00:36:00.13] like this, uh… in Exercises… from where… from where does it come I wonder [00:36:08.13] I wonder if it's good to say it comes from ourselves, somehow
[00:36:15.12] Receiving help (???), from TA teachers
[00:36:18.09] The help is, the help, it's help isn't it, even though we receive help
[00:36:22.27] Somehow, from inside of us, we go and make sense of it, if you will,
[00:36:29.03] Gradually go on learning it-
[00:36:33.02] I have that feeling
I: I understand.

[00:37:37.24] I: How would you explain this equation to a friend from college class?M: How... Can I use an object?I: Sure[00:38:00.25] M: Imagine this is a car (she lays the bottle of tea on its side on the table)... I'm explaining this, right?I: YesM: This is speed and here is the start line (makes a line with her hand on the table)[00:38:17.29] and here... The car is moving (she moves the bottle)The speed at this point is the initial speed, and it's the speed it already hadand in addition to that, that, t is time, a is acceleration, butthe speed is, depending on how the acceleration is acting, the speed gets gradually faster and faster[00:38:49.01] speed, no not speed, acceleration, acceleration is acting and while it's acting, after some number of seconds, how many seconds? If we take this to be zero seconds, some number of seconds, after t seconds, after some number of seconds, since you want to know what the speed is[00:39:03.08] the speed is the thing it already has plus alpha, from here, even more added,[00:39:13.28] added speed is what you add, and here (makes another line with her hand on the other end of the table), and the time you want to find, the speed can be found.[00:39:27.25] I: I see. Well, let's think about a different situation. (On a physics exam?)M: I'd draw a pictureI: Go ahead[00:39:35.18] M: Oh it's OK to draw a picture too (writes on paper for first time)I: Well, it's OK to draw a picture, you don't have to draw a picture if you don't want to, you can give an explanation verbally, either way, feel freeM: OK. This is t = 0[00:39:50.24] and the thing you are solving for is v and at this time, v0, is... what, v, v,v, v is v0 and[00:40:07.25] no...[00:40:25.03] what it has at this time is v0, t, and... after t seconds[00:40:45.20] at this time, oh, this is hard[00:44:13.19] (She at last looks up from writing silently)[00:44:16.21] I: (laughing) Can you please kind of read?M: (laughing loudly) Oh yeah, sorry!I: No problemM: Um, but the thing I was saying before, um...[00:44:28.24] I'm explaining this, and [00:44:37.15] This is the equation to find speed after t seconds and[00:44:43.00] that v0, when t is zero, it's the speed it already has [00:44:47.21] t is, you take v0 to be the speed that it already has, and, first get over the equation[00:44:54.20] and on top of that, that, here if we take this to be zero seconds, after t seconds[00:44:59.25] how much the speed increases, how much the speed became faster[00:45:04.20] to show that, the acceleration is, the acceleration, acceleration, the acceleration is[00:45:14.09] acceleration is, that, acceleration, relvative to speed, if you apply an acceleration, the speed gets faster, how much the time passes, a times t, you do that, and this part (at) is how much the speed increased or decreased, so you can find it, and in addition[00:45:38.29] the speed you had in the beginning, plus at - that equation is what you can use to find the speed after t seconds....[00:46:53.12] Speed is, looking at units too, unit-wise, um... m/s^2, right (she writes on the bottom of the sheet)? If you multiply that by t, you (???) the s, so you get out m/s, which is speed. But if it's just that speed, perhaps at t0, there might already be a speed there, or maybe not (with emphasis) - there are those times too, but if you, well, if it's not there, it's good to say 0, and if it is there, well, it's hard, if you will, that plus and additional speed I think, so, without forgetting this v0, this increased part or decreased part of speed, adding both together, you can find the speed at time t - it shows that equation I think.[00:48:13.03] I: I explain the two rocks prompt[00:48:58.01] M: Fourth floor, oh, yeah, it's the fourth floor balcony... and... the height... um, are they still (???) (gestures throwing both)I: One is just freely dropped, and one is thrown downM: thrown (gestures throwing a rock down)... but both have not yet reached the ground, right?I: Yeah, they have not reached the groundM: Ah, they haven't reached, they haven't reached... um... and, since it's 2 m/s (throws rock down) faster[00:49:26.12] Five seconds? In five seconds? (she rereads the problem). Which is it? Um... 2 seconds, 2 m/s...[00:49:48.12] oh, it's fast[00:49:54.13] You mean more fast?[00:50:01.18] more... um... more than 2 m/s... fast, fast, it's fast, fast, fast, it's fast[00:50:07.07] When you say "fast", do you mean less fast, more fast, or equally fast?[00:50:13.25] Oh, I see... uh...[00:50:22.26] It's comparing the two (holds two rocks side by side), right?I: YesM: If you're comparing the two, then it remains at 2 m/sI: How did you reach that answer?[00:50:37.07] M: Um... The rocks are the same (holds the two rocks and rotates them) - is it good to think that way?I: SureM: If that's the case, then the the mass (moves right fist in air like a cheer), the mass (moves left fist in air the same way) is also the same... huh?[00:50:50.11] From the same place (raises her fists to eye level), you throw them (lowers fists and raises them again), if you will, you drop them (lowers fists until they hit the table), and (raises fists and lowers them again)... the gravity acting the same (points down with right hand), if that gradually falling (moves downward pointing finger up and down)... (points down with left hand and moves that hand down as she makes a face of exasperation and sighs)[00:51:00.28] in that gradual fall (she alternates her hands moving up and down) , It's the gravitational acceleration acting (shakes right fist), it should be that the same amount is acting (shakes both hands with downward pointing fingers), and, and, I think, and[00:51:12.04] like this, if you throw the one rock at 2 m/s (throws rock)... huh, 2 m/s? The 2 m/s speed that is already there is how you threw it (throws rock), so, and, plus[00:51:23.16] like, the regular speed is carrying more than the already 2 m/s speed, so[00:51:28.16] really,[00:51:33.21] If you just dropped them both, they would gradually fall (holds two balls in her hands and lowers them and then repeats), but... they would fall the same (makes palms face her and then lowers the edges of her hands to the table), but it already has 2 m/s (half-heartedly throws a rock), so just that part (puts hands parallel in front, like brackets), that... it will fall fast (throws two rocks), I think[00:52:01.10] I: I perhaps understood. What you said is that the acting force is the same, so it falls the same wayM: In actualityI: And in that way of falling the same, [00:52:17.21] I: the one that you throw you add a little bit of extra to... is that what you said?M: Yeah, that kind of thing [00:52:39.22] I: That is one way to answer this problem. Is there another way to answer?[00:52:42.14] M: Another way of answering is... is it forbidden to return?I: NoM: Huh? Is it OK?I: You can returnM: Oh, it's OK to return?I: Yes[00:52:57.23] M: Um... with this (points to equation), in the problem I did previously,[00:53:03.05] in whether or not it has an initial speed,[00:53:11.13] that, after t seconds, after t seconds, how much... um, this[00:53:19.29] the Mr. little rocks, in the thing of what gives birth to the difference[00:53:23.25] and, um, v0's, no, this Mr. A's is... what, no, not Mr. A - it's not a person, Mr. A... Mr. little rock A[00:53:33.20] is, at a speed of 2 m/s, you throw, this one is zero - at the time you say that,[00:53:43.27] if you substitute these in, that... this way is gravitational acceleration is[00:53:52.04] decided by this (circles the number 10 provided on the interview prompt)[00:53:53.21] and a is acceleration, and 10 m/s s, and, time is the same... the same? Supposedly they fall at the same time (looks at interviewer and he nods affirmatively)[00:54:06.15] so, take it to be the same t, the already had, that, if you do that, here is like this, [00:54:14.13] well, you say it dies (cancels out the at terms), and the difference is just that[00:54:18.06] 2 m/s or 0 m/s is the difference, so[00:54:23.24] it's already, somehow, yeah. No matter what time you substitute in,[00:54:28.28] this one is already 2 m/s part of speed is fast.

[00:54:51.11] I: I want to show you yet another solution, and I want you to evaluate if it's good or bad and to what degree it resembles your own solutions and to what degree it is differentM: OKI: That way of answering is: Use this equation...
M: (laughs) Oh I see! Substitute in for the variables
I: Right
M: That kind of thing
[00:55:26.23] I: Right, and, um... one rock has an initial velocity of zero and the acceleration is 10, t is 5, multiply,M: Oh, right, it's 5 (laughing embarrassed)I: That's 50... sorry, what did you say?M: Nothing, just thinking that it's 5 secondsI: Right, um... so that means that after 5 seconds, you have 50 and the second rock's speed is, the initial velocity is, as written here, 2, and if you use this equation, insert again the acceleration of 10, and for time, insert 5, if you calculate, it's 52, and if you subtract, the differencere remaining is 2 m/s, therefore the answer is "still 2 m/s faster" - I've seen that way of answering, but, what do you think of this way of answering? First of all, is it the same? Or is it different?
M: This answer, this way of answering, in regards to this question, is it good or bad, is that what you mean?
[00:56:40.16] I: Yes
M: This, let's see here, uh, since I myself just now (???) (points to her own solution), um… this, let's see, this equation is… it's meaning if you will, I have a feeling that it's

not good to think of just substituting. In my case, first, like this (moves a bottle), an image if you will, actually, something like this, to some degree you have an image, and, and then something like, in a spirit of "let's look for the difference", (meaninglessly?) wrote it, but, if you just substitute like that… "since there is this equation, substitute and go, the answer comes out, the difference comes out, so, wow, it's two seconds, two meters/second always fast", in that kind of feeling, saying that is somehow not very good is the feeling that I get.
[00:57:54.25] I: I understand. If there is no image or anything like that, just a calculation, for example, I see.
[00:58:03.11] I: A little earlier in this interview, you said, huh... where can I write this... I'll write it hereM: OKI: No, I'll write it hereM: (laughs)I: Your way of thinking about physics, prior to Physics Exercises, you had a way of thinking about physics, that was[00:58:29.29] M:Mathematical formulas…
I:Yeah, calculations for example (writes "before" on the paper)M: Yeah, yeahI: And after entering Physics Exercises, you had an impression that was different, um, what you said was, for example, everyday experiences for example, from everyday life, physics learning can happen, for example, um... (writes "after" on the paper)[00:59:05.03] ThisM: this problem (points to paper)I: Yeah, these three, for example. For example, this, well...[00:59:13.19] Maybe, first of all, this way of answering (points to plug and chug solution given by interviewer), if you look at that, this way of thinking is (Miu interrupts the sentence and points to "Before"). Oh, it's this?M: (laughs and catches herself) Uh, well, yes.
I: And why is that?[00:59:31.10] M: Huh? Uh, ah, how would it be? Uh, uh, if it's the "before" me,
[00:59:47.16] this is this way (points to "before"). If you ask why,、
I:Yeah[00:59:50.21] M:An equation is just given, into this, if you substitute in the said things
[00:59:56.29] an answer comes out, that, that answer coming out thing is, it is that, but, but, [01:00:02.24] Now, if it's the "now" me, then maybe this (points to interviewer's solution) can also fit this way (points to "after"), it can fit[01:00:10.26] I: Oh this(points to interviewer's solution), goes in here (points to "after"), is what you said? Am I wrong?M: It, yes. Now (with emphasis), now, now that meaning is under… the meaning is understood, if you will, [01:00:20.02] On top of having an image, you put out an equation, if you will,
[01:00:24.06] there's that, and, and from there,
[01:00:26.23] that, if you take it to be setting out to find a difference,
I: Ah, you're talking about this way of solving (points to Miu's solution)? Not this way of solving (points to plug and chug solution given by interviewer), but this way (points to Miu's solution) of solving?[01:00:35.25] M: Ah, that's right, isn't it? If it's this (points to her own solution), it's this way (points to "after" but, unsurprisingly, one where this (points to the top part of her solution) is lacking, if it's only this (points to interviewer's solution), unsurprisingly, it's this way (points to "before")I suppose (pitch of voice drops, as though disappointed)[01:00:50.10] I: And, when you were explaining the equation? Which way of thinking was the way

of thinking close to? Or was it close to another way of thinking?M: Um, this, my way of thinking?

I:Yes, when you were explaining[01:01:04.03] M: When I was explaining, this part (points to unit analysis part)was, if I had to say so, would need to be this way (points to "before") I thought (sense of regret).

I: OK[01:01:09.06] M: This kind of thing is sort of, actually this kind of (lays bottle on its side), for example

I: YeahM: To use that, and explain would have to be this way (points to "after")I am thinking.

