

## ABSTRACT

Title of Dissertation                    A STUDY OF SOCIAL INTERACTION AND  
TEAMWORK IN REFORMED PHYSICS  
LABORATORIES

Paul Gresser, Doctor of Philosophy, 2006

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It is widely accepted that, for many students, learning can be accomplished most effectively through social interaction with peers, and there have been many successes in using the group environment to improve learning in a variety of classroom settings. What is not well understood, however, are the dynamics of student groups, specifically how the students collectively apprehend the subject matter and share the mental workload.

This research examines recent developments of theoretical tools for describing the cognitive states of individual students: associational patterns such as epistemic games and cultural structures such as epistemological framing. Observing small group interaction in authentic classroom situations (labs, tutorials, problem solving) suggests that these tools could be effective in describing these interactions.

Though conventional wisdom tells us that groups may succeed where individuals fail, there are many reasons why group work may also run into difficulties, such as a lack or imbalance of knowledge, an inappropriate mix of

learning styles, or a destructive power arrangement. This research explores whether or not inconsistent epistemological framing among group members can also be a cause of group failure. Case studies of group interaction in the laboratory reveal evidence of successful groups employing common framing, and unsuccessful groups failing from lack of a shared frame.

This study was conducted in a large introductory algebra-based physics course at the University of Maryland, College Park, in a laboratory designed specifically to foster increased student interaction and cooperation. Videotape studies of this environment reveal that productive lab groups coordinate their efforts through a number of locally coherent knowledge-building activities, which are described through the framework of epistemic games. The existence of these epistemic games makes it possible for many students to participate in cognitive activities without a complete shared understanding of the specific activity's goal. Also examined is the role that social interaction plays in initiating, negotiating, and carrying out these epistemic games. This behavior is illustrated through the model of distributed cognition.

An attempt is made to analyze this group activity using Tuckman's stage model, which is a prominent description of group development within educational psychology. However, the shortcomings of this model in dealing with specific cognitive tasks lead us to seek another explanation. The model used in this research seeks to expand existing cognitive tools into the realm of social interaction. In doing so, we can see that successful groups approach tasks in the lab by negotiating a shared frame of understanding. Using the findings from these case studies,

recommendations are made concerning the teaching of introductory physics laboratory courses.

A STUDY OF SOCIAL INTERACTION AND TEAMWORK IN REFORMED  
PHYSICS LABORATORIES

By

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## Dedication

For the late Paul Henry Gresser.

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# Table of Contents

<b>DEDICATION</b> .....	<b>II</b>
<b>ACKNOWLEDGEMENTS</b> .....	<b>III</b>
<b>TABLE OF CONTENTS</b> .....	<b>IV</b>
<b>LIST OF TABLES</b> .....	<b>VII</b>
<b>LIST OF FIGURES</b> .....	<b>VIII</b>
<b>CHAPTER 1: WHAT ARE THE STUDENTS DOING?</b> .....	<b>1</b>
INTRODUCTION.....	1
GROUP WORK IN INTRODUCTORY PHYSICS LABORATORIES .....	2
REFORMED LABORATORIES AS A DATA SET.....	3
RESEARCH OBJECTIVES.....	4
AN EXAMPLE OF GROUP-WORK.....	5
RESEARCH CLAIMS .....	7
OVERVIEW OF DISSERTATION .....	8
<b>CHAPTER 2: LITERATURE REVIEW</b> .....	<b>10</b>
INTRODUCTION.....	10
THE COGNITIVE MODEL.....	11
COGNITION AS A SCIENCE.....	11
RELEVANT PRINCIPLES .....	12
THE SOCIO-CULTURAL APPROACH .....	15
LEV VYGOTSKY AND THE ZONE OF PROXIMAL DEVELOPMENT.....	16
ALEXEI LEONT’EV AND ACTIVITY THEORY .....	18
SITUATED COGNITION.....	19
DISTRIBUTED COGNITION.....	21
THE INTERSECTION OF COGNITION AND CULTURE .....	22
FRAMES AND FRAMING .....	24
GREGORY BATESON: FRAMING AS INTERPRETATION .....	24
ERVING GOFFMAN: FRAMING AS ORGANIZATION .....	25
DEBORAH TANNEN: FRAMING AS COMMUNICATION .....	26
TYPES OF FRAMING .....	27
GROUP INTERACTION .....	28
TEAM ROLES.....	32
DISCUSSION.....	34
<b>CHAPTER 3: LABORATORY REFORMS AND SOCIAL CONTEXT</b> .....	<b>36</b>
RESEARCH ON SCIENCE LABORATORIES .....	37
PHYSICS EDUCATION RESEARCH AT THE UNIVERSITY OF MARYLAND.....	39
“TRADITIONAL” LABORATORIES.....	40
SCIENTIFIC COMMUNITY LABORATORIES.....	43
SCL-1 .....	43
SCL-2 .....	45
REFORMING THE LABORATORY .....	46
ELIMINATING THE LAB MANUALS.....	48
CHANGING THE CLASSROOM ARCHITECTURE .....	51
ASSIGNING ROLES.....	54
INCLUDING CLASS INTERACTION .....	56
ENCOURAGING THE LAB INSTRUCTORS TO GIVE THE STUDENTS SOME SPACE .....	57
THE REFORMED LABS IN ACTION.....	58



CONCLUSION .....	59
<b>CHAPTER 4: INTRODUCTION TO EPISTEMIC GAMES IN THE LABORATORY .....</b>	<b>60</b>
INTRODUCTION .....	60
PREVIOUS RESEARCH ON EPISTEMIC GAMES .....	61
COLLINS & FERGUSON: EPISTEMIC GAMES AS EXPERT STRATEGIES.....	61
TUMINARO: EPISTEMIC GAMES AS STRATEGIES PER SE.....	64
EPISTEMIC GAMES AS GROUP ACTIVITIES.....	65
ON THE PROCESS OF CONSTRUCTING EPISTEMIC GAMES .....	67
EVALUATIVE AND CONCRETIZING PLAN-MAKING .....	71
TWO EXAMPLES OF EVALUATIVE AND CONCRETIZING PLAN-MAKING .....	73
EQUATION BRIDGING .....	81
AN EXAMPLE OF EQUATION BRIDGING.....	83
RECURSIVE EQUATION BRIDGING .....	88
AN EXAMPLE OF RECURSIVE EQUATION BRIDGING.....	90
STRATEGIC MAPPING .....	91
AN EXAMPLE OF STRATEGIC MAPPING.....	93
EXPLORATION .....	97
AN EXAMPLE OF EXPLORATION.....	99
DISCUSSION.....	100
<b>CHAPTER 5: EPISTEMIC GAMES AS DISTRIBUTED COGNITION .....</b>	<b>101</b>
INTRODUCTION .....	101
SITUATED COGNITION .....	102
EDWIN HUTCHINS AND DISTRIBUTED COGNITION.....	103
THE LAB GROUP AS A SYSTEM OF DISTRIBUTED COGNITION.....	108
THE SCIENTIFIC COMMUNITY AS A SYSTEM OF DISTRIBUTED COGNITION.....	109
<b>CHAPTER 6: HOW EPISTEMIC GAMES ARE PLAYED IN THE LABORATORY .....</b>	<b>112</b>
INTRODUCTION .....	112
CASE STUDY: GROUP 1.....	113
EQUATION BRIDGING .....	115
DISCUSSION WITH STUDENT .....	117
RECURSIVE EQUATION BRIDGING .....	119
EVALUATIVE AND CONCRETIZING PLAN-MAKING .....	120
LOGISTICS .....	123
GAME CONFLICT .....	124
ASSIMILATION/FLOUNDERING.....	125
EVALUATIVE AND CONCRETIZING PLAN-MAKING .....	126
AN IDEA IN PLAY .....	127
GAME-SHIFT .....	128
DISCUSSION WITH TA .....	129
HOW THE EXPERIMENT PANS OUT.....	131
LONG-TERM STRATEGY OF STRATEGIES .....	131
TUCKMAN STAGE MODEL ANALYSIS OF GROUP 1 .....	134
CASE STUDY: GROUP 3.....	136
TUCKMAN STAGE MODEL ANALYSIS OF GROUP 3 .....	143
DISCUSSION.....	146
<b>CHAPTER 7: CONCLUSION .....</b>	<b>148</b>
OVERVIEW .....	148
RESEARCH FINDINGS.....	149
SUGGESTIONS FOR FUTURE RESEARCH .....	151
PIANO QUARTET REDUX .....	153