I: Closer to afterM: Yes

4. Tadao

[00:05:00.10] I'm interested in Japanese education system; what was your elementary school like? T: Yeah, right? It was pretty much, to an elementary school student himself it was pretty, how can I say this, right?... free... it wasn't really a feeling of (???), follow the will of an elementary school student, a pretty free feeling (???) I would say, right? [00:05:28.02] I: I see. Students were, like, by themselves, it was OK to do what they wanted, T: That's right, isn't it [00:05:35.04] What about middle school? What kind of feel was that? T: Middle school too, was largely the kind of feeling of (occupied that column???) and, it was the same kindo f feeling, but, to some degree it became a little strict, you (???) rules, along those lines, that, with middle school students, um, it's a thing where you (???), but that kind of feeling of going on having some control... how can I say this? [00:06:04.11] I: The teacher, to the students, a little T: A little I: It wasn't free - that was beginning T: That's right. But (???) a little. [00:06:13.14] What about high school? T: High school was already, unsurprisingly, pretty, that control kind of became a bigger thing, it was that kind of feeling, right? [00:06:26.05] I: Do you have an example? T: Ah, no, rather, more than the thing of teachers controlling, from students themselves, it was a feeling of let's go and do that (???) - there was a lot of that, right? [00:06:44.07] I: Students were controlling each other - is that what you mean? Or that, individually... T: Individually, by yourself - there was more of that I think That and, that individually by yourself thing was because there were a lot of people, that, you'd take the influence of those people, and with a feeling of "I will do that too", "I myself shall protect that (tightness???)" - it was that feeling. There were a lot of people like that. [00:07:09.29] I: I see. Generally, from a college student's eyes (usual prompt about which school stood out the most) T: For me, all three... that much, no, pretty, all three, different (???) they were different, weren't they? It's a feeling that they were all separate and... [00:07:50.00] I: I see. All three were different. I understand. Now, if you compare elementary and middle school to high school, what was the biggest difference? T: Elementary school and high school? I: Yeah, maybe... sure T: Yeah, right... [00:08:13.04] I: Well, like, think about something that elementary and middle school had in common, and if you compare those two to high school, what was different? T: Ah, unsurprisingly, students individually were, that enrolled in classes (???) people were numerous and, elementary and middle school were pretty, it was a feeling of "let's do our own favored (emotion???)" but, in the case of high school, unsurprisingly, going on to college, going on to the university, for example, also began to matter, so that part is, unsurprisingly, the mood was a little bit "decide your own course" and then go along that (path???), go along that path was the style of feeling that it became. [00:09:03.05] I:That's in high school? T: Yes. Elementary school, middle school was a little more, your own senses are half-hearted, if you will,there were a lot of "let's try putting our hands out into various paths" people I: You would try out various things, but when you entered high school, like, "let's do it like this", like, all the way... T: That's right. That is accurate. [00:09:25.10] I: I see T: I think that I myself was that way [00:09:34.29] Did the teaching style change? T: Ah, that did change, didn't it? Um, the survey, that, there's a survey that was given on Webclass, isn't there? [00:09:45.02] I wrote it there too, but, elementary school was that, pretty much in a group (???), we would talk together, um, students were meeting together, student remarks (???) but, in the case of high school, it was like that was absolutely not there [00:10:01.16] I: At that time, did you prefer the elementary school style or the high school style? T: I prefered the elementary school style. Pretty much thinking by yourself, we got a lot of time to do that - just thinking by yourself. Unsurprisingly, the educator, the educators, um, since they were thinking "let's put out a fun class, let's put it out in a fun way!", unsurprisingly, the classes, each one was fun. In the case of high school, unsurprisingly, getting into college, for example, started to be important, so... it wasn't mandatory, but, well, unsurprisingly, university entrance exams, um, it has an effect, does it not? I: When I look that word up... [00:11:25.13] I: Can you explain with different words, sorry... [00:11:31.29] T: (repeats pronunciation to self) I: Ah, OK... got it. In other words, in high school, for that entrance exam studying, um, the class curriculum was, um, like, well, students were taught so that they could do well on the entrance exams, T: That's right, isn't it [00:12:01.03] Is that what you're saying, I wonder T: The number one (???) is what they were teaching for us, right? They were classes for that purpose, but, elementary school classes were not that entrance exam, um, if it was that science, then science, if math, then math that they made us think about in a fun way. Since it was that feeling, unsurprisingly, that was better in my mind. [00:15:17.09] Tell me about Tutorial (standard prompt) [00:15:47.27] T: Is anything OK? I: Yes T: Yeah, right? Uh, in the past, I hated the thing called physics you know. [00:16:00.06] Uh, the calculations of physics, for example, that kind of thing, I was thinking it's a real pain. [00:16:14.21] It wasn't really a class where I was thinking "I am fond of this and want to do it!"; [00:16:21.03] however, the class of Tutorial is pretty, the thing that I like, since it's a feeling of being like elementary school classes... because it's the kind of class where you think in a group, put in order your own thoughts [00:16:36.20] I: Sorry, say that again, like elementary school classes... ? [00:16:43.03]T: Sure, um, you think in a group, uh, the thing you were thinking yourself, just as it is you can write it out and put it in order, [00:16:48.14] so it's pretty much a class to make you like physics is what I was thinking [00:16:53.23] I: OK, so like elementary school classes... that word, it's like "group"? T: yes, that's right [00:17:30.05] I: Oh, got it! You would think in a group, OK [00:17:35.09] T: Right [00:21:36.19] I: Does what you're learning now make sense or is it just something you have to memorize even if you don't understand it?T: Nah, I think it's pretty much making sense. Uh, myself, even for a human in the style of not coming from learning physics, uh, properly...[00:21:51.01] That's right, isn't it? Since it's not a feeling of (???) knowledge by itself... you think by yourself, uh, in reality, physics, uh, equations, for example, in the real world, properly "this is applicable, you know".[00:22:06.12] is something I understand, so I'm thinking in a way that is pretty easy to understand.[00:22:10.05] I: Did you take physics last year?T: I took it[00:22:19.04] I: Was that class different from Tutorial?T: Yes[00:22:27.16] T: It was different, right? Like, because it was a form of ??? knowledge, the teacher would, unidirectionally, on the blackboard, uh, be writing, and we would memorize that - because that was the feeling of the class.[00:22:38.27] I: But now, Tutorial, it's not about the teacher teaching unidirectionally, instead... just now you said "your own knowledge" or something you were saying[00:23:08.19] T: Huh?I: Tutorial is not receiving unidirectionally from the teacher[00:23:17.21] T: It is not that, uh, we ourselves, among the group members, we think together, and we go and derive answers ourselves - because it's that form.[00:23:28.01] I: What you just said was that the way you used to think about physics - calculations are a pain, for example. Was that from last year? Or was it from way back in the past?[00:23:56.18] T: It was also there a long time ago, for example, and in last year's physics class, unsurprisingly, I think "dang, physics is a pain."[00:24:05.23] I: Did you take physics classes before last year's? [00:24:09.23] T: NopeI: Where did that opinion come from?[00:24:12.01] T: That was, uh, in a middle school class, uh, a long time ago, calculations for distance, for example, uh, calculations for finding an angle, for example, even in math class, there are calculations that used pictures, are there not?[00:24:39.24] That kind of thing, I hated it, so... because of that, since I was understanding that there is a lot of that kind of thing in physics,[00:24:46.25] I thought "this is not for me" and I was quitting, right?[00:24:53.07] Basically, it was a kind of thing that I disliked without having tried it, and, uh, it was a feeling like "I've never done it, but it's becoming hated", so[00:25:08.26] I:Right, right, right. I get it. When you entered Tutorial, were you surprised?[00:25:12.10] T: That's right, isn't it... pretty much " there IS also that kind of way of learning physics" is what I thought, and I was surprised.[00:25:20.02] I:At that time, did you have this reaction "Huh, this is completely different than last year's physics class - is this really physics?"[00:25:34.01] T: Nah, that thing... it wasn't a feeling of "is this physics?", but rather there is a thing called physics, and, uh, in the approaching to it, uh, there are various ways to approach it is what I was thinking.[00:26:09.10] I: I see. That means that your previous approach was calculations, for example. Through calculations, you'd do physics. Last year's class, for example...[00:26:17.01] T: Last year's class, uh, it was a feeling of stuffing knowledge into your head.[00:26:44.02] I: And after entering Tutorial, what...[00:26:46.18] T: In Physics Exercises, from oneself, go and put out answers.[00:27:15.01] I: We are going to do some physics problems...[00:27:50.25] I: Explains velocity equation[00:28:00.28] I: How would you explain this to a friend in your college class?[00:28:03.05] T: That's right, isn't it... speed is, uh... ah, is it OK for me to (sense of regret) write on this?[00:28:35.08] I:Go aheadT: OK. Speed is, uh, from the past... the past... (drawing) and now... It's the, from here to here...[00:28:59.00] I will talk about the process; that is what I'm talking about, but... v0 is up until this point, uh, it's the past speed, and this "at", acceleration times time, is, from here til here, what kind of process, what kind of, uh, type of force application - it shows that, [00:29:36.07] no, that's a mistake. (scratches out left-most line) v0 is the speed at this point, and "at", acceleration times time, is here, from the past to the present,[00:29:54.04] that, the force is going up, if the speed went up, if it went down, it's that feeling, and, in addition, here is the v, speed, of the present now.[00:30:10.14] I: On a physics exam, there's this problem of "Explain this equation!" How would you answer?[00:30:16.12] T: Ah, I see. (Reading instructions to self)[00:30:26.29] Yeah, I will use a graph, but...[00:30:53.02] v is, let's see, the intercept on the v axis.[00:31:21.25] When time is 0, the intercept is v0, and, this... ah, I made a mistake.[00:31:38.01] Let's see, let's see, (talking to self: "slope..."[00:31:42.13] The slope of this graph is "a" and in the progressing of time, speed goes and rises just by "a". I will explain by using this graph.[00:32:10.23] I: Suppose there's a 12-yr old child. The 12-yr old comes walking up to you and asks for an explanation, how would you explain?[00:32:19.09] T: A 12-yr old child? That's fifth or sixth grade in elementary school, isn't it? This equation...[00:33:33.19] Let's see, example, I will explain by example, but... [00:33:37.26] In the period from 12 til 1 pm, a car will move. The, um, speed of the car when it is 12, there is this kind of speed, and the speed meter is, um, v0, well, for example, 60, 60 km, 60 km/hr, it's progressing at.[00:34:26.04] At the time of v, well, how many km is it? That's the style I would go and explain with.[00:34:41.00] I: How does that explanation connect to this equation?[00:34:47.13] T: Oh, v0...[00:34:50.16] I: It was just that last part that I didn't understandT: Ah. v0 is, um, 12 o'clock, for example, for example, when it's 12 o'clock, the car is at v0, speed v0, and, 13 o'clock, at 1 pm, this car[00:35:09.22] um, "it is becoming v km/hr, you know" is what it becomes, um, you pass 1 hour, um, if the speed (increases???) by just "at",[00:35:29.21] from this 12 o'clock til 1 o'clock, in the duration of that 1 hour, [00:35:34.22] speed is increasing by just "at" and, v=... ah, I made a mistake[00:35:45.03] The speed at this time, v0 +, um, the speed that it went up in one hour, "at", in that it is becoming v.◦ [00:36:30.20] I: (2 rocks prompt given)T: OK. A little more, eh, littl, one more time, read the explanation by myself... [00:36:36.28] I: Go ahead, yeah[00:36:52.05] T: I think it's still fast, right. The second rock is more, the thrown rock is more, compared to the time of normally dropping, still fast I think.[00:37:01.13] I:Uh, how did you reach that answer?[00:37:02.09] T: It's a feeling, isn't it?[00:37:05.01] I: Can you explain that feeling a little, I wonder?[00:37:08.01] T: Um, in the end, uh, the one your throw is... if it were really really high, uh, finally, I think the rocks would become the same speed, you know.[00:37:23.24] Uh, even if the height is different, even if the height that the two fall is different, uh, I do think that the falling speeds will come to be the same, but[00:37:30.28] with the stage of the fourth floor balcony, uh, if I wondered if the rocks' speeds would become the same, I thought that in the realm of my own experiences until now, that is not there, is it not, I wonder.[00:37:50.05] I: Ah, you definitely the speed will not become the same, is what you said?[00:37:59.18] T: Fourth floor balcony, uh, since the height is not enough, since I think it's not heigh enough, it's a number smaller than the maximum speed...[00:38:22.04] I: Oh, you mean both will hit the ground?[00:38:20.04] T: Yes.

The largest, it is before it has reached it's fastest speed[00:38:23.05] I: Ah, because there is air, it will not become the same speed, is that it?[00:38:30.13] T: Yes[00:38:33.14] I: I see. If there were no air... ?[00:38:34.28] T: Ah, the case of no air, if it's the case of no air, it's normally fast, right? Fast just as it is.[00:38:41.05] I: It stays that much faster. And why is that?[00:38:43.22] T: Since there's no air, uh, there is also no resistance that comes to effect the rocks, and normally, gravity, just like that continues taking over, so [00:38:51.05] since it's a thing of ??? acceleration, since it goes and falls, just like that, I wonder, it reaches fast just like that (inaudible)[00:39:06.19] I: Gravity is acting on the rocks and they accelerate, but why does that necessarily mean that the speeds[00:39:16.28] T: Will it not become that? Um, like what is in this equation, v0 is, uh, already different, uh, if it's the one that was normally freely dropped,[00:39:28.07] ｖ０ is 0 is it not?[00:39:30.15] But, the one that was thrown, the v0 is a little, there is a difference, and, that part, in the beginning, more than the one that was let go, it's faster just like that, is it not, I wonder, is what I thought.[00:39:42.14] I: I understand that there is a difference at the beginning, but why is it in the end that that difference is the same is still I'm not understanding... can you explain a little more?[00:39:56.06] T: Ah, um, since there is no air resistance, uh, there is no force acting up, so, uh, there is no seeming of it to become the same, is there not, I wonder, is what I think. [00:40:17.11] I: They will not become the same[00:40:24.16] I: But for example, that initial difference - does it not become larger?[00:40:34.00] T: The initial difference is big[00:40:35.27] I: Become big, does it not? In the event that there is no force pointing upwards, uh, the one you threw in the beginning, does not become slower, it does not become the same as the other rock's speed. I understand that, but the opposite, for example, the one you threw, [00:41:12.00] T: The one you aren't throwing. The one you dropped normally will become faster, will it not - is your question.I: For example. In the beginning, the difference in speeds is 2 m/s, right? But why is it, for example, that that difference does not become larger?[00:41:23.13] T: Ah! Ah, excuse me, will the difference become larger or not than this 2 m/s? Ah, it won't become bigger[00:41:36.29] I: Why?T: I was mistaken. Uh, this "a", the one called "at" here is gravity, so the rocks have the same grav, if it's the same mass, uh, gravitational acceleration is also a constant, since the masses are also a constant, uh, the same, since the accelerating is the same, with only the initial difference, since they go and become faster by just the same speed [00:42:10.02] I: Ah, both are[00:42:13.22] T: Yes. At the time of the initial speed, they go and become fast by the same speed.[00:42:17.24] I: I see. Are there other ways to solve this problem?[00:42:29.00] T: I think there are, but at the present stage it's not coming to me.[00:42:37.04] I: I see. Um, one way of answering that I have seen is... I will kind of show it to you, and I want you to evaluate it.[00:42:47.26] T: Ah, sure.[00:42:47.26] I: Whether it's good or bad, how does it compare, for example[00:42:49.21] T: OK[00:42:51.04] I: I'm going to kind of write on this. That way of answering is, use that equation, and use it twice. The first ball, er, rock, is, um, the initial velocity is 2 (begins writing). And, acceleration is 10, time is 5. Multiply, 50. If you add, it becomes 52.[00:43:15.21] T: OK[00:43:15.21] I: The second rock, in the same way, 0 plus 10 times

5[00:43:22.26] T: times 5[00:43:22.26] I: is 50[00:43:24.00] T: 50[00:43:24.00] I: Right, 50, and if you subtract, since it's 2 m/s, it remains 2 m/s faster. I have also seen that solution, but how do you think about this solution?[00:43:35.24] T: I think this is good too. But, this is, um, I do think that this is a way of answering for people who are accustomed to calculations and good at mathematics, you know.[00:44:00.28] I: I see[00:44:00.28] T: Um, good at mathematics, in regards to this, this way of teaching as well, this way of teaching is more easy to understand I think.[00:44:08.09] I: Is this calculation difficult?[00:44:13.06] T: No, it's not difficult, but, in this kind of style, um, showing properly in numbers is easier for it to really click I think.[00:44:25.21] "No matter what numbers you put in, the difference becomes 2 you know", doing a calculation in this style is easier to understand, isn't it. I prefer this direction.[00:44:39.20] I: You prefer this one (plug and chug)[00:44:39.20] T: Yes.[00:44:46.13] I: I got it. But at first, when I asked if there are other ways of solving, this way of answering didn't come to you?[00:44:53.23] T: Right.[00:44:55.14] I: Although you were using this equation, um, a way of answering via putting in numbers[00:44:59.28] T: That's right, isn't it, it didn't come to me.[00:45:04.28] I: Even though numbers are written in this problem, [00:45:07.20] T: Right.(smiles)[00:45:11.12] I: Wow, that's amazing. OK, I got it.[00:45:22.17] I: Have you solved this kind of problem before?[00:45:24.29] T: No...[00:45:27.18] I: Well, not the same as this, but this style of..[00:45:31.14] T: Yeah, yeah, yeah, I get it. [00:45:31.14] I: have you solved this kind of problem before?[00:45:35.29] T: I haven't really seen this, right? Um, I really wasn't taking physics before, so I haven't seen this kind of problem very often.[00:45:43.28] I: I see. In last year's physics class, well, you were doing a lot of calculations, right? But how were those kinds of problems different than this?[00:45:58.29] T: It is that there is not one decided answer, isn't it?[00:46:03.10] I: Ah... you mean, in this problem, the answer is not decided? Or in last year's class, the answers were not decided?[00:46:14.07] T: Last year's class was, um, the way of answering, the answer was decided, and, that, the approach in order to reach (???), the way of doing that too, the (???) was basically decided and... [00:46:26.11] this is, there are many ways of answering, are there not?[00:46:31.09] I: Oh, right, right, right.[00:46:31.09] T: Because any way of teaching it is OK, for example, and any way of answering is OK.[00:46:33.25] I: You decide your own way of solving, for example[00:46:37.15] T: Right[00:46:38.28] T: Moreover, it's because it's OK if it isn't right, or if it is right - it becomes that kind of problem.[00:46:42.01] I: I see[00:46:53.24] I: Um, a little before, um, the thing you said for me was, um, before you entered Physics Exercises, um, the thing of thinking about that approach... um,[00:47:03.20] before entering, um, like, in order to learn physics, you, like, stuff knowledge into your head, but... and, if I write it, that was the "before" opinion (writes "before"), the before impression[00:47:36.05] and, um, after entering, um, physics is, you can put out answers from yourself[00:47:42.22] T:Right[00:47:44.09] I:That, um, it became that opinion[00:47:45.28] T: Right[00:47:52.09] I:Um, kind of, this is perhaps a strange question, but[00:47:58.06] T:OK[00:48:01.25] I:Your way of solving this problem, and this way of solving （plug and chug)[00:48:05.12] How do they compare with these ways of thinking?[00:48:09.25] For example, um, this kind of way of solving, this kind of, um, put in numbers, calculate, um, that way of answering - is it close to that "before" opinion towards physics? Or is it close to the opinion after entering?[00:48:28.19] Or is it not close to either one?[00:48:37.11] T:The thing I said myself will come to change a little, but, um, I said that I like this direction better, did I not?[00:48:47.08] Even so, this way of solving is is closer to the before "stuffing" way of solving, isn't it?[00:48:53.06] I: Why is that?[00:48:55.18] T: It's a calculation, if you will. What is it, right? There's a machine-like feeling, you know.[00:49:16.00] I: Ah, a machine, like... a machine[00:49:18.12] T: That's right, isn't it? "If you do it like this, you do it like this" - that kind of, of one, "if you do one, you do it like this" kind of... I get the feeling like the answer is decided - that's why.[00:49:30.28] It is simple, you know.[00:49:42.13] I: You are saying this is simple?[00:49:44.13] T: That's right. I do think that it can be easily understood. Once you insert numbers, it's the end, is it not?[00:49:50.09] I:Yeah[00:49:52.28] T: It's not understanding words, but rather if you see the numbers, you already get it. So, I do think it can be understood easily.[00:49:58.17] Uh, in putting the point that the one answer is decided, in that, I think it more resembles the before "stuffing answers" way of thinking about physics.[00:50:14.14] I: I see. And which way of thinking is your way of answering close to?[00:50:21.06] T: I have a feeling my answer is closer to the after answer ???[00:50:27.03] I: Why is that?[00:50:34.03] T: What I myself answered was, uh, a way of answering like what I was writing in Physics Exercises myself, so this way, uh, I thought that it is really similar.[00:50:50.28] I:In Physics Exercises, you write your own thinking,[00:50:58.23] T: Problems in Physics Exercises, uh, it was a feeling of what is a good thing to do in teaching people who don't know, so[00:51:04.27] if this is people who understand physics, it quickly comes and enters into the head, so I thought that it's good, but[00:51:13.18] if we take it as teaching a person who doesn't know, well, for example, the 12-year old kid we were just talking about, I do think that they would kind of not understand this.[00:51:23.05] Because of that, I did think it's closer to this way.[00:51:33.13] I: And what you just explained is that, for example, it's not using numbers, like, well, a 12-yr old kid can understand it, since it was that kind of explanation...[00:51:40.24] T: (What in the world, because it was an explanation built on my own effort exerted to make it likely for them to understand???)[00:51:50.00] I: Got it. By the way, when you were explaining the equation, for example, when you were explaining to a child, which way of thinking was that close to, do you think?[00:52:00.02] T: This thinking?I: YesT: This is closer to this direction ("after") I think.[00:52:03.19] I: I see[00:53:06.17] Why was it so easy to adapt to this different style of class?[00:53:17.09] T:Is it OK for you to make me think a little?[00:53:21.08] I: Go ahead[00:53:50.22] T:It (sense of regret) becomes a question from this way, but, uh, to me, this thing of everyone properly adopting the class was straight-forward, but... [00:54:02.10] I: No, at Maryland University, TGU was easier to adapt[00:54:27.06] T: Oh. Concretely, in what way were they not becoming used to it?[00:54:33.08] I: Well, for example, UMD students say a lot of "why aren't you teaching us? Why don't you just tell us the answers?" And "I don't like working with others in groups during class!" [00:54:59.02] Ah! That's right, isn't it. If that's the case, perhaps... Japan and