<b>CHAPTER 8: SUGGESTIONS FOR LABORATORY INSTRUCTION.....</b>	<b>154</b>
INTRODUCTION.....	154
SUGGESTIONS FOR LABORATORY REFORM .....	155
CLASS POPULATION CONCERNS .....	155
SIGNIFICANCE OF EXPERIMENTS .....	156
DIFFICULTY LEVEL OF EXPERIMENTS .....	158
NEGOTIATING REFORMS WITH THE STUDENTS .....	159
FEEDBACK .....	161
SUGGESTIONS FOR LABORATORY DESIGN .....	162
EQUIPMENT .....	162
ARCHITECTURE .....	164
GROUPING .....	164
TIMING .....	166
GENERAL SUGGESTIONS FOR LABORATORY INSTRUCTION .....	167
FACILITATION RATHER THAN LECTURING.....	167
ENCOURAGEMENT OF SOCIAL INTERACTION.....	169
SELF-GOVERNING LABS .....	170
BEING AWARE OF EPISTEMIC GAME-PLAY .....	171
CONCLUSION.....	172
<b>APPENDIX A: COMPLETE TRANSCRIPTIONS.....</b>	<b>173</b>
<b>APPENDIX B: SCL-2 MATERIALS .....</b>	<b>237</b>
<b>BIBLIOGRAPHY .....</b>	<b>259</b>

## List of Tables

<u>Table 1. List of epistemic games across three contexts</u>	<u>67</u>
<u>Table 2: Timetable of student activity in Group 1, Experiment 6</u>	<u>113</u>

## List of Figures

Figure 1. The Johari Window	30
Figure 2. Lippmann plot of student activity in a traditional lab	44
Figure 3. Lippmann plot of student activity in a SCL-1 lab	45
Figure 4. Mission Statement	48
Figure 5. Sample SCL-2 laboratory handout	51
Figure 6. Traditional laboratory architecture	52
Figure 7. Students in a traditional lab	53
Figure 8. Scientific community laboratory architecture	54
Figure 9. Scientific community laboratory roles	55
Figure 10. Schematic diagram of students' moves with Evaluative and Concretizing Plan-Making	71
Figure 11. SCL-2 "magnet lab"	74
Figure 12. Idea setup	75
Figure 13. Schematic diagram of students' moves with Equation Bridging	82
Figure 14. Schematic diagram of students' moves with Recursive Equation Bridging	89
Figure 15. Two attempts to solve a problem using game strategies	90
Figure 16. Schematic diagram of students' moves with Strategic Mapping	92
Figure 17. Previously used homework problem	93
Figure 18. Solution to previously used homework problem	94
Figure 19. Schematic diagram of students' moves with Exploration	97
Figure 20. Belinda's idea	120
Figure 21. The evolution of group activity	131

## Chapter 1: What Are the Students Doing?

*None of us is as smart as all of us.*

Ken Blanchard

*None of us is as dumb as all of us.*

Anonymous laboratory graffiti

### **Introduction**

Recently I attended a piano recital that featured an exciting rendition of the William Tell Overture, played by a quartet of fourteen year-old children. There were two pianos set up side-by-side, with two children to a piano. I had never seen such an arrangement, and was surprised by both the richness of sound resulting from eight hands playing the keys in unison and by the tight coordination between the pianists. Their eyes darted rapidly from the sheet music to the keyboard to their teammates' hands and faces and back again. Subtle signals were exchanged. I was fascinated by the complexity of this arrangement. There was no conductor for this quartet, just a shared sense of purpose and a coordination of action so tight that it made more sense to speak of how "the group" had played, rather than how each individual pianist had played.

After the performance, I spoke with the teacher of these performers. The coordination was impressive, I told her, but why go through all the trouble to train

them to play in such a configuration, if they were unlikely to need that kind of skill? After all, there are no serious piano quartets. She replied that, in addition to the interesting musical effect, the piano quartet had a pedagogical purpose. Playing the piano cooperatively with a group of peers forces one to pay attention to one's own rhythm in a way that would not happen by playing alone.

Music instruction is just one of many disciplines that has begun to utilize cooperative learning. Students are now working in peer groups in every level of schooling. It has become almost conventional wisdom that students have the potential to learn a great deal through social interactions with their peers, perhaps even more efficiently than they would in traditional lecture environments. We know that peer interaction helps in the classroom. It behooves us now to attempt to understand *why* this is so, and to do this we must develop tools that allow us to explicate and discuss *what students are doing* when they work in groups and how it relates to their individual processes of thinking and learning. Many researchers are doing precisely this.

### **Group work in introductory physics laboratories**

The introductory physics laboratory is a classic example of an environment in which students are expected to learn through a cooperative activity. They are given a task that is normally too complicated and time-consuming to be accomplished by students working individually. Students seem quite capable of establishing a division of physical labor necessary to accomplish a task in the time allotted. On the other hand, it is rare to see genuine cooperation in *cognitive* labor. All too frequently we see lab groups in which one dominant personality takes charge of all the important

processes, such as planning an approach to the problem or evaluating a procedure, while others are perfectly content to retrieve materials, read gauges, and perform other tasks which, though essential to the experiment itself, do very little in assisting the participants in learning the essential cognitive tasks of experimentation. In such an arrangement, group-work can actually be detrimental to student learning, since students can be constantly involved in the activity and yet not understand how this division of labor fits into the general experimental plan. In this study we are primarily interested in finding and analyzing cases when students interact intellectually and productively in achieving a cognitive goal.

### **Reformed Laboratories as a Data Set**

This dissertation was carried out as part of a project conducted by the Physics Education Research Group at the University of Maryland, College Park, to reform an introductory algebra-based physics course for biology and pre-med majors. As part of this project, the laboratory portion of the class was radically redesigned with a new environment, set of activities, and goals. As a result of the changes made, we observed a considerable increase in productive student interaction. Rather than engaging in mainly logistical discussions on how to divide up the physical labor (Lippmann, 2003), the students were frequently engaged in meaningful discussions about physics. Cognitive activities that were previously accomplished non-verbally by the group's leader (or not engaged in at all) were now being accomplished by several students through complex discussions and sometimes heated arguments.

These laboratory sections provide an excellent source of information on how students coordinate their efforts when confronted with a task that requires cooperative

thinking. We will examine these groups in action via transcriptions of videotapes taken during normal lab time. By doing this, we see what is it students actually *do* during group-work, when not guided by detailed instructions on what to do. This is our glimpse into the natural cooperation of students, rather than cooperation of the type that can be forced upon them.

### **Research Objectives**

In this work, I attempt to answer the following questions:

- How might one describe the moment-to-moment activity of a small group of students and their shared interpretation of this activity?
- How does a group go about negotiating this shared interpretation?
- What sorts of shared interpretation lead to productive group work, and what sorts hinder it?

Before one can answer these questions, it must be decided what we mean by “the students.” Shall we regard them as individuals and answer this question separately for each student, or regard the group as a single entity and speak about what the “group” is doing? Shall we take an individualist perspective, or a social perspective? I intend to do both.

Clearly there is merit to taking this dualist view of group activity. Consider how one would answer the question, “What are the musicians doing?” in reference to our piano quartet. On one hand, we can describe a single pianist’s hand movements across the keyboard. On the other hand, we might also want to describe the group’s coordinated actions as if it were a single entity, as in, “the group fell out of sync.” Both descriptions shed light on what is happening. In order to accurately and meaningfully describe what “the students” are doing in lab, it may sometimes be



necessary to discuss what the individuals are doing, but sometimes it may be more helpful to treat them as a single unit.

Using this dualist approach, I extend existing theoretical approaches, such as epistemological framing and epistemic games, to describe what the students are doing, both individually and as a group. I also explore how individual action *guides* the behavior of the group (if and when the group is acting as a unit). Once we have a vocabulary with which to describe student action, it can be ascertained what kinds of behavior are productive and which are not.

It should be noted that I seek first and foremost a *descriptive* view of group activity, rather than a *normative* view. Much attention in education research has been given to how students *should* behave in the classroom, rather than how they *actually* behave. It is not my goal in this paper to propose an optimal method for groups to work in problem-solving, but rather to identify what methods *are* used. Therefore, we will need to understand what sorts of team knowledge-building techniques students bring into the classroom before assessing how they should put these skills to work. Then, as we learn to describe the variety of behaviors students engage in, we can begin to think about how to facilitate student learning in lab.

### **An Example of Group-Work**

Let us examine a short excerpt from one of these labs. The purpose of this lab activity is to determine how the force between two magnets depends on the distance between them. This transcript is from the first few minutes of the laboratory period.<sup>1</sup>

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<sup>1</sup> All names in the transcripts reported in this thesis are gender indicative pseudonyms.

<b>BELINDA:</b> We can measure the area of the magnet.
<b>DORIA:</b> But how do we measure...
<b>BELINDA:</b> Pressure...
<b>ANGIE:</b> But it's not... pressure times area...
<b>CONSUELA:</b> It's magnetic force...
<b>BELINDA:</b> Oh yeah, it's $E Q$ .
<b>DORIA:</b> No, but that's electric. Force of a magnet is just $F$ equals $Q V B$ sine theta. There's no distance in it.
<b>BELINDA:</b> Where are you coming up with that?
<b>DORIA:</b> It's in the book. And it's in... haven't you learned it for MCATs yet?
<b>BELINDA:</b> No.
<b>DORIA:</b> Really?
<b>BELINDA:</b> Really.
<b>DORIA:</b> That's the hardest stuff.
<b>CONSUELA:</b> Oh gosh.
<b>BELINDA:</b> Hey when do you get your scores back?
<b>CONSUELA:</b> I know, that's what you guys just said, and I was like oh yeah...
<b>BELINDA:</b> All right so $F$ equals $Q V B$ sine theta. What is this? Equal to $M V$ squared over $R$ . What's your $R$ ? Your radius?
<b>DORIA:</b> That's like the... because... well you see... not between two magnets. That's like... magnetic field caused by centripetal...
<b>BELINDA:</b> What is... what is $B$ ?
<b>DORIA:</b> $B$ is the field strength of the magnet.
<b>BELINDA:</b> But how are we going to measure any of that?
<b>DORIA:</b> Yeah, I know. So I don't know how it depends on distance.

What is this group doing? Is there an understood purpose to this activity, or are they just blindly brainstorming equations? Are they working towards a specific goal, or are they just muddling through, expecting something to become obvious later? Do the students share an understanding of a specific strategy that is being implemented here, or perhaps does one student have this understanding while the rest of the students are just playing along? To what extent do these students agree on what they are doing? If you asked this group what they are doing, how are they likely

to respond?

I argue that this group is engaged in a highly coherent activity, one which includes a specific goal and, a set of appropriate (and inappropriate) moves, and a shared understanding among most of the group members of how the activity is to be played out. This type of activity is known as an *epistemic game*, and can be immensely helpful for students in progressing through laboratory activity as a way of apprehending the situation and aligning their behavior accordingly. It allows a group of students to recognize the *kind* of activity that is being proposed, if not the minute details of that particular instance of the activity. Through epistemic games, we see the emergence of group activity that utilizes the network of individual minds in a unique and productive manner. Also, because these games are ubiquitous and identifiable, they provide a powerful tool for a lab instructor to diagnose what a group is doing, what their goal is, and even how they are interpreting the activity itself.

### **Research Claims**

As we examine students engaged in these laboratory activities, we will operate under the basic assumption that student action is nearly always *purposeful* rather than random, and that it may even be possible for a group of students to share at least part of this sense of purpose. By assuming the existence of intention, we can identify patterns in student behavior based on what this intention might be. In this dissertation, I demonstrate the following points:

1. Use of the vocabulary of epistemic games and epistemological framing makes it possible to identify common patterns of behavior in these reformed laboratories.

2. A small number of regularly appearing strategies can be classified by explicitly stated motives and those inferred through characteristic statements. They can also help identify what the groups are not doing that might be useful.
3. A group might come to share an understanding of these strategies, and therefore work towards a common goal, through appropriate social interaction.
4. Groups that make use of these shared strategies operate more productively than those that do not.

By identifying and understanding the nature of these strategies, we can have a better understanding what the students are really doing in the laboratory.

### **Overview of Dissertation**

Chapter 2 provides an overview of the chief research disciplines that concern the dynamics of group-work. It describes relevant works from cognitive science, sociology, education research, and social psychology that have inspired my particular take on group interaction in the laboratory. Here I present research that explores human activity both from the perspective of individual cognition and from the perspective of social interaction, as well as research that attempts to join the two disciplines.

Chapter 3 describes the laboratory course in which this study took place. These labs were specifically designed to be dramatically different from the so-called “traditional labs” that physics students traditionally take. These labs are sources of rich and complicated social interaction, which makes for a rich and interesting data set.

In Chapter 4, the concept of epistemic games is explored. We see several examples of students engaged in coherent, purposeful activities that last typically for

a few minutes per instance. Epistemic games will be our unit of analysis for further considerations.

Chapter 5 deals with epistemic games as social activities. *Distributed cognition* will be introduced as a point-of-view from which we can regard epistemic games as a distinctly social manifestation of a cognitive activity.

In Chapter 6 we observe in detail two groups of students engaged in the same activity. One group successfully aligns their behavior and engages in shared epistemic games, leading to productive activity and meaningful discussion, while the other group fails to connect in this way, and therefore flounders, incapable of operating as more than the sum of its parts.

Chapter 7 consists of advice on how one can, as an instructor, use the framework of epistemic games and distributed cognition to understand the behavior of laboratory groups and foster more productive teamwork.

## Chapter 2: Literature Review

### Introduction

In this dissertation, I focus on groups of individuals in the introductory physics laboratory, where activities typically require a sophisticated level of cooperation among the group members in carrying out cognitive tasks and linking them together. But to understand group work, we need to consider many different disciplinary angles of approach. Group work is a phenomenon that exists through the interaction between individual cognition, group behavior, and cultural influences and artifacts. This section provides an overview of the previous research that is relevant for the approach I set forth.

First I discuss the working model of the mind, which has been explored by cognitive scientists in various fields. Then I will discuss some of the schools of thought concerned with the social aspect of learning, known collectively as the *socio-cultural approach*. Next, I give an overview of research in "framing," which can be used to describe how people interpret and find meaning in the events they experience. Finally I outline some of the empirical studies on group behavior that are particularly relevant to this study because of their focus on learning environments.