America have different cultures, and in America, complaints, uh, (as one did???) to do, that, pretty much they do, I do think, but, if it's Japan, uh, one's superiors, uh, older people, for example, the teacher... more their opinion is what is absolute you know.[00:55:22.16] And, that, in order to protect that absolute opinion, it means that there is nothing for the individual but to go and adopt to the teacher's opinion.[00:55:30.09] Therefore, it's because we are used to that thing. I think it's because we are used to the meaning of protecting the things that the teacher said. [00:55:46.09] I: I understand. Have you experienced something like this class before?[00:55:56.06] T: A class like Physics Exercises?I: Yes, other than it. Well, maybe not a class, but maybe this kind of experience.T: Well, uh, since elementary school classes, for example, were essentially that kind of feeling... yeah.[00:56:07.27] I: Oh like what you were talking about before, right?[00:56:09.19] Physics Exercises is, like elementary school[00:56:13.27] And the thing that is in common is, in a group[00:56:15.16] T: Chatting in a group, uh, one's own... in elementary school, one tells one's own opinion to the teacher for example, but, if it's this class, we write on paper and the teacher reads it for us - that is the structure, and[00:56:29.15] well, uh, (in wanting to say that???), the form is a little, the way of doing it is a little different, but[00:56:36.11] In the structure of the teacher seeing our own opinions for us, and then, in a group, you make the people around you hear your opinion, what kind of, they in exchange benefit by (me hearing) in what kind of style the people around me are thinking. [00:56:58.00] I: Do you think those elementary school experiences helped you adapt? [00:57:01.19] T: Ah, I think it helps. Unsurprisingly, oneself has before now, having classes done like this, they... if it's when you're little, unsurprisingly,[00:57:16.08] there is a thing of wanting to try different things, is there not?[00:57:18.04] Uh, it's not a feeling of "I'm not going to do the things that I don't want to do", but rather "let's try it once", that is, pretty much, a characteristic of children I do think, you know.[00:57:28.12] So, unsurprisingly, when you're small, if it's something that you've tried doing, uh, there's also a feeling of nostalgia, it's easy to ??? I think. [00:58:02.22] I: Can anyone do physics if they try long enough, or? [00:58:09.17] T:They can I think. Because I originally hate physics, but I myself am thinking that I am beginning to be able to do it a little. Anyone can do it I think, you know.[00:58:45.21] Ah, I want to return to this once more[00:58:47.08] T: OK[00:58:49.11] I: Um, in solving this problem, this kind of way of answering did not come to you[00:58:57.11] T: Right[00:58:58.19] I: However, last year's class... well, it's close to your "before" way of thinking is what you were saying.[00:59:06.12] T: Right[00:59:09.22] I: Perhaps in this way, last year, were you not solving problems in this way?[00:59:15.08] T: Nope, I was solving in this kind of style, wasn't I[00:59:18.11] I: Why did you not think of it this time, do you think?[00:59:23.00] T: This time, um, unsurprisingly, I am in the middle of coming from taking the Physics Exercises class now, and, unsurprisingly, inside of me I am thinking "make that knowledge go, make it go", so[00:59:33.17] um, it's a feeling like I can't do any thinking other than that kind.[00:59:38.13] Now, I answer myself, and, um, I could not put out any answer other than that one[00:59:43.21] I: I got it. You already completely stopped this kind of thinking.[00:59:46.23] T: Right.[00:59:48.16] I: Got it.[00:59:53.01] T: But that doesn't necessarily mean that I think this way of thinking is, itself, bad, so[00:59:54.26] I: Right[00:59:56.08] T: For me, um,[00:59:57.27] I: Right, why was it that you preferred this one, one more time?[01:00:00.14] T: Um, this one is more, right away you can put out an answer, and it is easy to understand, you know.[01:00:06.13] Um, between people who understand, when talking, this way of thinking is more, um, easy to pass to the other person, and I do think it is more quickly transferred, you know.[01:00:13.02] I: OK, ok, ok[01:00:15.17] T: If it's a kid who doesn't understand, he would absolutely not understand this, zero, the percent of understanding is 0, but if it is between things that understand, I think it's 100, 100 (moves hand to gesture two people), you know.[01:00:24.02] And, my own thinking, I myself answered this, did I not? If it's the way of answering that I answered, even if it's a kid who doesn't understand, um, 50%[01:00:33.12] for example, an understanding of 60%, he would understand, but... [01:00:36.25] I: OK[01:00:39.06] T: Um, a person who doesn't, who does understand, even then, I do think it's a way of understanding that is about 70-80% you know.[01:00:50.24] I: I see, I see.[01:01:00.27] I: Is intuition useful in this class? [01:01:04.24] T: I don't know if the goal of the Physics Exercises class is actually like this or not, but, unsurprisingly, one's own experiences in the real world up until now, and, and then, physics equations, for example, to connect those ways of thinking, that style of...[01:01:31.02] style is the goal, that's what I am thinking, you know. On top of that, intuition, it is, unsurprisingly, since I think it is a thing of experiences from within coming to live in one's own real world up until now[01:01:41.21] that is, unsurprisingly, in order to get that to meet the physics way of thinking, intuition is necessary I think.[01:01:48.01] I: In the learning of physics, generally, that kind of connecting thing, do you think that's effective?[01:02:03.29] T: I think it is effective you know. Uh, unsurprisingly, if you go on and do it just with equations, for example, the physics way of thinking, for me, even if I reach a point where I understand, I still don't.[01:02:20.00] What would be good to say, right?[01:02:22.07] Unsurprisingly, studies, for example, scolarly ability, ???, it has as a ??? to (make itself be lived???) in the real world, does it not?[01:02:33.24] Therefore, not just the world of physics, uh, even if you can flourish, you have to (make live???) that knowledge in the real world or it's meaningless, you know, is what I think, so it stands up I think.

5. Daisuke and Gorou's Solutions to the Two Rocks Problem

Daisuke explained the equation by starting with the definition of acceleration. Since acceleration is defined to be the derivative of velocity with respect to time, when you integrate, you get v=at + C, where the integration constant, C, is v0. Although such an explanation contains mathematical information about the origin of the equation, it says nothing about what process the equation could be describing. Gorou explained the equation as follows:

> *[00:26:00.22] Gorou: Ah, I might use units. If I'm not mistaken, the units are this kind of feeling I do think, but... and the unit of a, the unit of acceleration.... (writes m/s^2) It was this, wasn't it... First I think I will give an explanation about acceleration. "It's, in time, how much the speed builds up, you know" is what I would say. But that unit is*

becoming like this. And if you do that, the dimensions unfortunately come to not match up, so to make those dimensions match up, you multiply by time.

Like Daisuke, Gorou demonstrated formal knowledge above and beyond the equation itself: units in an equation must match up, otherwise the dimensions don't match. However, it is unclear what the physical significance of the units not matching up is to Gorou. It is easy to imagine that he was quoting a rule that he knew must be followed.

Unlike Daisuke, Gorou connected the variable "a" to something in physical reality: it has something to do with how much the speed is increasing. However, again, it's not clear what he meant by "in time". It might be that he is thinking that, for example, if one second passes, "a" will tell you how many m/s the speed increases. Again, however, it might be that he was just reciting a memorized definition of the variable.

C. Consistent Pedagogical Messages

1. S302, Tutorial 10

[00:35:51.18](I.C. ExperimentAh?Eh?Rina: Eh? Something is strangeHaruka: Strange? Rina: Because it isn't lighting Haruka: Eh, but it's dimly lit. Yeah, it's not strange, right? [00:36:05.02] Haruka:It's dimly giving off light you know. Eh, why? Why, why?Rina: The way of connecting is strangeHaruka: Why does it not become half?Haruka: Huh?[00:36:25.09](Katashi-TA):In what style does the flowing current become?Haruka: The current passes through A, here it again becomes the same amount of current, since it's going in parallel, it's exactly the same part I have to think. I wonder if that is not so?TA: Well... if we say that here, for example, 1 is flowing, 1 is flowing here, and here, how much will flow in each one?[00:36:59.18] Haruka: Does it return to one 1 here? I want to, for example, make it 2 here, you know, right? That's it, right? That's right, you know, right? If I think it is 1,1, 0.5, .05 must make 1. That's right, you know, right? If it changes before and after it's something strange.TA: If you think that way, it seems you can make an explanation...[00:37:21.19] Haruka: Ah, I seeTA:Try thinking a littleTA leaves

[00:40:57.00](Katashi-TA returns)[00:40:57.21] Rina: I don't get itTA: You don't get it? What part don't you get? Rina: Like, in this situation, we can understand that both, with the situation of each circuit, it becomes the same brightness. But if it splits into 2, we have always had an image of, here, a current with amount of 2 flowing, right? But before, we were talking here, and we are likening this to something like an irrigation channel, when it flows all the way around, both have the same capacity. The height of the entire circuit is the same. The amount of water flows all the way around, and it becomes a conversation of how no matter which point you take, the same current is flowing - that is the situation of what is going on, is it not? That really clicked, but, well, this time, when you go this way, it's not that it's all the same current that is flowing... at this part where it became parallel, does it (sense of misfortune) decrease by half, is the thing that this time (sense of regret) won't click, and...[00:41:54.01] TA: Uhhh... at this time, if a current of 2 is flowing, it would divide in a style of 1,1 - is that what you're sayiang?[00:42:04.18] Rina: Eh? 2 is flowing? Here?TA: No, for example, if it's 2 that is flowing, they're equal, and then this way 1 flows, and this way also 1 flows - is that it? The thing you were just saying?[00:42:17.00] Haruka: That is, we were thinking originally, but, like, if you really think about it, if you are in that irrigation canal thinking, you reach a conclusion that it's 1,1,1, I guess, but... but if it's this way, it's that if it's that thinking, it doesn't go well, right? TA: If it's this way, it doesn't go well?[00:42:30.15] Rina: If I'm in a thinking that it's all 1... since this parallel was clearly darker, it becomes a thing of it not all being 1.[00:42:43.14] TA: Uhhhh, the thing about it not all being 1, if 1 comes flowing through here, this way also 1 comes flowing and this way also 1 will flow - is that what you're saying?[00:42:54.05] Haruka: But if so, it's strange, you know, right?TA: If so, although 1 was flowing, eventually 2 will flow, when it becomes the end, the current (sense of misfortune) will increase?[00:43:04.10] Haruka: YeaRina: If it's that way of thinking, why does it not become 0.5, 0.5 here?[00:43:17.01] TA: Umm, did it become the same brightness here?[00:43:22.20] S2: It appeared the same brightness, and it won't split and both are the same, I guess - it became that style, but, is that wrong?TA: Uhhhh... can you say that again for me???: I wonder if there is the thing that's wrong...??: I wonder if that's it...??: Was that wrong?[00:44:17.09](I.A. - they do the experiment a second time)??: I have a feeling they are the sameTA: It looks the same, you know, right?Rina: Huh???: The sameTA: It's the same and, if you do it this way, how does it become? Can you sort of do it one more time for me, this?[00:45:16.25] （They repeat the experiment of C）??: It's dimly flickeringTA: It's lit? A little bit. And, at this kind of time, the thing you don't understand is, at this kind of time, how is it becoming?Rina: No, we understand from experience, but we can't take it down in notes of theory, if you will??: You can't take it down in notes of theory???: I can't understand it inside my head[00:45:39.28] TA: If so, the truth, if you will, is that after this, a new concept called voltage comes out, so you might again understand there, so sort of, for now, continueRina: It's a feeling of writing down the results for future use?

Part 2[00:00:20.17]Haruka:We don't really understand current, and... voltage, it's a thing of height, right? Which means, if voltage is big, current also of course becomes big, which means you can also compare relative brightness with current, is it not, I wonder, is what I was thinking, but... just what was it that you wanted to ask?S2: Were voltage and current not now mixed? Haruka: Mixed?TA: Is it OK for you to sort of show this for me? How did the previous conversation become? TA: In the C.1 place, the brightness of bulbs 1 and 2 and A... did you actually try doing it for me?[00:01:32.26] Haruka: A single bulb circuit and the parallel thing... was it different?Rina: You mean, that you can know from the brightness?TA: How big the current is also matters. It's good if you think about how big the current is for me. But the truth is, it also comes to be concerned with voltage, for example.[00:02:16.02] Haruka: How big the current is does not equal the brightness?TA: They do not equalHaruka: They don't equalTA: However, if you think this, the time when there is just one bulb and when there are two bulbs connected in parallel, both have the same current flowing? This?[00:02:37.14] Rina: If this is all one theory, here is 2, and it is divided into 1,1 - there is that theory, but... but you can't measure current, can you? Therefore, since you can measure voltage, til now we've somehow understood, but... eventually since the size of the current can't be measured, they can't be compared is what it is...[00:03:08.10] TA: Ah, I seeTA: There is kind of a difficult place, right? Circuit A and the circuit this time, at first when the battery doesn't change, the current, is it the same in the two circuits? That or, but... maybe you don't know???: I don't really knowHaruka: I also don't really knowTA: At this time and when one bulb is connected in series, then, is the amount of current flowing through the battery the same?[00:04:04.18] Haruka: I was thinking they might be the same, but...TA: If they become the same, since the same amount is split into 2, would this way not seem to become darker?[00:04:17.12] Haruka: Ah...TA: If that's so, it won't become this kind of style. Do you understand what I want to say?Haruka: Ah, is that so... current...TA: Do you understand? Is it OK? TA leavesRina: Did you get it?[00:04:43.27] Haruka: Like, current? The flowing of current here and the flowing here are the same, no? So, current is divided here and here, you know, right? It was that kind of story, current is.??: Voltage doesn't change?Haruka: Right, right. Current divides, does it not? It becomes dark, does it not, is what he was saying.Haruka: It's hopeless... I really don't understand electricity... [00:06:05.14]Haruka: Like, yeah, you have to think a LOT about current and voltage, no? If that, like, unsurprisingly, it's faster to memorize, is the thing, you know, right? If it's parallel... kind of thing.

2. S302, Tutorial 4

[00:41:10.27] S4 calls TA and S3 does too[00:41:34.27] S4: Some answers came outTA (Shuji-TA) comes[00:41:55.25] ４：Ah, from this page? We are all in agreement, but...[00:42:02.08] ４：Because it's "please think in a group", right? It can't be helped, can it?TA: Tadao, how about A1?Tadao:You can say it's biggerTA:Intuitively?Tadao:Well, we matchTA: (S4), do you agree with Tadao?S4:It's got to be fine, right?S2:Is it alright for us to give it as our own views?S4:Ah, it's fine you knowTA:Well... B is (S3)[00:43:20.26] S3: The conclusion is that, intuitively speaking, he goes up at a constant speedTA: Well... how about #2??: They do not agreeTA: They don't agree? I see.Tadao: If it's intuition, I think he'd go up at a constant speed, I suppose[00:43:46.27] TA: And number 3?S3?? Just as it is (inaudible)[00:44:31.02] TA: How was number 4? S2: Doesn't match, that one wasTA: Ho... doesn't match. Please explain that.[00:44:42.19] S4: We're getting stuck by the tricks of the person who made this worksheet, aren't we? I have a feeling that we are neatly writing the answers that they are looking for; we are really exemplary students. [00:44:54.23] TA: Number 4? Can you explain that?Tadao: Why it doesn't match?TA: Right,Tadao: why it doesn't matchS2: Intuitively speaking, since the downward facing force is stronger than the upward pulling force, the kid isn't being helped is the conclusion that we get through, but if it's Newton's second law, he is slowly, little by little decelerating. In the beginning there's an upward pointing force acting, so relative to that, it's gradually getting smaller and smaller, and it's like he stops.TA: Ha...[00:45:35.23] Tadao: He wouldn't start falling from the start[00:45:40.26] ??: I seeTA: (S4), is that OK?S4: It is "I see".[00:45:55.19] TA: Well, as it is, can I hear number 5?S4: He goes up with constant speed. In the situation of it being balanced, only the location of the rope changes. In the situation of it being balanced with him standing still, the rope will be taken up and winded, so he moves.[00:46:13.19] TA: Ho, ho... I wonder if that is how everyone feels?Yes[00:46:30.05] TA: Well, (S3), how was #6?S3: At a constant speed...??: It agrees, right? That's #5. We're on #6.[00:46:41.19] S3: Even if the strength of the machine's force is strong, right - the speed that the machine is winding at is the same, so, right - so there's no meaning, you know.???: That's right.TA: Please continue[01:11:24.25]TA (Shuji-TA) comes (II C)TA (Shuji-TA): The part about the intuition boxes. I wonder, how was it... (S3), which were you? S3: Me? I became left, didn't I?TA: Left? Ho... first of all, shall I just hear which one you became. (S2)?S2: LeftTA: Left Tadao: LeftTA: Thank you. (S4)?S4: A venture to the right. Huh? At this point I was right.TA: Right? Ah... that's fine you know.S3: That's totally fine you know.S4: I was right at this point you knowTA: If we go to #2, which one seems to agree with N2?S4: Left. A huge negation occurred, so left[01:12:30.21] S3: Well, I am rightS4: Well, I am leftS2: I guess I'm leftS3: What is this, three vs 1TA: It had to become three vs 1, didn't it?TA: (S2), well, in what way does the left match up, I wonder if it's OK to receive an explanationS2: Unsurprisingly, in order to continue an object's motion, that kind of force is necessary, right? If you think, on the other hand, how it is when there is no motion, the force is, for example, more than a pushing force if the friction is big, for example.[01:13:38.23] S3:I do not think that friction becomes bigger than a pushing force!S2: You're right...TA: Tadao?[01:14:27.01] Tadao: LeftTA: An explanation of left...Tadao: It's in number 3TA: Well, let's hear number 3Tadao: Unsurprisingly, in the preservation, a force is needed I guess, is what I think. In actuality, you need a net force. [01:15:35.00]TA: A net force is what kind of force? Shall I ask (S4)? [01:15:45.00] S4: (S3 lies his head on the desk) When this kind of force is acting, in the moving is only this force, this is net force. It's necessary. In an object, it's like the resultant force.[01:16:04.06] TA: Aah, I see. Since if you do it with that, then that is necessary... in the very first problem, if we go there, an object's resultant force is, I wonder if it's good to produce this...[01:17:01.15] S4: From gravity and the rope's pull TA: I see.[01:17:23.08] S4: At the place where the knot is, gravity plus, at the time that the rope is pulling, the reaction force is a force pulling like this, so those three is what it would be, right, is what I'm thinking... [01:17:26.27] S2: When you thought about the girl? S4: The girl is gravity, right? It's good to just think of it as a plumb bob weight, right? So, the girl is a plumb bob, and if we take the pull to be like this, this way is gravity and from here is tension and from here is the pulling force, right? Is that not correct?S4: Wro-ng!S3: Wrong, ain't it? Keep trying!TA: (S3), what do you think?[01:18:11.26] S3: Eh? (Looks over at what S4 has drawn) Is that an apple? S2: You're not listening to our conversationS3: What is this, what is this?S4: We take this to be the girl, at the time when the rope is pulling, we draw all the actions of the forces, with arrows.S3: I see. Well, it's gravity isn't it? It's T isn't it?S4: They're the same, aren't they?S3: They're different, aren't they?S4: That kind of thing, any way is fine, you know. They're just arrows. [01:19:00.01] TA?? Here, don't T and T cancel each other out?S3: They cancel each other out don't they. Therefore these cancel each other and it becomes zero doesn't it. And what acts on the girl is g [01:19:11.20] TA: If that's the case, then you can't get Timmy out of the well, can you?S4: He sinks down - goodbye!S4: So therefore, this way, it's good to just have this one, isn't it? (looking at TA's face). If the main point is not that, then he cannot be rescued. [01:19:38.14]TA: How big does this become? S4: This is the force needed to stick to the rope. It's the force necessary to not become disconnected. It's just a little bit.S3: Is it? We do it like this, right? This way is force T acting like this and like this, so this doesn't cancel? I don't know. Is it OK to not think too hard about this part? I don't know, already!S2: This force, isn't it, in other words, the thing called gravity? Is it not a pulling force that is dependent upon gravity?S3: What is?S2: The ropeS4: You're wrong!TA: Is this T not the pulling force of the rope on Timmy? If you'd do that, it would be the opposite of this...S3: Force T of Timmy pulling on the rope[01:20:52.18] ???: Therefore, they cancel each other out, don't theyS3: The force of the machine pulling the rope. (???) then there becomes a relation between T and g.[01:21:25.14] TA: Ho-- if you do that, if you go to the left opinion, to say that a net force is needed to maintain, when you compare this and this, for example, at the time of Timmy, at the very beginning, if T is not bigger than mg, does it mean that it cannot be preserved?[01:21:58.20] S3: CertainlyS4: Because it becomes that, unsurprisingly, I wonder if it's not Right, is what I'm sayingTadao??: Is that intuition?TA: Now three of you have considered the left opinion for me, shall we try listening to (S4)'s Right opinion?S4: It's because it's intuition, this is. Because it's stubborn intuition, isn't it.TA: That's fine, you knowS4: It's intuition, and, would we call it an animal-like instinct?TA: Ah - not at all[01:22:35.27] S4: There is no reason, you know. It's a feeling, you know.[01:22:45.12] TA: Well, I wonder if I shall request an explanation of the result of that choice?[01:22:49.13] S4: Unsurprisingly, in the preservation, the thing of a net force. If a force were acting, would it not change I wonder, is what I'm saying.[01:22:56.10] TA: Ah, I see[01:22:59.20] S4: If it's just as it is, it's fine to be just as it is, isn't it? If you want to move it, you do it like this - apply a force.[01:23:05.07] TA: Ah, I see. If you apply a force, it changes.S4: A change occursTA: That is the Right opinion? S4: Right opinionTA: I see[01:23:03.07] S4: If it stays steady, nothing changesTA: After hearing the right explanation, how is it?S3: It clicks???: FinishedTA: Is it OK? Will you modify your view so easily?[01:23:31.26] TA: (S3)? Now the left opinion and the right opinion - you have received explanations of both, but upon hearing them, I wonder if something in your thinking has changed?Tadao: Well, Right is fine, isn't it?S3: Well, left looks appealing...[01:23:50.11] S4: It's bothS2: Well, if it is said that the answer is Right, then I have a feeling it's RightTadao??? I (think) the thing called net force is... S3: [01:23:59.10] A net force is necessary to initiate or change an object's motion (speed).S3: It's Right TA: It's Right? Ho- I see... are you really OK?[01:24:30.00] Tadao??? It is absolutely RightTA: How about (S2)?*****video B[00:00:05.02]S2: The thing called net force - is it not a force of substantial movement? Friction force and pushing force, if the pushing force is bigger, it's only that amount that it's bigger by.TA: That's right, isn't it?[00:00:19.08] S2: Therefore, if that were necessary to preserve, certainly just the part of the force that is acting, it would start to go bit by bit, bit by bit the speed would become changing.Tadao?? Ah, I see... S3: So then Right, isn't it?[00:00:41.09] S2: If it's Right, then maybe certainly it would be consistent? It's a feeling of "I wonder if it would be consistent"S3: The one about initiating and changing... unsurprisingly, it's Right, isn't it? It's Right, right? [00:00:58.13]Tadao: Ah, that's itS4: What is "that"?! Tell us!Tadao: I wonder if it is not the law of intertia. Therefore, if no force acts on a moving object...