Each of these disciplines has something to offer in the exploration of student interaction, from the small-scale point of view of individual human action to the observation of large-scale emergent phenomena in the social setting. Though some researchers choose to focus on either individual phenomena or social phenomena, for

this study, pieces from both will be necessary to understand what groups of students are doing in the lab.

### **The Cognitive Model**

In studying groups, it is helpful to consider emergent phenomena. We often speak of “the roar of the crowd”, “the spirit of the nation”, or “the team’s persistence” as if groups of individuals had qualities normally attributed to individuals. But the metaphorical nature of these anthropomorphisms is understood. At the end of the day, group behavior can in theory be traced back to the workings of the human mind. For a half a century, scientists from a number of fields have come together in an attempt to describe the workings of the mind through complex representations and computational procedures. This field is known as cognitive science.

#### *Cognition as a science*

The term "cognitive" describes "any kind of mental operation or structure that can be studied in precise terms." (Lakoff & Johnson, 1999) Cognitive science, therefore, is considered the scientific study of thought, as compared to other sorts of inquiry into the subject. This is a relatively new field, blossoming in the 1950's with the decline of behaviorism as the prominent approach to studying human behavior. Behaviorism was an approach to psychology based on the idea that only observable actions of individuals were legitimate variables to consider when constructing a model of human behavior. Cognitive science takes another route. Recognizing that we are a long ways away from being able to directly link our thoughts to specific neural pathways in the brain, cognitive science seeks to build mesoscopic models of

thought that is based on what is known about the physiology of the nervous system, yet is large enough to explain the complicated manifestations of cognition that we observe directly. Mental structures are hypothesized in order to account for cognitive activities.

Cognitive science is an interdisciplinary endeavor that synthesizes work from a number of fields, including philosophy (Russell, 1945, 1948; Fodor, 1974), experimental psychology (Pinker, 1999, 2002; Miller, 1956), linguistics (Chomsky, 1957; Fauconnier & Turner, 1999), artificial intelligence (Minsky, 1985; Penrose, 1989), and anthropology (d'Andrade, 1989, 1995). The history of how these fields came together is presented in Howard Gardner's *The Mind's New Science* (1988); and some of the basic cognitive models are discussed in Paul Thagard's *Introduction to Cognitive Science* (1996). The validity of a particular cognitive model is determined by to what extent it is based on legitimate neuroscience, what kind of explanatory power it has, and when simulated by a computer, how closely the results resemble human behavior.

### *Relevant principles*

Cognitive science is an enormous, thriving field, with applications in a great number of disciplines. I will not attempt to review this vast quantity of literature here, but rather will begin from a synthesis constructed for the purpose of applications to education. This synthesis focuses on the properties of the individual. I will consider the implications of these ideas from an individual functioning in the context of a group.



In E. F. Redish's "A theoretical framework for physics education research: Modeling student thinking,"(2003) he enumerates principles from neuroscience that have implications for understanding how students learn:

*Principle 1: All phenomena are describable as arising from the fundamental physical objects and laws that we know.*

and

*Principle 2: All cognition takes place as a result of the functioning of neurons in the individual's brain*

We can take this to mean that cognition should be considered a biological process situated in the central nervous systems of individuals. Though we can sometimes speak metaphorically about aggregates of individuals performing acts of cognition (i.e. "our class couldn't calculate integrals" or "the group knew all about magnets"), it is important to keep in mind that these emergent phenomena are the result of individual cognitive action. In my analysis of group work, for example, group action will sometimes be described using terminology that is typically used in reference to individual cognition. When these concepts are applied to groups, they mean something different.

Now consider:

*Principle 4: There is a real world out there and every individual creates his or her own internal interpretation of that world based on sensory input.*

This is an important idea to keep in mind whenever studying a group of individuals engaged in a joint activity, to understand that each individual has his or her own interpretation of what is going on. The extent to which a group can have a "shared

experience" is limited, and we may perceive that we are having a shared experience but we may be wrong.

Then we have the concept of constructivism:

*Principle 5: New knowledge is built on a base of existing knowledge by building new links and suppressing old ones.*

This further illustrates the problem of considering a group of students as a unit. It is not usually helpful to consider knowledge to be a material substance that can be shared by a group of people or directly transferred from one person to another.<sup>2</sup> On the other hand, constructivism gives us a way to understand why students seem to learn a great deal from working together with peers. While students may not have identical sets of resources from which to learn (i.e. real-world experiences and formal training), resources they do have in common constitute an important element of how we define a group's productive ability.

Fundamental to this model of knowledge structure are the concepts of *associational patterns* and *control structures*. When one posits the existence of knowledge as actively constructed resources, it becomes important to consider how these resources are connected, or what resources may be activated in what sorts of contexts. In order to process the abundance of sensory input to the brain, the mind must be able to select relevant pieces and ignore others. We call this selection process is called *framing*. In other disciplines, essentially the same phenomenon is described as "registers", "scripts", or "schemas." (Schank & Abelson, 1977; Rumelhart, 1975; Kant, 1998; Bartlett, 1935) Additionally, in order to pare down the abundance of existing knowledge elements, the mind groups together certain

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<sup>2</sup> Hammer and Elby (2002) refer to this epistemological concept as "knowledge as propagated stuff".

resources (and excludes others) to deal with similar situations. This process is the basis of epistemic games, which will be discussed in detail later.

### **The Socio-Cultural Approach**

So far, the issues we have discussed focus on activities situated in the mind of an individual. Since cognition is defined as a biological process, one might be tempted to study the individual in isolation and to extrapolate what is known about individual behavior in order to understand collections of individuals.

However, what this generalization misses is that the mind cannot act in isolation, and in fact its functioning depends highly on the nature of its environment and the other minds it comes into contact with. Even though we construct our own personal realities, the materials we use are signals from the objective reality outside. Some of these signals, such as light and sound, arrive at our senses unprocessed, ready to be interpreted and operated upon in the way our minds see fit. On the other hand, the most important signals we receive are often the products of the cognition of others. A simple sentence, for example, and the means by which to comprehend it, is the product of thousands of years of cognitive cooperation. The shared method of cognition and framing and the tools constructed to aid it, such as language, number systems, and traditions, are what we call *culture*. There can be many levels of culture relevant to an individual. One level can be the culture of human civilization, so all-encompassing that it requires a powerful imagination to think outside of it. On the other hand, a strong culture can also exist between two or three people, and this

culture may include private jokes, shared points-of-view, specific methods of communication, and temporary shared frames.

In this study, we examine small groups of individuals engaged in the process of learning physics. In addition to the large-scale culture that allows them to communicate with each other, we observe the development of a small-scale culture within the group, which may or may not lead to productivity towards this goal. A great deal of literature exists that stresses the importance of culture in cognition, and warns against treating the individual mind in isolation. Some of this research even goes as far as to suggest that the definition of cognition be expanded to include social activities. The general attitude that an individual's development is a product of culture is known as the *socio-cultural approach*.

#### *Lev Vygotsky and the Zone of Proximal Development*

By far the most influential contributor to the socio-cultural literature is early-20<sup>th</sup> century Russian psychologist Lev Vygotsky, whose work on child development (Vygotsky, 1978, 1986) was rediscovered and celebrated in the 1960's. Vygotsky proposes that intellectual development is primarily a function of social interaction, rather than, as Jean Piaget argues, a product of epigenesis<sup>3</sup>. Vygotsky's ideas inspired a generation of education researchers seeking to understand the effect of culture and social factors in student learning.

Vygotsky's work focused mainly on child development theory, specifically the development of mental faculties, such as language, thought, and reasoning. These abilities, he argues, are social in nature, meaning that they developed socially first and

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<sup>3</sup> Or, how the environment interacts with pre-wired tendencies.

only later became internalized as a tool one might use on one's own. He refers to these as *higher mental functions*, as opposed to *lower mental functions*, which are entirely innate. This dichotomy quite elegantly places nature and nurture side-by-side, though with more emphasis placed on the latter. Vygotsky's framework provides a way of understanding how the learning of higher mental functions is accomplished socially.

One of the most important concepts proposed by Vygotsky that has proven to be productive for socio-cultural researchers, is that of the *zone of proximal development*, which he describes as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers." (Vygotsky, 1978) There is a collection of knowledge that an individual does not yet possess, but has the ability to learn on his own. Knowledge that exists outside this area, the learner does not yet possess the ability to understand without developing a stronger cognitive framework. This is in agreement with the principle of constructivism, which states that new knowledge must be build on the foundation of prior knowledge.

Vygotsky suggests that with the guidance of a more experienced individual, one's potential to learn increases. The expanded learning potential between one's *actual level of development*, or what one can do alone, and one's *potential level of development*, or what can be accomplished socially, is the zone of proximal development. Vygotsky suggests that one's potential level of development is more indicative of one's abilities than one's actual level of development.

Few teachers will deny the main implication of this theory, that one's ability to learn is improved by the presence of a guide. But Vygotsky's idea of development zones is much deeper than that. Vygotskian scholar Annemarie Palincsar (1998) explains that the theory states that one's learning ability is more dependent on the social environment in which one interacts than on one's innate abilities. Education researchers find this egalitarian implication to be appealing and optimistic.

Vygotsky introduces the term *scaffolding* to describe the process by which an experienced individual can assist someone in the process of learning. How this takes place determines whether or not a student is able to learn more under the tutelage of an experienced other. We naturally think of the student-teacher relationship as being the primary arrangement for learning, however, peers can also help each other learn. In this study, we will be examining not only how students' abilities are augmented by the presence of the teacher and teaching materials, but how certain types of peer interaction can do the same thing. Research on cooperative learning suggests that learning in peer groups can be tremendously effective (Johnson & Johnson, 1989). Vygotsky's theoretical framework gives us a way to think about how this is happening.

#### *Alexei Leont'ev and Activity Theory*

The idea of a zone of proximal development suggests that, by examining student learning in isolation, one would miss a vitally important factor, that of the social environment. To Vygotsky, the perceptual input fueling cognition is not a concept to be ignored or swept under the rug. The importance of social interaction, as influenced by cultures of various grain sizes, was further explored in the science of

*activity theory*, spearheaded by Vygotsky and continued by Alexander Luria and Alexei Leont'ev (1981, 1978).

Activity theory expands upon Vygotsky's framework by suggesting that the development of higher mental functions is assisted through the use of cultural artifacts, such as language, numbers, and tools. Focusing on the importance of learning being mediated through these tools, he described human activity as lying "not in its reduction to single elements but rather in its inclusion in a rich net of essential relations," between the individual, the environment, and the tools used by the individual to interact with the environment.

Activity theory is an attempt to explain cognition through interactions between the human nervous system and the material world outside, interactions that are defined and guided by culture. Leont'ev discusses the use of tools as evidence of cognition outside the explanation of Pavlovian behaviorism. The presence of tools, and of the cultural meaning tied to them, mediates the transfer of knowledge. Activity theory can be useful for describing the interactions that take place in the laboratory, as students use both physical tools, such as computers and calculators, and cultural tools, such as the scientific method, to explore the physical world.

### *Situated Cognition*

After the Western world discovered the works of Vygotsky and his peers, the socio-cultural approach gradually began to influence educational psychology. One school of thought associated with these ideas is known as *situated cognition*, which posits that all knowledge is *situated*, or, exists within a specific context. Suchman

(1987) coined the term *situated action* to “(underscore) the view that every course of action depends in essential ways upon its material and social circumstances.”

The context dependency of knowledge explains why students may be capable of certain feats in the classroom, but not in real-life (or vice versa). For example, a student can be quite capable of applying physics knowledge to homework problems, but incapable of activating that knowledge in the laboratory with actual equipment. Another student may be extremely handy in the laboratory but not particularly good at applying their skills to abstract problems. This is a problem for any cognitive model that regards the individual mind as simply a collection of knowledge elements – one either “knows” how a circuit works or doesn’t. By expanding the cognitive view to include context, we can understand why knowledge is sometimes activated, and sometimes not.

Researchers in this field generally propose the expansion of cognition to include socio-cultural factors. This would include not only the specific context, but social interactions as well. Brown and Duguid make an excellent case for the importance of social arrangement in *The Social Life of Information* (2002). They demonstrate within the everyday work environment of a corporate office those ways in which the social environment can dramatically affect individual cognition, and ultimately the product of a group’s work. Lave and Wenger (1991) discuss the situated nature of knowledge through the portrayal of apprenticeships in a variety of cultures, arguing that skills may be effectively taught through active participation, as opposed to direct instruction. They use the term *know how* to describe knowledge deeply-situated within a context, such as one’s ability to cut produce correctly, as



opposed to *know what*, or knowledge that can be explicitly stated and exchanged sans context. Researchers have used situated cognition to describe a number of other phenomena (Clancey, 1997; Brown et al, 1989; Brighton et al, 2003).

### *Distributed Cognition*

Another socio-cultural school of thought known as *distributed cognition* was developed by Edwin Hutchins and explored in his book *Cognition in the Wild* (1995). Hutchins takes as one example the process of navigating a navy ship, and he describes how the necessary information for this process is spread out among the crew and the artifacts they use. Hutchins stresses that no one person possessed the knowledge to navigate the ship on his own, but that this knowledge was arranged in a unique social environment. This is an example of a process, not unlike that of doing science, in which an immense cognitive task is carried out not by a single mind, but by many minds interacting with both each other and with the environment and certain tools. It is just as difficult to pin down the knowledge of ship navigation to a single mind as it is to argue that the ability to navigate a ship exists outside of the ship context.

Chapter Five of this thesis explores the physics laboratory group as a system of distributed cognition, encompassing the minds of the individual group members, physical tools, and cultural artifacts, into a single entity capable of complex computations.

## **The Intersection of Cognition and Culture**

Neither cognitive science nor the socio-cultural approach can, by itself, provide a satisfactory view of group learning. While cognitive science has given us several useful models of the human mind, its scope generally excludes the influence of culture. The socio-cultural approach places culture and human interaction at the center of importance to human thought. Although focusing on the output of a group, rather than the workings of individual minds, may be perfectly sufficient for someone concerned exclusively with that output (like a project manager working with the ideas presented in Duguid and Brown), however, it is not sufficient for an educator whose primary concern is the state of individual minds. The study of group lab-work requires that we give attention to both cognitive and social factors. We seek to understand both how individual minds contribute to the construction of a social unit and how social interaction affects individual thought.

Donald Brown (1989) provides an extensive list of *human universals*, or activities that exist independently of culture. This includes methods of classification, artistic expression, and ways of making sense of the world. Steven Pinker (2002) argues that these universals may have come about as the result of psychological evolution over the millennia, which, like physical evolution, has resulted in much more overt similarity between human beings than differences. Our brains, having developed according to the dictates of the genes, are pre-wired to facilitate the learning of certain types of behavior and ways of thinking. Regardless of one's upbringing and perspective of the world, one's mind will develop in certain ways for purely epigenetic reasons. Child psychologist Jean Piaget (1983) studied these cases

extensively and his results illustrate quite a few early cognitive developments that are inevitable, and quite independent of current cultures.