3. TA Debriefing, after Tutorial 5

[00:40:42.28] Mizuki-TA: Ah, also, today I heard a ???[00:40:44.15] Sensei: a ???[00:40:45.12] Mizuki-TA:There is a desire to have the answers to Tutorial up [00:40:47.06] Sensei/Shuji-TA: （Sigh) Ah [00:40:48.17] Sensei: I get that[00:40:54.04] Hayate-TA: If they think that they won't finish,[00:40:54.27] Mizuki-TA:They say they want to arrive[00:40:57.00] Hayate-TA: Right? There are also things that they are not really getting, right? [00:40:59.12] And the time also passes, right? And next time's(everyone is making uncomfortable faces) scholarly activity, scholarly activity if you will, (Sensei puts her hands on her head and leans back in her chair, eyes cast down at her computer screen)[00:41:04.22] they won't necessarily do it, for example[00:41:06.09] Shuji-TA:if they don't know ???, like, （he is holding his wrist and smiling nervously, leaning away from Sensei while looking at her. She is avoiding his glance) they cannot be satisfied （Sensei raises her eyebrows and nods her head, understanding their feeling)[00:41:13.19] Hayate-TA:Tutorial up, it might be good to put the answers up, right?Tutorial[00:41:17.14] Sensei:I wonder if that's so(looks at Hayate-TA skeptically) ・Hayate-TA:??? is forbidden, I wonder[00:41:19.00] Hayate-TA:TA??? ・Researcher:What is "answer up"? ・Sensei (to Hayate-TA): ？？？ [00:41:20.01] Shuji-TA: For example, uh, if this time's Tutorial finishes, and everything is finished, for example, ・ （misc chattering voices)[00:41:27.29] Akiko-TA?: yes, yes, yes, yes （Makki looks over at their conversation) ・Shuji-TA: for example, midway, there is an unease in students about whether something is really correct [00:41:35.18] if you resolve that ???, if it's afterwards, forthat, for example, that, Tutorial's answer key[00:41:45.09] Researcher:Ah, the answers, for example[00:41:47.22] Shuji-TA:In ???ing the answers, （Sensei returns to an upright posture with a thoughtful frown on her face. Makki is holding her chin with a downcast gaze)[00:41:52.15] make it so that selves can see it - that kind of thing (Sensei shakes her head from shoulder to shoulder)[00:41:56.13] Researcher: Ah, by "selves", you mean TA's? [00:41:58.09] Shuji-TA:Ah, um, students themselves want to know ???[00:42:01.00] Researcher:Yes, they want to know [00:42:01.00] Shuji-TA: ??? [00:42:07.09] Visitor: ???(something about the web, which sounds similar to "above") [00:42:07.09] Researcher:Ah, above, for example, above the blackboard, for example,[00:42:09.27] Sensei:No, "web". [00:42:14.06] Researcher:Ah, I understand. Shuji-TA:Become a state of taking that access [00:42:14.11] （Sensei furrows brow and sighs) Sensei: Hm[00:42:17.14] Hayate-TA: Like, with conditions attached - I think it's not very good to do that with everything, and... ・Sensei: Don't like it, I don't like it! It is a displeasing thing, right? ・Visitor:???[00:42:24.23] Hayate-TA:That, I think that it's not necessary for everything, and, those Free Body Diagrams, for example, at the extent of this kind of thing where the answer is decided, I wonder if it is OK for me to humbly say and give [00:42:32.23] Just interpretations, for example would be "fine, you can have it".[00:42:34.27] Shuji-TA: Do American students also think, for example, that they want those answer keys[00:42:42.13] Researcher:: Yep. American students want it much much more. （multiple people respond with interest and minor surprise with "Hm" said with a rising intonation)[00:42:45.29] They say many many more complaints, for example, absolutely[00:42:50.04] Hayate-TA:Like, is it that, "let's chat by ourselves" thing, but （Laughs)[00:42:52.23] I didn't know[00:42:52.27] Sensei: It's not about chatting; it's the thing of "let's think", no? [00:42:58.02] Hayate-TA: If ・Visitor:??? is bad, but, no, it might really be a relief, to say that kind of thing[00:43:02.22] Sensei:Yep[00:43:04.04] Hayate-TA: Certainly ・Sensei:(with conviction) That's right. I want them to think until they can find relief by themselves (Sensei is smiling at Hayate-TA)[00:43:08.13] Hayate-TA: Ah, I see[00:43:14.05] Mizuki-TA: That's right, isn't it, if at first they aren't confused, it won't be clear and neat, right?[00:43:17.16] This way is, like, it will totally be clear and neat in the end. [00:43:26.15] Hayate-TA: That kind of haziness is that? It's good if it becomes a chance to like physics, but... [00:43:36.21] Sensei:That being said, when they really understood something, do they say "is this right?" [00:43:40.17] Hayate-TA: As I recall, yes (Sensei again looks a little concerned)[00:43:48.06] Visitor: Dang, ???, you know （Laughs)[00:43:49.06] That kind of worry is.[00:43:53.24] Shuji-TA:That... I see. Perhaps it's not an unpleasant thing for very ??? long, is it? [00:44:01.14] Sensei:Perhaps it has to be hazy (she returns to her confident smile)[00:44:04.06] Hayate-TA: There's no time, for example, kind of thing [00:44:05.12] Shuji-TA:Perhaps, that ??? ・Makki: they will think it's a pain [00:44:07.02] Hayate-TA: This kind of thing is just physics ・Shuji-TA:??? I think they have (sense of regret) gotten used to having answers soon coming out [00:44:11.21] Sensei: Right? That's right, right? But in order for that kind of thing, let's ??? （Shuji-TA laughs)[00:44:14.01] Hayate-TA: That message is good, no? （Makki laughs)[00:44:16.22] Sensei: （firmly but smiling) Yes (others laugh)[00:44:18.15] Hayate-TA: Well, that's fine I think [00:44:19.09] Mizuki-TA:Mizuki-TA is worried that students might get used to not having to get the right answers, since it isn’t graded. Makki thinks that since there’s an exam, they’ll keep going at it.

D. Why was it so easy to adapt?

Beginning with Yui (in other words, after Saika, Yamato, Akane, Sakura, and Manami), prompts were added to the interview protocol to get at why it was easy to adapt to Tutorial. In total, these prompts were given to 21 students. Their responses are below. Many students identified that they had had **prior similar experiences** that helped make the class more digestible. Maeda, Ren, and Taichi identified that since the students will become teachers, it was not difficult to value engaging with this kind of class.

- **Aoi:**[31] [01:02:30.03] If all four people in your group have learned physics, like, while thinking about the intentions made from the problem, like, "why do they want us to find this equation anyway?", kind of, really, you think that and gradually (sense of regret) proceed arbitrarily I think, but, unsurprisingly, if there's someone who doesn't know, you talk together with that person, like, "it's because this is like this, right?" and, like, the person who doesn't know comes to ask "But why does that turn out like that?", so I think you can think more deeply.
- **Chinatsu:** [00:46:22.09] It's clear what we needed to do. It wasn't "think freely"; it was more broken up into steps that guided us... It was easy to do because we're the same major and we get along well. **We had four experiment classes last year and we spent six hours together and wrote reports together when we had questions like "how should we do this one?" We adapted to talking with each other. Everyone in the science department were doing experiments together.**
- **Daisuke:** [00:48:22.08] At first we didn't know what to do but gradually we learned what we were supposed to be doing
- **Gorou:** [00:38:37.22] Nobody told us we were wrong, so we were able to just kept going with our own way of thinking
- **Haruka:** [00:42:23.28] We've never had a group class like this until now, but **during classes, we have experience intermittently talking together. Also the class now is easy to understand, the content is easy to understand, and we understand how to talk together... [00:43:20.09] It wasn't a consistent hour of talking in groups, but we'd do it when the teacher told us to When? The time I did it recently was this last semester [00:43:56.24] It wasn't physics. It was a class where they made us think It was a class to talk about things like how you feel about mandatory English in elementary school She will become an elementary school teacher [00:44:29.07] It was a class for teachers who will become elementary school teachers [00:44:55.01] Did all students take it? I think everyone takes it, oh but these are second-year students... Oh, I see. Did you have other classes, like as a first year student?[00:45:12.16] We also often had experience of talking to our neighbors in high school and middle school... I think we're used to talking to each other And elementary school [00:45:43.19] Was there one that was more frequent than others? I guess elementary school, but I don't really remember elementary school**
- **Kaede:** [00:55:07.00] That's because Japanese - we're very flexible people Fish can only live in areas fit for their body types, but us students, even though we've been living in one river, we can get by in another river too. So if we think "oh, this is a good thing to change," then we can take it in. [00:56:37.00] Why do you especially think that's true for Japanese? We don't really have a strong sense of

[31] [01:02:22.09] Interviewer: Why do you think it has been so easy to adapt to this sort of strange class?

self. We don't have strong opinions. [00:57:13.29] That or... that's a bad meaning, but in a good meaning, there is a wide spectrum that we can take in. I don't know if that's because we're Japanese, but the fact that we are students probably has something to do with it too, but I don't know.**[00:58:09.12] Or if we had taken only the same style of class in every school, then maybe this wouldn't be enjoyable for us but, we've done something like this in elementary school - students talking with each other, not being lectured at by the teacher. We've taken that, for example, and probably everyone has had an elementary school experience like that, so I don't think there will be many kids who think "huh, is this even a class?" [00:59:00.16] That was elementary school math and social studies classes [00:59:11.23] But science classes, all you remember are experiments, so that's different [00:59:51.13] So the thing that's in common is thinking in groups? Or is it thinking for yourself and learning yourself? The context is ???, so more than thinking for yourself, it is similar in the regard of talking to your classmates.[01:00:29.21] There is a feeling of "let's think!" like elementary school, but unlike middle and high school**

- **Madoka:** [00:51:13.16] Well, we are able to use previously learned knowledge... it's not completely different content
- **Maeda:** [00:51:52.12] Well, a big thing is that people at this university are into figuring things out, thinking, and making others think. I went to a different university and did research in science, but the focus was on getting knowledge [00:52:55.11] But since people here are going to become teachers, they are thinking about teaching people... **[00:53:42.21] There's a lot of work done at Gakugei, more than at other schools, to rethink what people have learned in high school so that they can teach it themselves[00:54:18.13] Gakugei has more of an emphasis on asking why something is the way it is, whereas at other schools it would be like "if it's this equation, then it's an equation." [00:54:50.24] Gakugei has a lot of work in other classes too of rethinking what was learned in high school**
- **Mayu:** Why do you think it was so easy to adapt? The "let's learn the way to think about physics" meaning of the class is interesting to us
- **Miu:** [01:02:14.12] It's interesting to do something different than what we learned in high school and middle school, the fun of learning that this is physics, and[01:03:05.09] There are some people who can and can't do physics, but we're thinking in the same way. Because it's interesting, we like it, and gradually get used to it.
- **Nao**: **[00:50:40.17] Middle school, high school, so many years passed, but even so, during the time of elementary school, chatting, talking, solving problems all together was fun [00:51:00.04] Tallking with people about things that you know, being taught the things you don't know that others do know, [00:51:08.00] the important things of that, since we know that, [00:51:11.26] til now, that kind of being taught one-way by a teacher, even if we take that class, [00:51:18.19] so, getting used to this class quickly ??, there is elementary school experience [00:51:25.18] I see. So in**

elementary school, you formed groups and solved problems together [00:51:34.02] Yeah That was in science class too? Science, japanese, Math That was in Tokyo? You said Tokyo, right? Yeah

- Ren: **[00:50:51.17] We've had a year to get to know each other Well, the physics majors have. I don't know the biology people** Also, this is an education school - we want to teach people who don't know [00:51:48.19] People who don't know right down the answers and if they don't understand something, they ask
- Rina**:** Didn't ask
- **Shiori:** [00:32:37.05] Generally, college classes are lots of information thrown at you. Especially last year's physics class. Here, however, they don't throw lots of new stuff at you really quickly. Just the opposite; we've already seen this stuff in middle school. If it were really hard content it might not work so well, but that's not the case.
- **Tadao:** [00:53:50.20] It becomes a question from my end, but, for me, this style of class where everyone is talking to each other seemed pretty natural, but...[00:54:24.20] It was easier for Gakugei students to adaptConcretely, in what way are UMD students not adapting?[00:54:31.10] Well, for example, they say a lot of complaints, "why aren't you teaching us? Why don't you just tell us the answers?" And "I don't like working with others in groups during class!"[00:54:59.02] Ah, if that's the case, then perhaps Japan and America have different cultures, in America, complaints... the attitude of doing what you want to do... but in Japan, with people who are above you, like teachers, what they say is automatically right.[00:55:23.23] And, in order to absolutely protect that opinion (of the teacher), you apply what they say. So, we become what the teacher says. We protect what the teacher says.
- **Tadashi:** [00:59:57.14] The level of the content is low... last year's physics class had content that was too high in level, and it was hard for me. It appears that people who took it in high school did not get used to it. So, Tutorial is... and it's close enough to daily experiences
- **Taichi:** [00:45:33.02] Why do you think it was easy to adapt?It might not have been so much getting used to it, as it was that we did it, and it was fun. If it's fun, you can get used to it, right? Because other physics classes were different, working with people around you was fresh... til now it's just been classes where the teacher teaches one-way, and you'd have to think for yourself... so, yeah, it's fun.[00:46:38.04] UMD isn't as effective - that's why I'm surprisedIs UMD a school for preservice teachers?NoThe way that Tutorial asks us is like, what would you say to people who don't know, there are a lot of questions like that, and Gakugei students are interested in teaching, so they're thinking about that and like Tutorials
- **Takahiro:** [00:59:25.24] Why do you think the class was easy to adapt to?Even amongst those who have taken classes, there are people who want to study physics and those who do not. Inside of that, there are four people debating about one problem, and that's... for a student who doesn't understand, he has a chance to understand, and once they do, they like that feeling of enlightenment.

Our other classes have just been doing it without knowing the reason for the experiment or the calculation. Even students who took physics made discoveries, and explaining to students who don't know was really a learning experience. If you try to explain something, you can often realize that you don't really know, so the difficulty of explaining something to someone is something you can feel.

- **Teiko:** [00:47:29.29] Since no one has experienced this before, it's fun. other classes are strict and rigid, where you just listen and think it's boring or sleep, but here you can say your individual opinion and if you don't understand, you can ask
- Yasu**:** Didn't ask
- **Yui:** [00:57:53.13] Once we realized that this is what the class is about, we had no choice but to adapt, and you gradually come to think. For people who took it in high school, they might find the class to be completely different, but it might be a feeling of "Oh, this is what college classes are like", so they just take it.[00:58:37.28] Did last year's physics class resemble this class? No, it was utterly different... even though it's different, "well, this kind of thing also exists. I guess there's also this way of studying physics." So last year's class was more a high school style and this year's class is more college-style. It's not just memorizing laws and equations; rather it's actually understanding the equations, so I think there are people who have understood that Tutorial is what a college-level class is like.
- **Yukiko:** [01:00:33.03] You can say your own opinion, and most students aren't uncomfortable with that [01:00:54.10] We don't hate talking in front of people, so it was easy for many students to go from the lecture environment to a discussion environment for many students
- **Yurie:** [00:59:35.03] Uh... well, it was hard at first, but we just got used to it. We came to understand what the worksheet was wanting to ask us.