As important as these epigenetic factors are, they do not account for everything we learn. In fact, Vygotsky adamantly insisted that the important elements of mind, such as our reasoning strategies and language, are developed through socio-cultural interaction. It is quite obvious that our worldviews are heavily influenced by cultural artifacts. It is not by coincidence that most people in France communicate using the French language. We come into this world and adopt pre-existing strategies of apprehending our environments, communicating with others, and dealing with the problems we encounter. It is no surprise that our culture, or our community's established "way of doing things" influences how we think.

There are two types of culture that are pertinent to the study of group behavior. First there is the *macroscopic* culture in which we are immersed (and may be, for the most part, unconscious). It is from this culture that we inherit our language, our general sense of manners, our numerical system, and the tools we use to operate on the environment, such as our calculators, computers, pencils, and paper. A group of scientists could accomplish very little together without this kind of shared common culture. Secondly there is a *microscopic* culture that can emerge in a group. Small groups can develop their own ways of doing things and a common understanding of procedure and purpose. These microscopic cultures differ from macroscopic cultures in that a single person can easily interact within many microscopic cultures, but may find it tremendously difficult to interact in another

macroscopic culture. It is the existence of these microscopic cultures that, as we will see in the next few chapters, boost a group's productivity.

### **Frames and Framing**

Because we are confronted with an enormous number of signals from our environment every second, it is necessary for us, as individuals, to have a cognitive tool for parsing and interpreting signals in a way that creates meaning. We need a method of organizing what we see, hear, and feel in a way that we can understand "what's going on." This activity is known as *framing*. Framing is an example of an individual cognitive activity that is heavily influenced by our respective cultures, microscopic and macroscopic, and that allows us to interact within these cultures.

#### *Gregory Bateson: Framing as Interpretation*

Framing builds on the development of the Gestalt theory in psychology in the first half of the 20<sup>th</sup> century (Wertheimer, 1922). These researchers demonstrated the importance of the individual's organization of their perceptions and their response to contexts.

Gregory Bateson used the idea of context dependence to show the importance of considering not just behavior via stimulus and response, but mental states that affect the individual's interpretation of a stimulus. The first important piece on frames is Bateson's "A Theory of Play and Fantasy"(1955). In this essay Bateson suggests that "human verbal communication can operate and always does operate at many contrasting levels of abstraction." He describes *metacommunicative messages* as parts of communication that contain information about how to interpret the message,

and demonstrates several levels of abstraction in which people can communicate, where the necessary means of interpretation is supplied as part of the message.

As an example, Bateson describes a pair of monkeys he observed at the zoo engaging in an activity we would call "play." Play resembles actual combat in terms of action; however, messages seem to be exchanged between the participants that clarify that these actions are to be taken as moves in a game of amusement, rather than deliberate attempts at bodily harm. The messages that convey the understanding that "this is play" establish a "psychological frame", which Bateson describes as that which "is involved in the evaluation of the messages which it contains" or "assists the mind in understanding the contained messages by reminding the thinker that these messages are mutually relevant and the messages outside the frame may be ignored."

Bateson's concept of framing was a serious challenge to behaviorist doctrine, which suggested that all psychology could be reduced to stimuli provoking responses. The fact that animals engage in a process of interpretation meant that something important was happening inside the mind that could not be accounted for with the dominant psychological model of the early 20<sup>th</sup> century.

*Erving Goffman: Framing as Organization*

The concept of "framing" in communication theory was extensively elaborated by sociologist Erving Goffman, who presented an expansion upon Bateson's ideas in a book entitled *Frame Analysis: An Essay on the Organization of Experience* (1974). Goffman describes *primary frameworks* as ways in which people interpret their experience, or, the means by which one would answer the question,

"What's going on here?" He helps explain Bateson's example by illustrating play activity as:

*"...closely patterned after something that already has a meaning in its own terms - in this case fighting, a well-known type of guided doing . . . Bitinglike behavior occurs, but no one is seriously bitten. In brief, there is a transcription or transposition... of a strip of fighting behavior into a strip of play."*

To Goffman, framing is the active use of cognitive schemas through which people interpret and describe the world around them. Answering the question "What's going on here?" is framing, while the "frame" can be thought of as the answer. For example, when one sees two men fighting to the death with swords, one might draw the conclusion that this is a Shakespearean play and enjoy the action in a "play frame." Alternatively, one might frame this situation as a genuine altercation, and react quite differently.

*Deborah Tannen: Framing as Communication*

Frames are explored further by Deborah Tannen (1999) and other researchers in socio-linguistics (Lakoff, 2004). One of Tannen's ideas that is useful for us is that framing is a social activity that allows the communication of meta-messages, or messages that are communicated through one's prior knowledge and expectations rather than through actual spoken words. Framing, then, is how a single phrase, such as "How are you?" can be interpreted as having completely different meanings, depending on who is saying it to whom, what their past history is, and other information not included in the sentence itself. Through framing, language takes on a richness and versatility that could not exist through "face value" communication.

An example Tannen gives of framing is the joking that takes place between boys and young men. When a group shares a “joking” frame, insults about one’s mother are not taken personally, but rather interpreted as moves in a friendly game. Someone who has not framed this situation appropriate might interpret these comments much differently, become offended, and start a fight.

### *Types of Framing*

An excellent review and synthesis on framing is provided by Gale MacLachlan and Ian Reid (1994). They present as a simple example of the use of framing the act of “interpreting” a book. The text itself is not the whole of the book’s message. One looks for clues within and outside of the text to determine how to interpret that text. The same text will be interpreted differently if it is sandwiched between a pink paperback binding, sold at the local grocery store, and written in internet *leetspeak*, than it would if it were found at a university science library, written with careful, precise language. In one frame, I would skim and try to enjoy myself, while in the other I would read it very carefully.

Redish defines an *epistemological frame* as “the set of epistemic resources the individual assumes is appropriate to carry out the task at hand” (2004). Just as one can read a book in different frames, students can interpret a classroom exercise in a number of different ways, and how the activity is framed will affect what sorts of cognitive tools they bring to bear in the exercise. And just as a misframing of a joke can lead to insult, a mutual misframing of a laboratory activity between students can lead to ineffective work. Other researchers have studied epistemological framing in different contexts (Shaffer, 2005; Schwartz & Sherin, 2002).

Framing is both an individual cognitive activity, as described by Goffman, and a social activity, as described by Tannen, and is therefore an important concept to keep in mind when observing social discourse. In a group, each individual frames what is going on in his own way. It is possible and desirable for a group of individuals to have some level of consensus as to how they choose to interpret events and communications, and to reach this level, they engage in what Redish refers to as "frame negotiation." But just as a group's strength can come from sharing a common frame, it can also come from the combination of different methods of interpretation.

### **Group Interaction**

Another branch of social science, known as *group dynamics*, claims that individual behavior is highly dependent on the group context, and deals with the nature of groups. In this section I outline some of the contributions made by researchers in this field that are relevant to our discussions. Although it is useful to examine what has been learned about group interaction, much of this research is too general to be of use in answering the question of how students interactively deal with conceptual physics.

Social psychologist Kurt Lewin, the proclaimed "father of organizational development, published a number of works (1935; 1948; 1951) in the early 20<sup>th</sup> century on group dynamics that have had a profound impact on the field. One of his primary research objectives was to determine the causes of ineffectiveness in groups. This led to Lewin's *force field analysis*, which provides a graphical method for groups to analyze the various factors influencing their productivity. In this analysis, there are *driving forces* and *restraining forces* that respectively boost and hinder



group productivity. *Equilibrium* is reached when these forces equal. The purpose of force field analysis is to assign scalar quantities to physical events, and consequently to be able to determine what effects certain changes will have on the group's productivity.

Many researchers on group dynamics propose that groups pass through certain predictable stages in their development. One of the most frequently-cited works is Bruce Tuckman's stage model (1965, 1977), which posits that a group passes through four distinct stages in its evolution from a collection of individuals to an effective team. These stages are: *forming*, *storming*, *norming*, and *performing*. *Forming* is characterized primarily by the establishment of boundaries through testing and the establishment of dependency on group leaders. *Storming* is characterized by conflict and interpersonal polarization. *Norming* is characterized by the establishment of roles and a growing inter-group cohesiveness. And *performing* describes the phase in which the group utilizes these new roles in the accomplishment of tasks. Though Tuckman's model is linear, other researchers have made use of it by adding stages or creating a non-linear representation of how a group can progress (Bales, 1965; Schon, 1983). Tuckman's original model, nevertheless, is still frequently used in management research (Rickards & Moger, 2000; McGrath, 1997).

Tuckman's model is a Piaget-style stage model for epistemology. However, as I demonstrate in Chapter Six, this model is too simplistic to accurately describe how lab groups develop, owing to the transitive nature of group characteristics. A resources model (Elby & Hammer) would be more appropriate. The Tuckman model proposes phases of activity that last for a considerable length of time, while lab

groups seem to be able to shift from a “well-oiled machine” to a “rusty heap” and back again several times during a class period. What can be learned from the phase model, however, is that the formation of a “good” group requires certain social processes that take time. Nevertheless, this model only provides a general understanding of groups, and treats the task at hand as a static component. Laboratory activities require much interpretation and manipulation on the part of the group; therefore we require a theory that includes interaction between it and the participants.

Another attempt to describe the evolution of a group is the *Johari window*, named after its creators, Joseph Luft and Harry Ingram (1955). They describe the window as “a graphical model of awareness in interpersonal relations.” As shown in Figure 1, the window encompasses the group’s behaviors and motivations, which can be separated into four quadrants:

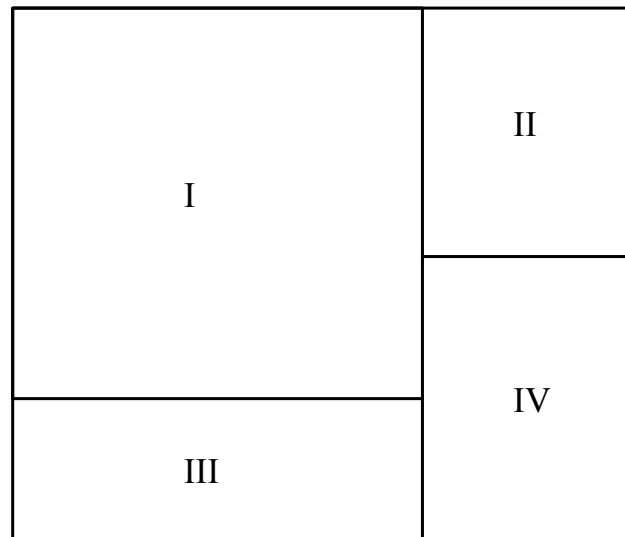


Figure 1. The Johari Window

Quadrant I, the “open” quadrant, refers to that which is known both to self and to others. Quadrant II, the “blind” quadrant, refers to that which the individual cannot

see in one's self, but which others can observe. Quadrant III, the "hidden" quadrant, refers to that which is known to the individual but not to others. Quadrant IV, the "unknown" quadrant, refers to that which nobody is aware of.

According to this model, a change in one quadrant will result in a change in other quadrants. Group evolution typically involves an increase in Quadrant I, with more behavior becoming "shared", accompanied by a decrease in Quadrant III. This model presents a more dynamic view of groups than the Tuckman stage model; however, it shares a few of its shortcomings. The window is context independent, and therefore is assumed to be evolving without regard to contextual changes that happen on a short time scale. This means that its resolution is insufficient to describe the transitions observed in our laboratories.

Another method for group analysis known as *sociometry* was created by Jacob Levy Moreno (1950, 1951). He describes it as "the mathematical study of psychological properties of populations, the experimental technique of and the results obtained by application of quantitative methods". It is intended to reduce conflict and increase communication within a group by measuring the degree of relationship between the group participants.

Sociometry involves surveying the group members about their feelings towards the other members. This information is put together in a *sociomatrix*, a graphical representation from which various conclusions can be drawn about the group as a whole. A variety of studies have shown that group productivity is correlated with the level of sociometric cohesiveness between the members, and that using this technique can increase productivity, safety, and harmony within many

different group settings (Val Zelst, 1952; Hoffman et al, 1992) As I explain in the next chapter, it was our intention to use some sort of metric to arrange laboratory groups, but due to various constraints, no such method was ever implemented.

### *Team roles*

A common endeavor in group research is the attempt to classify various team roles, and using these, to hypothesize what sorts of combinations make up an ideal group. On such study done by Meredith Belbin (1981) places people into nine categories known as *team roles*, which are defined as “A tendency to behave, contribute and interrelate with others in a particular way”:

Action oriented team roles: Shaper, Implementer, Completer Finisher

People oriented team roles: Coordinator, Teamworker, Resource Investigator

Cerebral oriented team roles: Plant, Monitor Evaluator, Specialist

These team roles are defined by both the skills and weaknesses these personalities bring to bear in a group situation.

Richmond and Striley (1996), in their study of 10<sup>th</sup> graders engaged in science laboratory activities, provide another classification of individual behavior, this one in terms of participation style. Most important to the working of the group is the emergence of a group “leader” and the style in which this person interacts with the rest of the group. They identify three types of leadership: *inclusive*, *persuasive*, and *threatening*. Preferable of the three is the inclusive leadership, under which the leader actively tries to establish cooperation in the group, rather than competition. We will see in video transcript later on that the emergence of a team leader is quite

typical of our laboratory environment as well, and that the behavior of this individual can make or break the group as a working unit.

Rather than focus merely on types of individual behavior, Shepardson (1996) insists that the important feature in scientific inquiry is the negotiations that take place between the participants. He identifies four types of negotiations that take place during this activity. A *negotiation of materials* involves the distribution of the physical materials at the students' disposal. A *negotiation of actions* is done to bring about some kind of physical manipulation, such as setting up equipment or drawing a picture. A *negotiation of status* refers to an interchange that results in the designation of leadership or some other individual role. Finally, a negotiation of meaning brings about a shared understanding of the task concepts.

There is merit to understanding the nature of exchanges, just as it might help us to understand the sorts of personality types that emerge in a group setting. Unfortunately, neither of these formulations is specific enough to help in the present study. Categorizing students in terms of a scheme fails to describe what I demonstrate as happening during the labs: that roles can change, and sometimes quite frequently. Categorizing exchanges ignores what is learned from the literature on framing, that a particular negotiation can be construed differently by each member of a group. I will show that these classification schemes are too static for our purposes.

Researchers David and Roger Johnson are two of education's most enthusiastic advocates of group learning. Their studies (1989; 1993) on how to effectively implement group learning environments in the classroom heavily influenced the laboratory reforms we examine in the next chapter. According to

them, “any assignment in any curriculum for any age student can be done cooperatively.” Central to the implementation of cooperative learning is the *theory of social interdependence*, inspired by both Piaget and Vygotsky, which claims that during the act of cooperative learning, skills are developed through the *cognitive disequilibrium* brought about through the social interaction. Interaction with peers exposes students to many different perspectives, and can inspire thought in a way that traditional classroom environments may not be able to do.

## **Discussion**

As previously mentioned, the focus of this research is on the interplay between individual cognition and social interaction. The chief concepts that will be taken from this research are those of epistemological framing, distributed cognition, and Tuckman’s stage model.