E. Student Complaints

- Akane: Didn't ask
- **Aoi (students who know teach students who don't)**: Students who know the answers are teaching students who don't know the answers, and the students who don't know just copy it down
- **Chinatsu (We are tested without getting correct answers):** [00:14:43.01] We don't get all the way through, so even though we don't know the answer, we still have to do homework [00:15:02.01] In high school, we'd argue, but the next week, the teacher would give us the answers the following week [00:15:22.02] So we don't know the right answers and get it wrong on exams
- **Daisuke (it's hard because I'm used to memorizing equations):** [00:15:35.08] It's a class that makes you think [00:15:42.03] However, I'm accustomed to memorizing equations so this class is difficult
- Gorou: Didn't ask

- **Haruka (translation is bad and so are my grades):** [00:12:56.18] my grades are really bad, and I think it's because I don't understand the Japanese.
- **Kaede (it's necessary to have a student who knows physics):** [00:26:03.26] if those pupils who were good at physics were not there, it would be pretty hard.
- **Madoka (it's hard because I'm used to memorizing equations):** [00:14:33.29] Up until now, we've been thinking about calculations and numbers... we haven't paid attention to contradictions with our intuition or anything like that. This is different than the physics I've done so far, so it's hard.
- **Maeda (students who already know physics don't try seriously to make sense of the material):** [00:19:17.02] My group is made of guys who have taken physics 1 and physics 2 and aren't as receptive to the idea of rethinking what they are already confident about. There's a lot of times where we slack off. [00:21:15.07] It's a situation where we've already had the equations in our heads, so we don't take the idea of "let's think about this" very seriously. I think it works better with students who haven't had physics before.
- **Manami (I'm nervous that I'm not learning the material correctly because we aren't given answers / the material isn't new, so I don't feel like I'm learning):** [00:15:07.14] we're really nervous that we might not be learning new stuff correctly. In high school, we learned that the forces are equal if a truck crashes into a car, but I was always suspicious about that and didn't trust it. But when we went through Tutorial 3, I really felt "wow, we are building our understanding." I still feel uneasy about the class, though. [00:25:24.25] "I feel like I'm not learning new things in the class right now. Last year's class (Peer Instruction with Prof. Nitta) was also basic mechanics, but I felt like I was learning. Now it feels like it's high school material."
- **Mayu (I feel like I'm not thinking in the way the Tutorial designers expected and that makes things difficult):** [00:23:18.07] We can tell that the developer of the Tutorial expected students to think in a certain way and developed the worksheets expecting students to do a certain thing [00:23:54.25] But we don't always think like that. Sometimes we have a different way of thinking about it. Our process is different than that of the worksheet. So I'm not sure about what to write.
- **Miu (We are tested without getting correct answers):** [00:19:36.16] For people who don't already know physics, we have to make it all the way to the end, but we often don't, and we leave not knowing if we're right or not. We have to do homework etc not knowing if it's right or not. It's hard to figure out what it's asking [00:21:49.04] The exam comes even though we don't know the answers to our questions and without us knowing if we're right or not [00:23:13.05] I want answers to both the homework and the Tutorial worksheets, but if we could get the answers to Tutorial worksheets, we'd be able to figure out the homework
- **Nao (translation is bad):** [00:30:45.04] The Japanese is hard to understand. The way we talk is really different than what's written. It's different language than what we always use.

- **Ren (we could learn better if we were given the answers to the homework and worksheets):** [00:34:57.07] I think the bad thing about this class is that they aren't giving us answers. They should give answers to everything, including the weekly worksheets. I think I could understand if I had those answers.
- **Rina (students who know teach students who don't):** [00:31:49.11] My group was a group of people who failed last year - people who can't do physics [00:32:18.14] If there had been a student who knows physics, he would have just taught us and we would have just listened [00:33:10.27] This would be a good class for students just learning physics for the first time
- **Saika (some students are just learning passively and the teacher doesn't notice / We are told that it's important to learn interpretations and talk in groups, but we aren't told why):** [00:17:21.07] It might be that the teacher is not getting across what he wants to teach to all the students[00:17:51.02] There are a lot of classes, so students might not be listening to the teacher[00:18:25.06] In this physics class, students are in groups of four, but there are two people in my group who are just doing it passively[00:19:38.01] I think other students in the class, like those two, aren't getting much out of this[00:20:21.17] There are a lot of classes where you don't get anything out of it if you just sit and listen[00:21:07.27] The teacher just tells without noticing whether or not the students are actually listening/ getting it*[00:23:21.06] The way of doing interpretations for example, is really a focus of this class. But we aren't told why it's important, only that it's important. We are told that it's important to talk in groups, but not why. I understand it's important to relearn what we've already studied, but I don't see how interpretations will help.
- Sakura: didn't ask
- **Shiori (unless it specifies, it's hard to know whether to think individually or as a group / People who haven't had physics depend on people who have had physics as a source of knowledge):** [00:23:18.28] Tell me about the class you're taking now. At first it was hard to know what we were supposed to do. It's nice having "Think as an individual" or "Think as a group" because then you know when you're supposed to do what. [00:24:28.06] There are a lot of people who think that people who took Physics 2 really know what's going on. The other three people in my group are all Physics 1 and when I give my opinion they all immediately agree and don't give other opinions.
- **Tadao (we could learn better if we were given the answers to the homework and worksheets):** [00:19:11.05] There's just one answer in physics. The teacher doesn't make that answer clear, so it's confusing. It's fine for people who know physics, but people like me aren't able to check that their understanding is right, and so we don't know if the answers we reach are correct or not [00:20:07.19] They just make a circle or a slash, it would be nice if they gave suggestions [00:20:31.11] Interviewer: Would it be good if Tutorial worksheets have answers? Tadao: That's more about... there are a lot of things that don't have answers. It's a lot of questions about how you might teach someone who doesn't understand... it would be helpful to be given examples of things that might be helpful

- **Tadashi (This class won't help you with calculations / they aren't giving the correct answers and I don't know what I'm doing wrong):** [00:19:28.13] if you want to get good at calculations, this class isn't so good [00:21:44.28] They don't tell me why I got something wrong, just that it's wrong [00:22:19.29] I've tried answering differently each time, but it's still wrong It would be nice to have a hint
- **Taichi (translation is bad):** [00:18:55.17] Was this translated from English? Because in Japanese I don't really understand what it's asking
- **Takahiro (there are some places where we can't figure it out ourselves / we could learn better if we were given the answers to the homework and worksheets):** [00:25:28.00] Sometimes students just don't understand it and can't figure it out themselves [00:25:50.06] I wanted to talk more to the TA's and teacher; my group had given up and didn't want to continue [00:26:10.08] It was a class designed to connect your own experiences to physics concepts, but there were places that we really just couldn't make sense of [00:26:57.20] The teachers don't tell us the answers, and that' fine, but class ended without knowing the answer (makes face of disgust)... that has been the nature of this class.[00:27:42.19] They don't need to tell us the answers, but maybe just give us more hints
- **Teiko (I feel like I'm not thinking in the way the Tutorial designers expected and that makes things difficult):** [00:10:59.27] Tutorial was... when we first started [00:11:56.16] It was hard when we were asked what our intuition is [00:12:08.14] From the perspective of someone who had never done physics before... [00:12:19.19] The way of thinking is completely different for people who had taken and not taken physics before, people who liked and didn't like physics [00:13:45.21] What is the force acting on an object moving at constant speed? [00:14:12.29] So my thinking is that it makes sense for there to be no net force,
- **Yamato (the material isn't new, so it feels redundant):** [00:17:53.03] However, we did this last year, and it feels like we're doing it over again.[00:18:23.10] It would be good if there was new information
- **Yasu (some students are passive):** [00:13:22.25] Basically it's a class where you discuss in a group, but I think there are some groups where it's just one person's answer
- **Yui (there isn't enough time / you need someone who has done physics before):** [00:29:07.26] We always run out of time. [00:29:22.05] Sometimes we only get half-way through. [00:29:32.06] It becomes a class where we think slowly and deliberately, so we run out of time...[00:29:53.08] You can ask TA's if you don't understand something, but there isn't so much time, so[00:30:05.17] If there isn't someone who knows physics, you can't do it.[00:30:22.21] There are other people who are taking the class over again who aren't so good at physics. Having people who don't know talk to each other kind of doesn't work, so, the class assignments...[00:31:12.20] But if you make the assignments shorter, it would be a shame...[00:31:39.15] One semester is not enough for this class, but we can't expand this class to a second semester

- **Yuriko (not enough time):** [00:16:48.14] Personally, I wanted to have more time to talk so we could have gotten to the end
- Yurie: Didn't ask

F. Student complaints on Professor Uematsu's survey

Favorable comments are in green, complaints about language issues in the worksheets are in blue, and other complaints are in red. The two underlined students had something favorable to say regarding how the style is relevant to their future teaching.

意見要望	
• 答えが知りたいです。(宿題とか、チュートリアルとかの) •授業で明確な答えがないままテストをするのは、公平ではないのでは？	• I want to know the answers (to homework and Tutorials for example) Is it fair to test without clear answers being given in class?
• 以前うけた授業よりもわかりやすくて、今まで物理の中でわからなかったことが、少しわかったような気がします。考える力がつく気がします。	• It was easier to understand compared even with previous classes, and things that I never understood in physics classes before I feel like I've come to understand a little. I feel like I've connected with thinking power.
• チュートリアルが終わらず、明確な答えが出されることもないままに宿題やテストをするのは難しい。	• It's difficult to give homework and exams without clear answers being given before Tutorial ends
• 早く終わらせて欲しい。このアンケート書いてる現在14:19なう。今、14:20になったが、何故か移動させる気配なし。何事？	• I want this survey to end soon
• 授業終了時刻は守ってほしい。チュートリアルは周りと討論でき、様々な考え方のできる活気的な方法だが、物理の苦手な者と得意な者が班にまじると、得意な人の意見にながされがちになるというリスクもある。	• I want the end time (of class) to be respected. In Tutorial, you discuss your ideas around, but there's also a risk in mixing students who hate and who are good at physics that the ideas will flow from the good students.
• プリントの日本語が時々、矛盾している感じがしました。日本語を理解するのに苦労しました。	• Sometimes there were contradictions in the Japanese of the Tutorials. I struggled to understand the Japanese
• 今回の授業では新しく気づかされたことや"こんな目線""あんな目線"とこれから出会う多くの子どもたちに動ようせずに対応できるような力を身につけられ	• *In thinking about "this way of thinking" and "that way of thinking", I thought that we would get the power to deal with many of the children that we*

たのかなと思いました。

- 授業の目標はわかるが、内容が不十分。まとめがないからモヤモヤして終わる。結局この授業で何が得られたかわからない。むしろ新しい概念がごっちゃになって混乱した。やるなら最後まできっちりまとめて欲しい。先生とTAが頑張っているのは伝わるが、正直からまわりしていた。
- 物理なのにここまで日本語の問題になるとツライ。
- ありがとうございました。
- プリントの文章が日本語になっていないので何がしたいのか分からない。
- 物理の基礎をあまり知らなかったので、間違えやすい部分を重点的に考えることができてよかったです。文章がもう少し明解であればよりやりやすいです。
- 日本語がわかりにくいです。
- 今まで何度説明されてもよく理解できていなかった“仕事”が、この授業で理解できるようになりました！ありがとうございました。
- TAの人がとても親切でわかりやすかった。TAがいなければ、この授業は成立しなかったと思う。先生は、側にいても何もしてくれなかった。何のためにいるのかわからない。問題文が日本語じゃない。
- この授業を受けて、イマイチ物理が分からなくなってしまった。
- TAの方の説明がわかりやすい人と、そうでない人がいた。

- 物理全体を扱ってほしい、波などについても、(時間がないが…)TAさんをもっと増やしてほしい。
- もう少しTAさんの人数を増やしてほしかった。

will meet

- I understand the goal of the class, but the content was not sufficient. Since there was no conclusion, we ended confused. In the end, I don't know what was gained in this class. Rather new concepts were intermingled and that confused us. If you do that, up until the end, I want you to firmly tie it all together. It was clear that the teacher and TA's were trying, but I have told the truth.
- It's not fair that, despite being physics, the problems were language problems.
- Thank you very much
- The handouts' sentences are not Japanese, and so I don't know what they want us to do
- Although I did not know the basics of physics very well, I'm glad that we could focus on areas that are easy to make mistakes in. It would have been easier to do if the language had been a little more clear.
- The Japanese is hard to understand
- The topic of work, which had up til now been explained to me many times but I still didn't get it, finally made sense to me in this class! Thank you very much.
- The TA's were really kind and easy to understand. If the TA's had not been there, this class would not have worked I think. Although the teacher was nearby, she did nothing for us. I don't know why she's there. The wording of the problems was not Japanese.
- After taking this class, I became confused about the physics I learned previously
- The explanations of some TA's were easy to understand, other TA's, not so much
- I want all of physics to be done this way, including waves for example (there isn't time but …) I also want you to increase the number of TA's a lot

- I wanted there to be more TA's

- 昨年よりもとても分かりやすかったし、自分で考える機会が多く用意されていて良かったと思います。
- 今まで何をやってきたのかよく、分からなかった。正しい解答がほしかった。
- 授業の意義・目的が理解できない。これが必修である必要があるのか。各チュートリアルもやりっぱなしで意味が結局分からない。
- 何が目的なのか理解できない回がありました。

- TAの人がんばってた。先生の説明わかりにくい。プリント日本語おかしい。なにもみにつかなかったと思う。なにがいいたいのかよくわからない。
- 物理が全く分からなかったけれど、この授業を受けて分かるように少しだけなったように感じます。
- 暑いです。
- 暑いです。
- １４時２０分に間に合って終わったことがない。次の授業があるため大変迷惑である。アンケート記入が２０分から始まるとかおかしいだろ。
- 教室が暑いです。
- 宿題やチュートリアルの解答を教えてほしい。
- 教室が狭く、密度が高いため、６、７月は暑くて集中できませんでした。
- 毎回、机持ってくるのが大変そうだったので、もう少し大きな教室で行なえばよかったと思う。

- ちんぷんかんぷんな数式だけの授業より、話し合い、意見を聞き合いながら、理解を深めていけたので、とっても良かったです。ぜひ、他の授業でもやりたいです。半期ありがとうございました。

- It was even easier to understand than last year, and I'm glad there were so many opportunities provided to think for ourselves

- I don't really understand what we have done this semester. I wanted the correct answers
- I don't understand the significance or purpose of this class. Is this required or necessary? Every Tutorial ended without me understanding the meaning
- There were times in which I did not understand the purpose
- The TA's did their best. The teacher's explanations were hard to understand. The Japanese of the worksheets was strange. I don't think anything stuck with me. I really don't understand what they were trying to say.
- Although I absolutely did not understand physics, after taking this class, I feel like I've come to understand it a little
- It's hot
- It's hot
- I have never completed the survey by 2:20. There's a class after this and it's a huge inconvenience. It's strange to start the survey so late
- The classroom is hot
- I want you to tell me the right answers to the Tutorials and homework
- The classroom was small and full of people. In June and July it was hot and I couldn't focus
- It seemed hard for the TA's to bring desks every time to class, so I think it would have been better to have the class in a bigger room
- ***More than a class of just gibberish mathematical formulas, talking together and listening to each other's opinions deepened my understanding, and I'm really glad. I definitely want to do this in other classes. Thank you very much for this half year.***

• 物理に関してより楽しみに聞けるようになり、先生になっても生徒たちに教えたいと思った。	• ***???More than physics, listening became something to look forward to??? When I become a teacher, I think I want to teach my students this way***
• テストが難しい。	• The test was difficult

G. Prior physics experiences of students

What previous physics classes did students take, and what were they like? This appendix section supports the argument that Tutorials were different than previous physics experiences. There are at least two sections for each student: "high school" and "college". For 15 students, there is also the section titled "image". This last section describes the student views about physics and physics learning prior to taking Physics Exercises. Unless noted by "(no change)", that student changed his/her views about physics to be more expert.

NOTES:

- Only Aoi, Madoka, Miu, Tadao, Tadashi, Taichi, Daisuke, Chinatsu, Rina, Yurie, Gorou, Takahiro, Yukiko, and Teiko were asked about their before and after image of what "physics" is. Maeda freely told the interviewer without being asked.
- "Memorization" in parentheses after the student's name indicates that the student mentioned either (memorizing) OR (applying equations without thinking about the meaning behind them) AND did not identify an alternative physics experience that contrasted with that BEFORE I asked the "why was it so easy to adapt?" prompt.
- "Lectures" means that (the student mentioned that the physics class was lecture-based OR (that high school classes in general were lecture-based AND college physics classes were like high school physics classes)) AND did not identify an alternative physics experience that contrasted with that BEFORE I asked "why was it so easy to adapt?" Note that Yui, for example, talked about how there was a lecture and students would then solve problems in last year's Physics Exercises class (the class was almost entirely group work for most students). However, her mentioning lectures and NOT mentioning groupwork, makes the class "lecture-based".

1. Akane (Memorization)

a) High school

Akane reported that she didn't do much physics in high school. She talked about how the physics course would occasionally have a visiting lecturer from a university who was strange and whom Akane disliked. He went outside the textbook and did things that didn't make sense. For example, he shined a strobe light on a spinning fan and showed how the fan looks like it isn't moving, but nobody knew why he was doing that. There were a lot of experiences like that – experiments where the students didn't understand why they were doing what they were doing.

High school was also geared toward studying for entrance exams. Akane and her classmates solved a lot of problems as preparation, which involved searching for the right equation and algorithmically applying it. She reported that the plug and chug solution of the two rocks problem is an example of this.

b) College

She took (Five physics classes?) her second semester of freshmen year

2. Aoi (Lectures, Memorization)

a) High school

Aoi took physics 1 and some of physics 2. Physics 2 wasn't needed for the entrance exam, so she didn't solve the problems assigned in the class, but rather just sat and listened a little.

Although the teacher would sometimes talk about the meaning of equations, it basically just felt like memorization. There was lots of problem-solving practice to prepare for the entrance exam, where the emphasis was on choosing the right equation and then applying it, and not on deep thinking about why something becomes a certain way. She cited the plug and chug solution to the two rocks problem as being an example of this. It was also rather disconnected from the real world. Instead of thinking about the damage to a car in a collision, it was just "Object A travels blah blah blah".

b) College

Last year's classes were lecture-based and more than solving problems, the emphasis was on physics phenomena and showing how equations can be derived. Unlike high school where there were a lot of numbers used, last year's class worked primarily symbolically. The teacher lectured from the blackboard and didn't ask for student opinions and ideas. The material was presented as something to just memorize without interpretation.

Same as high school: no deep thinking about why something becomes a certain way. It was also rather disconnected from the real world. Instead of thinking about the damage to a car in a collision, it was just "Object A travels blah blah blah".

c) Image

Use equations to solve problems that have minimal connection to the world around you, without asking why it becomes the way it does or thinking about the phenomena that the formalism describes.

3. Chinatsu

a) High School

She only took Physics 1. She went to a super science high school (which had a focus on science education), and in her class, the students would argue with each other, but the answers would always be available the following week. However, the work done wasn't in groups; rather, the teacher would give a problem and then elicit opinions of students and then have the students return to thinking individually again.

b) College

She took 基礎物理 and 物理概論. In those classes, there was no debating – it was completely lecture-based. The contents were difficult, and her friends helped teach her the material before exams. Although the teacher might have given explanations about the meaning of equations, the explanations were too hard to understand. The problems were "too hard to solve by feeling" and so there was a heavy dependence on equations. An example of this is the plug and chug solution to the two rocks problem.

c) Image (no change)

Physics contains calculations which she dislikes

4. Daisuke (Memorization)

a) High school

He took physics 1 and 2 in high school, and the emphasis in those two classes was on solving problems to prepare for entrance exams. The problem solving strategy was to memorize which equations to use in what situations and how to use them (when to integrate, for example). There was back-and-forth discussion between the students and the teacher, but there wasn't group work.

b) College

As opposed to thinking about the meaning of equations, the emphasis was on first memorizing equations and then using them. An example of this is the plug and chug solution.

c) Image (no change)

Equations contain meaning and reflect reality

5. Gorou (Lectures, Memorization)

a) *High school*

Gorou took Physics 1 and then started Physics 2 but dropped out. The classes did not move out of what was in the textbooks, and didn't question why it's true that the force on a car would be the same as that on the truck. They would use equations without knowing why. Although he and his classmates were aware that what they were learning in physics was inconsistent with their daily experiences, they just accepted it and didn't care much. Rather than aiming to think clearly about phenomena, high school classes focused on preparing students for exams by getting students to memorize equations and then use them to solve problems. An example of this is the plug and chug solution. Instead of working in groups, students would copy down what the teacher wrote on the board. The emphasis was on memorizing things from the teacher (including the **forms-based** explanation of the velocity equation).

b) *College*

He took 実験、基礎物理、物理学概論 last year at Gakugei.

Like highschool: The classes did not move out of what was in the textbooks, and didn't question why it's true that the force on a car would be the same as that on the truck. They would use equations without knowing why. Although he and his classmates were aware that what they were learning in physics was inconsistent with their daily experiences, they just accepted it and didn't care much. Rather than aiming to think clearly about phenomena, these classes focused on preparing students for exams by getting students to memorize equations and then use them to solve problems. An example of this is the plug and chug solution. Instead of working in groups, students would copy down what the teacher wrote on the board. The emphasis was on memorizing things from the teacher (including the forms-based explanation of the velocity equation).

c) *Image*

It was OK to use equations without really knowing why

6. Haruka (Lectures)

a) *High school*

Haruka didn't take physics in high school.

b) *College*

She took physics during her first and second year at Gakugei (she was taking Tutorial during her third year). The previous classes didn't make much sense. The first year was hard to understand, and the second year just kept going even though she had no idea what was going on. Although she heard Newton's Third law, it never really made sense. There was a lot of technical language that was difficult to interpret. There wasn't group work; all the knowledge was from the teacher.

7. Kaede (Lectures, Memorization)

a) *High school*

She took physics 1 in high school, but doesn't remember it at all. Although she was physically present, it had been like she wasn't really there, as though she didn't take it. It was a hard class. Unlike Tutorial, there wasn't an atmosphere of "let's think!"

b) *College*

Like high school, although she was physically present, it had been like she wasn't really there, as though she didn't take it. It was a hard class. She always had an image of "I'm passively learning physics," and nothing was able to enter her mind. The lectures had been rigid.

8. Madoka (Lectures, Memorization)

a) *High school*

Madoka took both physics 1 and 2 in high school. The style of class was plug and chug, focusing on calculations and numbers and ignoring contradictions with intuition. There was no groupwork, just one-directional teaching from the teacher. Students took notes, did calculations, and solved problems. The problems that they were asked to solve were "not multiple choice like the two rocks problem; they would just be "What happens?"" and were very difficult.

b) *College*

He took 物理学概論、基礎物理学. It was a body of physics laws that were taught didacticly: "Here are phenomena that happen". Although there were explanations for the laws, they were hard to understand. Like high school, the classes focused on calculations and numbers and ignored contradictions with intuition. There was no groupwork, just one-directional teaching from the teacher. Students took notes, did calculations, and solved problems.

c) *Image*

Physics is nothing but calculations and connections to the real world are unclear

9. Maeda (Lectures, Memorization)

a) *High school*

Maeda took both Physics 1 and 2. Equations were used to solve problems, and everyday experiences got in the way of that. To get good grades, students had to ignore conflicts with their everyday experiences and just use equations. There were, however, opportunities to think about the meaning that equations contain.

The teacher would ask what an equation means, and students would think a little about during class and think about how it connects to the real world. However, the depth was always at the level of "there's something called 'momentum', and it's mv. If you move quickly, you have more impact, and so the momentum is greater." To get a deeper explanation, you'd have to think on your own. Maeda acknowledges that although he probably was not the only one who actually did this work, it's also true that not everyone did it. Although students thought a lot, that wasn't the emphasis of the class. The emphasis was on memorizing. He felt it a waste to memorize equations just to forget them when the exam was over, so he has always tried to think about what he's learning and make sense of it. But the high school classes didn't reward that kind of thinking about the meaning of what you're learning much.

b) College

Maeda described his previous college physics classes as being like his high school classes.

c) Image

The meaning behind what was being learned didn't need to be there; intuition would sometimes interfere with doing well in physics, so it could be ignored.

10. Manami

a) High School

Although they learned that the forces are equal if a truck crashes into a car, she was always suspicious about that and didn't trust it.

b) College

She took Hideo's Peer Instruction the year before she took Tutorial. Although Hideo reports that in the 70 minute class there were only 3-4 clicker questions, Manami's memory is that the class was basically JUST clicker questions with professor explanation. In that class, although it was basic mechanics, like what she had seen in high school, she nevertheless felt like she was learning (as opposed to the basic content of Tutorial).

11. Mayu (Memorization)

a) High school

She took a science class in high school that was half chemistry and half physics. The physics did not involve mechanics. It had been teaching like a one-way arrow from the teacher, but, she would say at the end of the interview when asked if she had had prior similar experiences, there was also an emphasis on discussing and half the time was spent that way (however, she had earlier said that in high school in general, the teacher leads discussions). There was not so much thinking time; rather, it was just "law, law, law". She did, however, have science labs, where they would make predictions in groups. That wasn't as much talking as Tutorial, however.

b) College

The physics lab course that she took the previous year (also taught by Uematsu-sensei) felt a little like Tutorial. There was problem solving in groups, for example. Other physics classes, however, like high school, were a one-way arrow from the teacher. There was not so much thinking time; rather, it was just "law, law, law".

12. Miu (Lectures, Memorization)

a) High school

She did take physics her first year of high school, but she hated it and avoided it, so it felt like she didn't do it. The emphasis had been on calculating (the plug and chug solution to the two rocks problem is an example) and taking equations as things to be memorized. She felt that equations are necessary to get answers and derive physics laws. Instead of working in groups, students would just write. If students had questions, they'd ask the teacher after class.

b) College

Her physics last year emphasized memorizing equations and doing calculations (the plug and chug solution is an example). You apply and equation and get out an answer. Although she likes to watch calculations, she doesn't want to do it herself. Like high school, students would take equations as things to be memorized. She felt that equations are necessary to get answers and derive physics laws. Instead of working in groups, students would just write. If students had questions, they'd ask the teacher after class.

c) Image

She used to think that physics is about difficult equations that are used to solve problems, and she identifies the plug and chug solution as being an example of this. She also thought of these equations as being the source of physics knowledge.

13. Nao (Lectures)

a) High school

Nao took one physics course with contents that merged physics 1 and physics 2.

Although Nao took experiment classes where students were talking with each other, in physics, students were quiet and taking notes. The teacher would teach, and students would solve problems themselves.

b) College

Like high school, the teacher would teach, and students would solve problems themselves.

14. Ren (Lectures, Memorization)

a) High school

Students didn't talk to each other in class. There were practice problems that aren't used in the class as homework or exams, but nevertheless reveal patterns of how to solve problems. By following example problems and seeing these patterns, he was able to do a little better in the class.

b) College

Prior physics classes were lecture-based and didn't have those practice problems. Students take notes on what the teacher lectures on. Unlike Tutorial, the knowledge comes from the teacher.

15. Rina (Lectures, Memorization)

a) High school

She was able to avoid taking even Physics 1.

b) College

Although she would listen to the teachers' lectures, they would be too fast with lots of stuff that is irrelevant to the real world. She felt that even if she could succeed in that class, it doesn't mean that she really understands "the world of physics". Her classmates told her to not try to think so deeply about the material or connect it to the real world, but rather to just accept that physics is about thinking in a certain way. So she gave up on trying to really understand and instead just thought "Huh, maybe I can use this equation". Even though she didn't really understand why she was calculating, she just learned that with certain types of problems, you apply a certain equation (the plug and chug solution is an example). She considers herself to have failed that class.

c) Image

Physics isn't supposed to make sense, so just memorize it

16. Saika (Lectures)

a) High School

Did not talk in groups. Didn't listen to the lectures; slept in class.

b) College

Did not talk in groups. Didn't listen to the lectures; slept in class.

17. Sakura (Lectures, Memorization)

a) High School

She did not take "physics", but rather a science class that included a portion of physics, similarly to what she did in middle school. In both middle and high school, the physics was really basic, but was still hard to understand. Students solved problems by memorizing equations, which was difficult since they didn't really understand what they were doing, and it wasn't fun. There were not many experiments (which are fun).

b) College

She took a course in the fall and in the spring. The classes were nothing but lectures, and they made her sleepy.

18. Shiori (Memorization)

a) High School

Shiori reported that there were a lot of experiments done in high school, where students worked in groups and energetically talked to each other.

Learning physics had been memorizing material whether it made sense or not. "F=ma, got it?" "Got it!" Thought that physics is very far from everyday experiences. From an experiment (in middle school, actually) about things falling at the same speed in a vacuum tube, she learned that physics is made more difficult if you think about daily experiences.

b) College

Generally, college classes consist of lots of information thrown at you, especially last year's physics classes. Like her high school classes, learning physics had been memorizing material whether it made sense or not. "F=ma, got it?" "Got it!" Thought that physics is very far from everyday experiences. From an experiment (in middle school, actually) about things falling at the same speed in a vacuum tube, she learned that physics is made more difficult if you think about daily experiences.

19. Tadao (Lectures, Memorization)

a) High School

Tadao hated physics because he thought it was nothing but painful calculations. He knew that since middle school, and so he didn't take physics in high school.

b) College

At TGU, the physics course Tadao took confirmed that physics is nothing but painful calculations and that he doesn't like it. The class was about getting knowledge from the teacher that was written on the blackboard and memorizing it. It felt like stuffing your head with knowledge (an example is the plug and chug solution, because it feels like a machine, where the answer is already decided).

c) Image

he had known that physics has a lot of calculations, like calculations for distance, and the class he took last year confirmed it. He hates that kind of thing.

20. Tadashi

a) High School

Tadashi didn't take physics in high school.

b) College

His experiences in college regarding physics showed him that Japanese physics classes are about lots of equations that need to be interpreted on your own. Physics felt far away, like something in a book. He didn't know how to apply that material to the real world. Last year, he took Hideo's clicker class. There wasn't enough time for discussion in that class, so the conversations got cut off and answers would be immediately provided after clicking in. The main point was not discussion, but to learn the material. Other than that, classes he took were traditional, with the teacher lecturing and students taking notes, and no group discussions at all. It was entirely the teacher's knowledge being passed to the students.

He used to solve problems just with plug and chug (the plug and chug solution is an example) and without having a deep meaning.

c) Image

Examining the world like with binoculars, but from far away.

21. Taichi (Lectures, Memorization)

a) High school

Although physics was not needed for the entrance exams and he hated it, he still took it. There wasn't really a back and forth in class – teachers would occasionally make students solve problems during class, however. Classes were taught uni-directionally. The teacher writes on the board, the students memorize that, and then solve problems.

b) College

Like in high school, classes were taught uni-directionally. The teacher writes on the board, the students memorize that, and then solve problems.

c) Image

Memorize equations and types of problems. For the situation in the problem, use equations, and go and solve.

22. Takahiro (Lectures)

a) High School

In high school, Takahiro at first didn't like physics; however, he was able to get a handle on it and succeed and progress to a physics major in college. He hadn't previously learned trig functions like sin and cos, but he took enough classes and looked the functions up on his own, and asked the teacher and classmates for a lot of help. By the end of physics 2, however, he still didn't really like electronics, current, and voltage, because it didn't match up with his own experiences. Although he was able to solve problems, it wasn't really clean and neat.

Classes were about taking notes on what the teacher said in lecture, as opposed to making sense of stuff during class. Knowledge came from the teacher. Students did what they did without knowing the reason for the experiment or the calculation.

b) Image (no change)

You can show things that you experience in everyday life like throwing a ball with mathematical equations and that's awesome. But things like electricity are really hard to have an image of.

c) College

Concurrently with Tutorial, he took a physics math class, that made the students get used to integrals and derivatives. In college classes as well, although he knew the answers to circuits problems, he still wasn't really able to make sense of electrostatics.

Although his own attitude towards physics didn't really change, he saw other students who hadn't done a lot of physics, who had previously taken lab classes and had just focused on how they have to submit reports and not really worry about whether or not they understand the material.

Like in high school, classes were about taking notes on what the teacher said in lecture, as opposed to making sense of stuff during class. Knowledge came from the teacher. Students did what they did without knowing the reason for the experiment or the calculation.

23. Teiko (Lectures, Memorization)

a) High School

Teiko took both Physics 1 and Physics 2 in high school. She felt like there weren't "concrete" explanations for why something is the way it is; rather, material was presented as just "this is the way it is."

The format was lectures, with lots of stuff on the board; it was hard. Students were taking the teacher's knowledge. Classes were strict and rigid, where you try to listen and either find it boring or fall asleep. Even if you don't understand anything that's going on, you just memorize it (equations, etc.) as "this is this". Students were not working in groups. Physics was very technical and specific, not very clear. To solve the two rocks problem in a high school way would entail drawing a graph, "doing it mathematically", plugging into an equation without thinking because the equation is good to use in such situations. (Plug and chug solution for example) Such a solution doesn't feel like "thinking"; rather, it's just memorizing.

b) College

She took four physics classes last year. Like high school, the format was lectures, with lots of stuff on the board; it was hard. Students were taking the teacher's knowledge. Classes were strict and rigid, where you try to listen and either find it boring or fall asleep. Even if you don't understand anything that's going on, you just memorize it (equations, etc.) as "this is this". Students were not working in groups. Physics was very technical and specific, not very clear. To solve the two rocks problem in a last year way would entail drawing a graph, "doing it mathematically", plugging into an equation without thinking because the equation is good to use in such situations. (Plug and chug solution for example) Such a solution doesn't feel like "thinking"; rather, it's just memorizing.

c) Image

Was more scholarly, specialized, and less clear

24. Yamato (Lectures, Memorization)

a) High School

In high school, teachers just lectured and told us what was going on directly (in contrast to actually thinking about/ understanding what you're learning)

b) College

The only thing Yamato said about his prior physics classes is that the content in Tutorial is the same as what he's already seen, so it makes it hard to take Tutorial seriously.

25. Yasu (Lectures)

a) *High School*

Yasu took physics 1 in high school and physics 2 through juku. He recalled that teachers were very interested if students could show a different way to solve a problem, and they were more likely to elicit student opinions than in elementary school. At the same time, however, the TIMSS videos of students working in groups surprised Yasu, which suggests that his high school also was not like that.

Indeed, he said that he was not solving problems in groups. He agrees that previous physics classes were one-way arrows of teaching from the teacher to the students. Although students might think deeply during the homework, they weren't really doing so during classtime itself. He personally, however, has experienced stopping taking notes to just sit and think about an equation that didn't make sense to him (during class).

He said that his high school teacher didn't force students to memorize equations; rather, the emphasis was on deriving and proving equations.

b) *College*

Like high school, there was not solving problems in groups. He agrees that previous physics classes were one-way arrows of teaching from the teacher to the students. Although students might think deeply during the homework, they weren't really doing so during classtime itself. He personally, however, has experienced stopping taking notes to just sit and think about an equation that didn't make sense to him (during class).

26. Yui (Lectures, Memorization)

a) *High School*

Yui reported that she didn't take physics in high school, but she does make several comparisons to high school when talking about college physics classes.

b) *College*

She said that her classes last year were "like solving the same problems in high school." There was a lecture and problem solving. She copied answers from other people. She never got rid of her wrong ideas and mistakes about physics laws, she says, because all they did was refer to textbooks and reference books, if you only study things that are right, you won't correct your misunderstanding. She found previous physics classes to just be memorizing laws and equations without understanding of them, and she didn't like physics.

27. Yukiko (Lectures, Memorization)

a) *High School*

Yukiko took physics 1 in high school. She thought physics is hard and all about memorizing mathematical equations.

Students would come to understand the material by taking notes from what's on the board. Unlike Tutorial, knowledge was taught unidirectionally. Rather than tapping into daily experiences, the lectures were about understanding equations, not connecting to daily experiences. An example of this is the plug and chug solution to the two rocks problem, which is what would be needed for entrance exams, where there isn't time to think or explain.

b) *College*

Last year, Yukiko took 基礎物理 and 物理概論. Like in high school, students would come to understand the material by taking notes from what's on the board. Unlike Tutorial, knowledge was taught unidirectionally. Rather than tapping into daily experiences, the lectures were about understanding equations, not connecting to daily experiences. An example of this is the plug and chug solution to the two rocks problem.

c) *Image*

Used to think that physics is hard and about memorizing mathematical equations.

28. Yurie (Lectures, Memorization)

a) *High School*

Yurie took Physics 1 and physics 2, but did poorly in the latter and doesn't remember it well.

Classes were about lectures and memorizing equations, so she memorized a lot. It was just equation-based thinking. "Because the equation is like this, numbers go in like this". The calculations were different than those in Tutorial; they were just "Here's a problem – solve it." Never thought about why things like F=ma are true. Did not connect the formalism to daily occurrences. She hated it. She knew that physics is something that shows daily occurrences in laws and equations, but only because the teacher had told her so. As opposed to the forms-based solution to the two rocks problem, it did not look at underlying concepts, and just used equations. It was not something an elementary school student could understand.

b) *College*

Her first year at TGU, Yurie took 基礎物理、物理学概論, and the lab course.

Like high school, classes were about lectures and memorizing equations, so she memorized a lot. It was just equation-based thinking. "Because the equation is like this, numbers go in like this". The calculations were different than those in Tutorial;

they were just “Here’s a problem – solve it.” Never thought about why things like F=ma are true. Did not connect the formalism to daily occurrences. She hated it. She knew that physics is something that shows daily occurrences in laws and equations, but only because the teacher had told her so. As opposed to the forms-based solution to the two rocks problem, it did not look at underlying concepts, and just used equations. It was not something an elementary school student could understand.

c) Image

You memorize and use equations that supposedly reflect reality

29. Total

Out of 28 students, 21 students described pre-Tutorial physics as being lecture-based. 20 students described pre-Tutorial physics as emphasizing memorization.

H. Professor Uematsu’s Debriefing Notes

1. After Tutorial 1, 2011:

Mike が C301 に行っていた，TA の保坂さんが発熱で休み，と初めから想定外のことが起こる．

追加の履修者が多い．グループで座らせるのにやや時間がかかる．教室の机と椅子が不足しており，S401 から借りるが，窮屈．

一応机の前後に座って，グループで話す体制を作ったが，上体だけを向けるようになる．二つの机を合わせて両側から向き合わせるか，机を一つにして両側から向き合わせる，など考慮する必要あり．机を並べた隣のグループとの間に境界がない．机を離すと，TA が見回るスペースがなくなる．→ボール紙などを立てる，というのが Mike のアイディア．

一部屋 3 人の TA が，担当する学生を決めて対応するのは，人数が多くて今のところ機能しない．手がすいた人が対応している．写真をとって名前を覚える余裕はない．

S301 で，初めに説明をするので，TA は全員 S302 のサポートに．S301 で改めて Mike を紹介しビデオ撮影などのインフォームドコンセントの話をしてもらう．植松も TA と隣室に行って，今日の進行と大声を出さないようにという注意を話す．書類の記入が終わったころ S301 で「運動の表し方 1」を説明．約 20 分．スライドは，授業で見せないもの(数式の書いたもの，2 次元の場合など，やや複雑なもの)と合わせて事前に Webclass にあげてある．講義中は静かで，チュートリアルは活発な議論がなされ，順調．

説明の終わった後，S302 に植松は移動して TA の不足を補う．物理科の学生が話して，他の学生が同意する，というパターンを崩しにくいところはあったが，全体にやはり活発な議論がなされ，順調．終了 25 分前に議論や作業を終わらせて，こちらでも Mike のインフォームドコンセントの話．その後植松が説明し，学生がよく聞いてくれたものの，チュートリアルの議論を続けたかった様子が明らかで，説明する意義があるのか疑問．

以下は TA meeting で．

・TA に答えを求められたとき，顔つきでばれてしまう

→TA と話し合うことではなくて，グループ内で話し合うことが重要，と言う．

・全員一致して同じ答えだ，と言われて合っているときに，先に進ませてよいのか迷った．

→(Mike) TA は答えが合っていれば先に進んでよいと言う，という印象を持たせていけない．十分議論ができていれば，答えが合っていなくても先に進ませることがあってよい．

・初めの TA の説明にもかかわらず，TA からの答えを待っている学生がいたように思う．

→(Mike)答えは学生の中から出てくる，ということに慣れるのには時間がかかる．続けているうちにできるようになる．

・初めは自分の考えをまとめている時間があったが，だんだんグループのデ

ィスカッションかできるようになっていた．物理を議論していた．

Ⅱ．A の解釈　誘導尋問のようになってしまう．

Mike から　全体に議論はうまくいっていた．楽しそうに議論していた．机の配置を考え直した方がよい．名前を覚えるために，大きな紙を活用する

Mike went to C301, a TA wasn't there because of a fever – from those unexpected things happening is how it began.

There are a lot of additional students. Making them sit in groups took an unexpectedly long time. There weren't enough tables and chairs, so we borrowed from S401, but it was cramped. We created a system of sitting in front and behind desks to talk in groups, but it becomes only the upper body turning. We need to consider whether to have two desks facing each other or to use only one desk and move the other desk to the sides of room, for example. There is no boundary between desks of groups sitting side-by-side. If you separate the desks, the space for TA's to look around the room goes away.

→ Mike's idea is to stand up cardboard paper

Three TA's in one room, deciding to deal with certain students doesn't work because the number of students is so large. Empty-handed people are supporting. We did not have the affordance to take photos and memorize names.

In S301, since I give the explanation first, all the TA's went to support in S302. I again introduced Mike in S301 and he gave a talk about video shooting and informed consent. Uematsu and the TA's went to the other room, told how to progress today and to warn about speaking in a loud voice. At about the time that the worksheets were done being filled out, I explained "How to show motion 1" in S301. It lasted about 20 minutes. Slides match things that aren't shown in class (written equations, 2-dimensions, for example, somewhat more complicated things) and are up on Webclass beforehand. It was quiet during the lecture, and it made lively discussions in Tutorial, favorable.

After the explanation, Uematsu went to S302 to compensate for the lack of TA's. ***It was hard to break the pattern of physics students talking and other students just agreeing, but overall, as expected, discussions were lively, favorable. …***

25 minutes before the end, the discussions and work were ended, and Mike here again gave his talk about informed consent.

After that, Uematsu gave the explanation and students listened well who clearly wanted to continue the Tutorial discussions, and it is questionable whether there is significance to the lecture.

The following is from the TA meeting:

- When asked to answer by a TA, they look at the face for whether they are right or not

→ Tell them that the important thing is not to talk with the TA, but to talk within the group

- When all the members say that they are in agreement and have the same answers, unsure whether or not it's good to have them proceed.

→ (Mike) We must not give the students the impression that if the answer is correct that TA's will tell them it's good to go ahead. If they could discuss enough, even if the answer is not correct, it's good if there are times when they are told to just go ahead.

- Despite the explanation that TA's gave at the beginning, it seems there were students who were waiting for the answers from the TA's.

→(Mike) It takes time to get used to answers coming from inside of students. It is in continuing that they become able to do it.

- There was at first time when they were finding their own thinking, but gradually it became able to have group discussions. They were debating about physics.

II.A 's interpretation becomes a leading question (sense of regret)

From Mike, overall, discussions were going well. They were discussing in a way that looked like fun. It would be good to rethink the placement of the desks. In order to memorize names, use big paper.

I. Epistemologically Similar Prior Experiences

1. Kaede

[00:03:11.18] I: I am interested in what kind of thing Japanese education is, in general. First of all, what was your elementary school like?

[00:03:20.01] K: That's science, science content? Overall?

[00:03:24.04] I: Well, both? First of all, generally...

[00:03:26.19] K: Overall, what kind of... yeah... right? What kind of... hm,

[00:03:36.06] I have a feeling it was not really the kind of school that makes you study (lightly hits desk with fist to add emphasis on "study").

[00:03:44.12] Like, and, it depended on the teacher, however, I think, but, well...

[00:03:48.20] (???) class, for example, even in Japanese class, for example, [00:03:52.23] For example, if it was math, he would make us solve (with emphasis, as though conceding) a problem, but after solving that problem,

[00:03:58.07] absolutely (with emphasis)... that, he would make us stand, he would make the children stand, and

[00:04:03.07] talk to other kids, go to the place, and "how did you solve this problem?"

[00:04:10.05] It was, I (???)

[00:04:12.00] "Please show me your way of answering" - he made us have those conversations

[00:04:15.14] You'd show the way of doing it that you wrote down to the kid you were talking to

[00:04:18.13] "Ah, is that so? That's the style that you solved it in, right?" we would say.

[00:04:20.00] In the end, we'd (crowd???) for example,

[00:04:22.17] and in times where there was a problem you didn't know, between you and your nearby friend, you could (crowd???)

[00:04:27.17] it was a feeling of (crowding???)

[00:04:29.21] Not really... the teacher, the way of doing it was definitely, the way of doing it after, kids who understood would,

[00:04:33.19] to each other, kid to kid, since it was (???) level,

[00:04:39.16] it becomes an (observation record???) memory. And then (in science??? On the first day of summer???)

[00:04:44.21] After that, what in the world, even the teacher, for example, during vacation time, would play with us. I have a feeling like he was volunteering for us, for example、

[00:04:53.16] Hm, it was not (a significant degree???) of thinking that going to school was unpleasant, right, in my case.

[00:05:00.00] I: Going to school was unpleasant?

K: That's what I did not think.

I: You did not think that. It was fun, you said?

K: It was fun

[00:05:04.23] I: Did you say that that was especially science class?

[00:05:07.09] You were saying that science had some kind of "vacation" feeling?

[00:05:11.23] K: Science class?

I: Right

[00:05:14.20] K: Eh? (looks up into the air, thoughtful)

[00:05:17.09] I: What did you say, I kind of didn't understand... I thought you said "vacation", but... maybe I was wrong...

[00:05:17.09] K: Vacation...

I: Science class, say it again?

K: Science class? Science class was, uh, just how was it...

[00:05:29.20] Hm, there isn't really a remaining impression from science class... unsurprisingly, the biggest one remaining is that we did experiments.

[00:05:43.23] A starch experiment, for example... and an alcohol lamp experiment, for example...

[00:05:51.00] I remember the contents of the experiments, but

[00:05:55.03] other than that, there isn't particularly... calculators were...

[00:05:59.09] I have a feeling like we were using computers.

[00:06:02.12] I: Students were using computers?

[00:06:05.00] K: Yes, if I'm not mistaken.

[00:06:07.15] I:Oh, your own? Or, like...

[00:06:09.01] K: The school's. With the same explanation, well, in science class, we researched (???)

[00:06:16.22] I have a feeling like we researched, like a story about (having to wait in the Sim???) Milky Way

[00:06:24.17] I: At the beginning, the explanation you were giving me was that the teacher would... a student would solve a problem, that student would stand, go to another student, show that way of solving, and give a signature - you were giving an explanation about that?

[00:06:45.14] K: (looks confused) Ah, signature... ah! It wasn't just one person, everyone would stand

[00:06:48.29] I: Ah, everyone would stand

[00:06:51.03] K: Everyone would, um, kids who didn't understand too, kids who understood too

[00:06:54.04] Everyone would stand, move, to a friend...

[00:06:58.11] Me, if I did not understand, "I didn't get it, how did you solve it?" - in that style I would ask, and we would show our ways of solving, for example

[00:07:07.06] And, if the way of solving was similarly understood, one's own way of solving would (crowd???), so

[00:07:14.01] It wasn't a thing of one person's result being the model; rather, everyone was doing the same thing

[00:07:19.14] I: Everyone stood, moved, people who understood found people who did not, and, they would teach with each other

[00:07:27.02] K: That's right, isn't it?

I: I understand. That was always in pairs? Or would there be 3, 5?

[00:07:37.00] K: Ah, when we'd do it, it was in pairs, but it wasn't an end with that kid... for example, Mr. A and Mr. B met, after that Mr. A met Mr. C, and then met Mr. D. Mr. B likewise met Mr. E and then Mr. F - it was that kind of feeling

[00:07:49.03] There would be various unions, and if time ran out, (???) in that week.

[00:07:52.20] I: Many times they would stand and walk around, during class

K: Yes. During class, hm, regarding big problem number 1, we would stand once, then, after that,

[00:08:02.12] we would repeat practice problems, and

[00:08:05.08] if you still didn't understand after class, that

[00:08:06.20] that kind of, (???), for example,

[00:08:08.29] The part that was (???)

[00:08:11.11] I: Which class was that? Did you say Japanese class?

[00:08:14.09] K: That was math, ah, arithmetic... arithmetic

[00:08:16.23] I: Arithmetic?

[00:08:16.23] K: Yeah

[00:08:18.23] I: I understand. What was middle school like?

[00:08:21.03] K: Middle school...

[00:08:25.02] I: By the way, are you hot?

[00:08:25.02] K: Ah, I'm OK. It's OK

I: You're OK?

[00:08:27.11] K: Yes. Middle school, eh, class... hm, that's right... hm, which classes... eh, it changed depending on the teacher.

[00:08:59.26] Like, there were teachers who stressed worksheets, there were teachers who would have classes for us that would attract student attention,

[00:09:10.22] and there were teachers who were following a flow of us hearing lectures. - that's the feeling I get.

[00:09:16.05] I: It depended on the subject?

[00:09:18.09] K: More than the subject, it's the teacher, right? It really was different depending on that teacher, right?

[00:09:35.01] I: How about high school?

K: High school, um, middle school... a place of one collection was stretched across...

[00:09:40.23] Middle school, high school, the same (appearance???), and so

[00:09:43.26] We did it like this, and the contents did not change much

[00:09:48.21] just like that, it depended on the teacher (???)

[00:09:55.17] I: Generally, from the eyes of a college student, which school stood out the most (standard prompt)

[00:10:17.22] K: Ah, hm, the three... that's right, right? Elementary school and, elementary school and middle/high is the feeling I have, I do.

[00:10:29.25] I: I see, and why is that the most different?

[00:10:39.17] K: Along the lines of the feeling, elementary school was learning (in a good way???)

[00:10:51.25] There isn't the emotion that we were learning, but, well, that, over there, the acquired knowledge becomes one's foundation is the kind of feeling

[00:11:01.04] I: (looks up unknown word: "foundation")

[00:11:28.16] I: In elementary school, since you were making your own foundation, you were learning with a good feeling

[00:11:33.05] K: Yes, well, I get the feeling that there also wasn't a feeling of "learning"

[00:11:37.12] Perhaps, it's like we were absorbing (waves hands in front of her, as though wafting a scent) everything

[00:11:42.23] I: (looks up unknown word)

[00:12:06.29] I: Oh, I see! You were doing that with knowledge, right? You were absorbing knowledge?

K: Right

[00:12:06.29] I: OK, so it students weren't feeling "OK, now we're learning",

K: They weren't

I: it was just, absorbing...

[00:12:21.04] K: Since we were absorbing, it entered easily, for example[00:12:24.24] Middle school and high school, for some reason, the scholarly activity, if you will, hm, it was like "I have to put this in me"

[00:12:33.25] "This is necessary knowledge!" - it was with that kind of feeling that we were

[00:12:38.24] dealing with classes, for example, so... "ah, we have class next" is the kind of feeling it becomes, for example

[00:12:45.10] eh, that, that is just me perhaps, hm, but,

[00:12:53.03] It isn't really remaining, inside of me. During elementary school, [00:12:57.16] If I was asked "what kind of activity was there?", "we did that thing, we did this thing"

[00:13:02.20] is how I could remember it, but, for some reason, when it became middle and high school,

[00:13:06.11] It was like "the textbook, the work, (gestures to desk) and me (points to self)"

[00:13:09.28] The fact that, more than expected, I can't remember class formal knowledge, is, unsurprisingly,

[00:13:15.14] that I was forced to do scholarly activity, like I was made to do that,

[00:13:20.23] I was made to do scholarly activity - that's the feeling I have, right?

[00:13:23.26] I: Middle school and high school, perhaps, even if you weren't interested, the teacher was saying "learn this!" and so you'd study, but if it's elementary school, you would think "oh, this is interesting!", not learning, right... how are learning and absorbing different?

[00:13:50.00] K: Absorbing and learning (no hand gestures this time), hm, learning... what in the world... uh, if I change the words,

[00:14:06.00] What is good to say, hm, passive (again waves hands as though wafting)... passive, in regards to learning

[00:14:18.02] Middle and high school were passive (wafts), but elementary school, well

[00:14:20.02] active (reverses hands, moving from shoulders to table with palms up, as though sending something out),

[00:14:35.22] I: (Looks up unknown word "active")

K: assertive, if you will

[00:14:40.19] I:Do you have some example, I wonder?

[00:14:44.06] K:An example... hm, ("is it an interruption"???) are also different, but in elementary school,

[00:14:56.28] for example, this, when this problem would be given out (???)

[00:15:03.19] When the teacher would, to us, "Well, I wonder what happens with this answer?"

[00:15:07.19] we said (raising and waving hand) "Me, me, me, me, me!" for example...

[00:15:09.29] I think there were a lot of kids who would already blurt out the answers, but when it became middle school, high school, for some reason, that was decreasing

[00:15:18.14] like, "we are just being requested to give the correct answers, aren't we?" is how we would (sense of regret) feel, for example, if middle/ high school

[00:15:23.12] But, in elementary school, like, it wasn't about whether the answers were right or not;

[00:15:27.16] regarding the thing we've been given by the teacher, assertively, I want to answer myself.

[00:15:33.27] Maybe there isn't a feeling of "I want to answer", but, hm, first of all,

[00:15:38.26] everyone could properly participate in class, could they not? is what I think

[00:15:44.12] I: I think I understand. In middle and high school, the teacher was looking for the right answer, so if students would have an unease about whether or not they were correct, they wouldn't talk. But in elementary school, there was not that unease, everyone wanted to express their own answer, and it was much more active.

[00:16:14.09] K: (nods head)

[00:20:30.24] What I would say

[00:20:36.04] Hum, we make groups of 4 people, do we not?

[00:20:39.09] At that time, physics, till now, a kid who has taken physics

[00:20:48.11] till now, in middle school, for example, in high school, if there is not approximately 1 kid who has studied physics, it won't hold up. That thing.

[00:21:21.04] I think it's hard. Perhaps as far as the class contents go, I think that it's written in the flow of do the basics to a kid who doesn't know, in what manner do those kids do the everyday, for example, and then, "let's learn physics in a way that is easy to understand!", but

[00:21:45.03] til now, I have come having not studied physics, so,

[00:21:57.29] um, that, fundamentally, I don't know what is good to start thinking from, so

[00:22:04.19] unsurprisingly, that common sense for example,

[00:22:08.23] also, I think in this way, but if that, much later (gestures going down the page) is written in a different manner, ah, like, huh?

[00:22:17.03] I made a mistake from here, is what it (sense of regret) becomes, so that kind of miss is pointed out for me by a kid who came having learned physics now.

[00:22:24.18] "Nah, this is perhaps like this, you know" she says for me, "oh, really?"

[00:22:27.10] is what I say, I am able to ride that kind of current - it's that feeling, so, if there is not even one kid to let me ride in that flow, gradually gradually it (sense of regret) goes with that,

[00:22:39.05] no power reaches me, if you will, I (sense of regret) end just like that, without understanding the purpose - that's the feeling I have.

[00:26:03.26] I: that was a bad part about this class - if those pupils who were good at physics were not there, it would be pretty hard. Is there a good thing about this class?

[00:26:14.27] K: A good thing inside the class is that it's not stiff.

[00:26:22.14] (language confusion)

[00:26:46.15] It's a feeling like what I previously said about middle and high school, right?

[00:26:51.10] Like a normal lecture, like, not streamlined, if you will, (uses hand gesture and onomatopeia to suggest compression)

[00:26:53.09] - since it's not a class that becomes like that and you take it,

[00:26:59.26] you can approach it comfortably, and that is a good thing, right?

[00:27:11.05] I: Not stiff. That was - middle school and high school were more stiff, and... lectures were stiff... but the class now is different than that

[00:27:45.19] I: And why is that a good thing?

[00:27:49.23] K: Hm, that, first of all, since I hate physics, I have an unpleasant feeling towards physics from the start, so

[00:28:06.00] first of all, more than learning physics, as before,

[00:28:12.25] if the feeling of going to take physics is heavy

[00:28:17.23] not much comes in, if you will.

[00:28:19.18] It's because the contents of the the physics we are studying does not come inside of me.

[00:28:24.07] But, that, the feel of the class itself is relaxed, and, in that if even one equation

[00:28:35.08] comes inside of me, well, I think it's good, I wonder, right?

[00:28:42.28] I: You said this earlier, but in high school, you did not take physics...

[00:28:47.11] K: I took just a little of Physics

[00:28:52.26] I: You took Physics 1 but you did not take 2

[00:28:56.28] K: I have not taken it

[00:28:56.28] I:Ah, when you say you took it just a little... that means, you took physics 1 and finished it? Did you take all of physics 1? Or did you do just little of physics 1 and quit?

[00:29:12.26] K: I took all of Physics 1, but I don't remember it

[00:29:18.06] I: I got it. And there were no physics classes last year?

[00:29:22.16] K: There were

[00:29:22.16] I: I see. But you were saying that you haven't taken physics...

[00:29:29.29] K:I took it - that high school, I went to the place of that physics class,

[00:29:41.27] I went to the place where they were doing that class, but, in reality, nothing entered inside of me, so

[00:29:45.06] it's about the same level as if I have not taken it, so

[00:29:48.19] I (sense of regret) am saying that I haven't taken it

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[00:54:47.00] Why was it easy for people to adapt?(standard prompt)

[00:55:06.14] K: Eh? Perhaps that is like - because we're Japanese.

[00:55:12.08] Is it not that we have high adaptability, if you will

[00:55:17.04] (laughing)

[00:55:34.02] I: Huh, I wonder what that could mean. I looked up the word, but... please explain a little

[00:55:34.02] K: For example, (talking to self: since it's adaptability...)

[00:55:39.22] That, that, for example... if you have a fish, fish, um, concentration is... they can't live in any place other than those with concentrations that are fit for their bodies, you know, right, many fish are so.

[00:55:58.03] But, maybe, we kind of students are, for example, even if we (???) in a sea til now,

[00:56:07.21] We go to a sea, even if we first go to a (???) different river, we can live.

[00:56:12.06] That is, and we think, ah, well, it's good to become able to live in a river!

[00:56:17.11] In that way of doing it, our way of taking (the class) is not like "Ah, this isn't the sea and I don't like it", I think.

[00:56:26.18] I: And you were saying that you think that is for Japanese, did you say? Or did you say that that is for humans?

[00:56:29.20] K: Hm, Japanese I (sense of regret) think, right? Somehow

[00:56:34.16] I: Why especially Japanese?

[00:56:34.16] K: Eh? Because we don't have a self.

I: (Language confusion) You don't have "self"?

[00:56:37.10] K: We don't really have a self.

[00:56:44.05] I: You mean you don't have your own things?

[00:56:41.11] K: We don't have our own opinions.

[00:56:43.25] That non-acceptance.

[00:57:01.16] I: (looks up word "opinion") Ah... like "I am like this, you know!", like... strong opinions for example

[00:57:04.21] K: Right, right. I have a feeling that we don't really have that, and

[00:57:09.09] that or, I said that with a bad meaning, but

[00:57:14.10] with a good meaning,

[00:57:18.14] the width that we can take in is wide, if you will.

[00:57:24.26] That is perhaps, well, I think it's not because we are Japanese, but perhaps it's because we're students - that's there too, like... but I don't know

[00:57:36.02] Regarding that class, til now everyone has come having taken various classes, so, for example,

[00:57:43.07] til now, in every class and in every school, with the same system,

[00:57:50.22] classes emphasizing worksheets, if they had been doing that,

[00:57:53.11] perhaps this time Physics Excersises, everyone would (dislike it???) I think, but

[00:57:57.10] that was not necessarily the case, and, in my case,

[00:57:59.29] in elementary school, I could do the class of this year's Physics Exercises, for example

[00:58:05.13] I: Wait, what did you do during elementary school?

[00:58:06.21] K: Uh, unsurpringly, they resemble each other, do they not?

[00:58:09.22] That conversing of students with each other, not a style of the teacher (strongly???) teaching,

[00:58:15.06] There is that style of class of students conversing with each other, for example,

[00:58:19.24] we have the experience of coming from (defeat???), for example, well, [00:58:23.16] it's just everyone, various, that kind of class was how (???), with some (???) teacher, they have the experience of seeing it and coming, so

[00:58:33.12] til there, like, "Eh, this kind of class... is this thing called a class?" - I don't think there are many kids who will think like that.

[00:58:42.18] So, (???), if you will...

[00:58:46.00] I: I think I understood. You're saying that Tutorial was kind of like your experiences in elementary school... by the way, is that math class... or which class in elementary school?

[00:58:59.03] K: Ah, math was also like that, and social studies was the same feeling.

[00:59:05.18] I: But you said that if it's science, what you remember is just experiments, so that's kind of different

K: (nods head)

I: I see. That means, if it's a student who does not have that experience, when entering Tutorial, they might think "What in the world is this, is this really a class?!" for example, there would perhaps be that kind of surprise, but like you, if there was that experience, the student can think "Ah, yeah, this is a kind of class" - is that what you mean?

[00:59:39.29] K:That's correct, right?

[00:59:40.28] I:That area that is similar is that you are talking in a group? Or is it that making discoveries yourself and learning for yourself?

[01:00:04.11] K: Unsurprisingly, because the content is high-level... so more than learning for yourself,

[01:00:11.09] With people, umm, with kids in the same group, I think the conversing part is similar.

[01:00:19.00] I: I see. Ah, before you said that elementary school was active; is Tutorial also active like that?

[01:00:27.08] K:Hm, ah, but there is also a feeling of "let's think!" [01:00:37.19] I:Like elementary school?

[01:00:39.03] K: Yes

I: Different than high school?

K: It's different, right?

I: And different than middle school?

K:It's different

2. Tadashi

[00:10:10.06] Ｉ：Did the teacher's way of teaching also change, I wonder?

[00:10:16.16]　Ｔ：The teacher's way of teaching was, at any high school, the upper people and the, the people with higher grades and separate from the people with the lower grades I think, but they are basically not taken care of

(moves hands from outside in, as though patting a basketball on the table)

[00:10:29.08]　It was a high school of ??? by onseself.

[00:10:50.21]　Ｉ：Teachers were taking care of people with low grades?　Were not?

[00:10:58.12]　Ｔ：Um, it's called "mandatory training".　Grades are bad, people with bad grades absolutely must take it.　There is training, and it becomes a thing of everyone was doing it there.

[00:11:11.05]　It becomes that the teachers weren't really teaching various things privately.

[00:11:20.24]　Ｉ：That was in high school

[00:11:20.24]　Ｔ：Right

[00:13:20.22] I heard that in elementary school...

[00:13:36.27] Ｔ：That's right, isn't it.　There is that practice.　Yes, whether or not it is one-on-one attention - in regards to that, the elementary school teachers were much more, one-on-one, legitimately giving attention (???) I think

[00:13:52.18]　Ｉ："To give attention"... is that like, the same as "to care for", I wonder?

[00:13:58.09]　Ｔ：Ah, right.

[00:14:04.29]　Ｉ：But in high school, the teachers, like, well, private conversations were few, I wonder?　More in high school...

[00:14:10.28]　Ｔ：Yes.　The class itself, "do it yourselves" - that kind of high school student ??? it seems there was that.

[00:14:24.06]　Ｉ：High school was more, the students were doing it themselves, um, more than elementary and middle schools, is that it?

[00:14:31.04]　Ｔ：Yes

[00:14:53.21] Ｉ：　I see.　Between that elementary school style and that high school style, which did you prefer?

[00:14:50.04]　Ｔ：Ah, I preferred the high school style

[00:14:52.15]　Ｉ：Ah, really?　And why is that?

[00:14:56.01]　Ｔ：Yeah... right?　The thing of "Act feely" is, at one's own discretion,

[00:15:02.16]　discretion, if you will, it's the thing that the width of what you can choose yourself is wide

[00:15:06.22]　That's right, isn't it?　Grades and, without studying, just forget about grades and do nothing but play concerts - there were also those humans,

[00:15:15.00]　and then, like me, I also wasn't studying, but, get into doing those school festivals

[00:15:24.06]　and, enter various ??? and were doing work, and then,

[00:15:30.20]　ah, there were also people who were really studying.　The width was wide.

[00:16:17.01] Ｉ：Tell me about Tutorial... for example, suppose there's a student who is thinking about taking the class...

[00:17:26.01] Ｔ：Yeah... right?　Japanese physics classes are, you understand this when you open the textbook and look, but, they are classes where there are really a lot of mathematical formulas

[00:17:37.16]　And you stare at these formulas and you have to progress by interpreting yourself what these equations are representing

[00:17:45.01]　You don't really understand the meaning of what is written in the textbook.

[00:17:49.10]　I myself began physics from college, so the Basic Physics I took at the beginning of my first year, the Basic Physics lecture course - I didn't understand what it was about and

[00:18:05.06]　even though I read the textbook, it was nothing but mathematical equations coming out, there weren't any principles being done, and...

[00:18:11.14]　But in this Physics Exercises, more than mathematical equations, it's meaning that is important I think, so...

[00:18:23.29]　yeah... right?　???

[00:18:30.07]　Ｉ：More than mathematical formulas, meaning is important

[00:18:37.07]　Ｔ：yes

[00:18:40.00]　Ｉ：And, in previous physics classes, if you open a textbook, it's nothing but mathematical equations, and, um, it was hard to understand - is that what it is?

[00:18:46.26]　Ｔ：yes.　"Get used to", if you will, in the getting used to the appearance of physics, since it took about half a year, the Basic Physics Lecture of that time was a D.

[00:19:01.03]　Ｉ：Ah, that was the grade?

[00:19:06.22]　Ｔ：Ah, yes.　But, at first I had been taking this one, since I would presumably understand the meaning, yeah... right?　I think it depends on what in physics you are looking for.

[00:19:20.09]　If you want to see the things you see yourself in a physics way, if it's a desire for a physicsy way of seeing things, I think I can recommend this Physics Exercises. On the other hand, if it's a situation of really wanting to just do calculations, I can't recommend it - is what I'm thinking.

[00:19:45.21]　Ｉ：... that, the thing you are seeing, in a physicsy way...

[00:19:55.26]　Ｔ：In a physicsy way, um, to see, the way of seeing, a physicsy way of seeing, it was good for learning a physicsy way of seeing.

[00:20:18.03]　Ｉ：Ah, "way of seeing", like, what it looks like...

[00:20:18.03]　Ｔ：Yes

[00:20:18.03]　Ｉ：To see in a physicsy way, for example... but, physics c;asses before this were, well, first of all, that, um, like, things you are seeing - to see them in a physicsy way... those things you are seeing... where are you seeing them?

[00:20:42.09]　Ｔ：Ah, things you are seeing in the everyday.

[00:20:50.07]　Ｉ：And, that is different from previous physics classes?　Previous physics classes didn't have that kind of thing?

[00:20:55.25]　Ｔ：Um, yeah... right?　It was a feeling of being far away, physics was, really, a subject that is inside a book is how it felt.　"Acceleration", for example, "velocity", for example.　And then it was "impulse" for example.

[00:21:12.06]　There was a lot coming out, but how it actually applies, in what way it actually ??? is what I didn't really understand - it's that.

*[00:32:04.04] I: Were you surprised when you entered Tutorial?

[00:32:12.04] T: Yes

Ｉ：　What was?

Ｔ： Yeah... right? Off hand, since I was thinking it would be something done in that traditional style,

[00:32:20.23] yeah, right? That, everyone talking together kind of class itself is

[00:32:29.25] something like what was during elementary school... since it wasn't something there in middle and high school.

[00:32:37.10] It was absolutely fresh.

[00:32:39.11] Ｉ："Fresh"... like, "new", I wonder?

[00:32:54.28] Ｔ：Ah, yes.

[00:32:59.23] Ｉ：What you said is that in elementary school, something was there, but in middle and high school, something wasn't there. Was that the act of talking together?

[00:33:08.17] Ｔ：Ah, yes. Um, you learn in a group, you go out answering as a group (emphasis) - it's that thing..

[00:33:17.02] Ｉ：You talk in a group, and you put out answers as a group

[00:33:34.25] Ｔ： (nods head)

[00:34:59.21] What do you think physics is?

[00:35:03.09] Ｔ：Physics? Physics is... yeah... right? Mathematics is laws that humans ourselves have thought up, but physics is a ??? thing of laws in nature is what I am thinking.

[00:35:17.18] Ｉ：In nature, ah, there are laws in nature

[00:35:25.08] Ｔ：Yes

[00:35:25.08] Ｉ： And physics is, those laws, eh, what was it...

[00:35:28.08] Ｔ：Yeah, right? It's a thing like you're seeking through binoculars...

[00:36:07.29] Ｉ：That kind of opinion, that kind of image, that kind of, like "What in the world is physics?", um, did it change after entering Physics Exercises I wonder? Before Physics Exercises, um, is it the same as the image after entering?

[00:36:22.28] Ｔ：Yeah... right?

[00:36:26.19] Previously, there was that image of looking through binoculars, but now it's a sense like I can take it in my hand. It's a distance that has become personally close I think.

[00:36:39.08] Ｉ: Got it. Now is more, like, it's feeling close. But, before that, like, it was feeling much much farther.

[00:36:46.14] Ｔ: yes

[01:00:40.01] I: Have you had this kind of experience before?

[01:00:47.03] Ｔ: No, I haven't, have I?

[01:00:50.12] Ｉ: For example, maybe not in another physics class perhaps, but, for example, in another college class, middle school, elementary school, for example, somewhere, have you had this kind of experience?

[01:01:05.27] Ｔ: Mostly in elementary school, in a large container, decomposing starch - that was also done in a group, and I remember that well.

[01:01:21.17] Ｉ: You had that experience, and do you think it is helpful now?

[01:01:25.11] Ｔ: Yeah, right? The truth is that I am now 26 years old, so when you become 26, the act of "remembering" itself, in just that there is meaning I think. Because the things that you can't recall comes to become many.

[01:09:03.23] Ｔ: We're going to be doing quantum mechanics starting next year, but, everyday things, and, like this time, can we make it match with our intuitions?

[01:09:23.12] Ｉ: That's a great question, isn't it. Um, one more time, which area of physics?

[01:09:29.18] Ｔ: Quantum mechanics

[01:09:43.25] Ｉ: Quantum mechanics - ah! Yep, you can, you know.

[01:09:45.19] Ｔ: I can?

[01:09:45.19] Ｉ: Yep, you can, you know, but it's hard to do. Is it basic? Is it basic quantum mechanics class?

[01:09:55.25] Ｔ: It's quantum mechanics 1 and 2, I wonder?

[01:10:07.25] Ｉ: What is intuition?

[01:10:11.21] Ｔ: Yeah... right? Intuition... intuition is perhaps in what way one is seeing things kind of thing I think, so... not supposed to be a thing of seeing with your eyes, so... yeah... right?   Whether or not you can understand or not as an image within your head - it's that.

[01:14:07.00] Ｉ : Do you think this "after" way of thinking will help you next year?

[01:14:10.12] Ｔ : It SHOULD help.   Unsurprisingly, if you don't know the meaning of an equation... I think it's no good if you look at that equation and can't make an image of what is going on, so it absolutely SHOULD help.

[01:14:24.04] Ｉ : Ah, the future class is this, um, even if it's not those equations of this semester, do you think it will help?   For example, new, um, contents, for example, in that case?

[01:14:39.08] Ｔ : Ah, yes.   That is.   Uh, the equations that are written, properly, one by one, inside oneself to go and understand and be able to create an image is this time ???, so... that SHOULD help.

[01:14:56.25] Ｉ : I understand.

[01:15:00.29] Ｔ : If it's a pretty difficult equation, I perhaps can't do it, but...

[01:15:02.14] Ｉ : And then, before this class, did you not find the meaning inside of equations?

[01:15:10.29] Ｔ : ??? "It is this kind of thing"

(makes hand gesture of holding an object and presenting it while using an authoritative tone of voice including staccatto)

[01:15:16.09] ???, in my mind I took it to be something that was "defined to be"

(repeats gesture and emphatically says "defined to be")

[01:15:23.06] and, unsurprisingly, it wasn't a thing of thinking very deeply.

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