Epistemological framing is not only a useful tool for describing an individual’s interpretation of reality, but can also be a tremendously powerful tool for dealing with groups. I will demonstrate that how effectively a group works can depend highly on whether or not there is a shared framing of the type of problem before them, and what cognitive tools are appropriate to handle this particular problem. Distributed cognition is a socio-cultural concept that nevertheless places importance on the cognition of individual minds. This concept is used to describe how groups can appear to take on “a mind of their own”, or at least operate in a way that is difficult to reduce to the actions of individual minds. Tuckman’s stage model is presented as a dominant model of group evolution, and will be used in contrast to the model constructed in this work.

This chapter presents two distinct types of research, cognitive and socio-cultural, which can be combined in order to explain the workings of a lab group both collectively and with respect to individuals. In the next chapter, I present research specific to science labs, which inspired the reform project that resulted in the labs that we will be observing.

## **Chapter 3: Laboratory Reforms and Social Context**

This study was conducted as part of the Learning to Learn Science (LLS) project, which proposed to reform an algebra-based introductory physics course at the University of Maryland, taken mainly by pre-med students, biology and life-science majors, and architecture students. The class consisted mainly of juniors and seniors. This course included a laboratory much like those conducted at most physics departments – a two hour activity supervised by a graduate-level teaching assistant. Between twenty and thirty students, working in pairs, make up a class. Typically, the lab activities were scheduled to roughly coincide with the corresponding topics in lecture, so that the instructor would have covered any new material that might be relevant to the lab activity. Occasionally, this was not the case, forcing students to encounter certain concepts in laboratory for the first time.

Videotaped studies of these classes (Lippmann, 2003) revealed that the students were not accomplishing certain important learning goals. Although the students were dividing up labor, they were not engaging in a great deal of productive teamwork. Meaningful discussions about the physics concepts being explored were rare. Students spent most of their time following directions and trying to get through the lab manual, and not much time making use of peer interaction as professional scientists do.

Over the course of several semesters, my colleagues and I at the University of Maryland implemented many reforms to the introductory physics labs. Some of the



goals of this reform project were (a) to inspire more productive and meaningful teamwork, (b) to present open-ended exploratory-based activities, rather than those heavily-guided by a lab manual, and (c) to present the topics of uncertainty and measurement analysis in a novel way. In this chapter, first I present some of the relevant research on lab reform and pedagogy that inspired this project, and then I illustrate the end result of these reforms, the laboratory class which we will be studying in detail.

### **Research on Science Laboratories**

Much recent research on science laboratories is inspired by an early work by Fred Reif and Mark St. John (1979). In this, they enumerate the goals of the laboratory as a learning environment, differentiating between “basic skills”, such as estimating quantities, determining errors, and applying useful measuring techniques, and “higher-level skills”, such as effectively describing experiments and using the resulting knowledge in different situations. They note that after taking a traditional laboratory course, students are generally incapable of explaining what they have done in a way that makes sense to others.

We have observed a similar trend in our introductory laboratories. Even students who appeared quite competent in manipulating the equipment had difficulties articulating what they were doing and why. On the other hand, the SCL labs, in which inter-group discussion is more frequent and whole-class discussions are held each week, students were observed to be far more capable of explaining the details and meaning of the experiment, as shown in lab reports of increasing lucidity.

Further inadequacies of the laboratory class are explored by Séré (1993, 1998). Séré showed students in an introductory physics lab having woefully incompetent conceptions of measurement uncertainty and how to deal with it. Rather than accepting uncertainty and spread in a data set as vital components of the experimental results, they used the concept to apologize for what they deem to be poor experimental skills, or “human error.” Lippmann made a point of banning “human error” from the SCL labs, consistently sending the message to the students that spread in a data set is a feature of the answer, rather than a flaw of it.

These studies suggest that the students’ view of the nature of measurement is much different from that which one would seek to teach them. Buffler et al (2001) did a study to determine what exactly the students think about measurement. By administering and analyzing a questionnaire, they concluded that students’ beliefs about measurement fall into two categories: the *point paradigm*, which centers on the idea that the goal of measurement is to approach a single value, and the *set paradigm*, which understands measurements as establishing intervals, or spreads. The researchers’ view is that students holding the former view must be brought around to accept the latter view. Hans Niedderer and Dimitris Psillos (1998), through extensive case studies of laboratory work, came to the conclusion that two types of assessment were necessary to determine the effectiveness of the course. First, a comparison must be made between what the students are doing during the lab activity and the intended activities. Secondly, the learning outcomes as assessed after the lab must be compared to what was intended.

The research cited in this chapter provided a background for the various types of problems with the laboratories that other researchers have explored. It influenced the reform project in its early stages, and led to a set of lab activities that we feel addresses many of these problems, particularly with making sense of the nature measurement-making in general.

*Physics Education Research at the University of Maryland*

Finally, my research is most directly inspired by the works of two of my colleagues, Rebecca Lippmann and Jonathan Tuminaro. As graduate students, Lippmann and Tuminaro both wrote dissertations concerning the very population of students we will be examining later in this work.

It was initially Lippmann's idea to initiate a campaign to reform the traditional labs. This task was nothing to take lightly. Few people in a physics department are anxious to tamper with the undergraduate laboratory, an ancient institution which, though not exactly the proudest feature of our department, has managed to exist for a long time without causing crisis.

Lippmann introduced a reformed set of labs in the fall of 2001 and directed them for three semesters. These labs focused intensely on measurement issues, such as the treatment of uncertainty, error bars, and function fitting. Lippmann had observed that, in traditional labs, students spent a great deal of time discussing logistics of setting up equipment and very little time in "sense-making mode." One of the goals of this project was to reverse this trend by removing the lab manual and carefully engineering the activities so that these measurement issues would need to be seriously addressed.

Her dissertation (2003) explores how students spend their time in these new reformed labs. To me, this project was of vital importance in that it demonstrated that radical reforms in the laboratory were possible with the resources at our disposal. My set of labs, which will be discussed in the next chapter, were only possible because of Lippmann's groundbreaking work.

My immediate predecessor, Jonathan Tuminaro, also conducted interesting research that is carried on the present work. Tuminaro took Collins and Ferguson's concept of epistemic games and used them to describe the problem-solving attempts of our introductory physics students. We will be discussing Tuminaro's version of epistemic games in detail in chapter four.

### **“Traditional” Laboratories**

As a first step in this research, my colleagues and I made several major reforms to this laboratory course. Among the many goals guiding these reforms was our desire to design a laboratory environment in which there was a great deal of social interaction fostering cognitive sharing and increasing the fraction of time students spend in sense making about physics and measurement. In addition to this being beneficial for the students, this would also happen to yield rich activities that are easily studied in real time through video and audio recorders. The result of this reform effort was a set of activities we call *scientific community labs*, which foster much richer social interactions and teamwork than traditional labs.

The term *traditional labs*, which is typically used to describe those labs that existed prior to this study, is somewhat misleading, since they by no means are the same activities as the *Harvard forty* (Menzie, 1970), the original set of laboratory

standards proposed in 1886 when laboratory courses began to proliferate in the United States. However, despite modernization and reform, not only in response to improved technology but to the expansion of physics itself, several of the Harvard forty experiments are still found in today's undergraduate laboratories.

The idea of modernizing the introductory physics labs is not new; Robert Millikan (1903) suggested more than a century ago that laboratory work “often degenerates into a servile following of directions, and thus loses all save a purely manipulative value.” He laments the fact that too little of a connection is drawn between theory and experiment in physics courses. The fact that labs are still taught separately from lectures, often with different instructors and separate grades, suggests that some of Millikan's problems with the laboratory are still waiting to be solved.

In a typical lab, students are given a short description of a physical phenomenon they are to investigate, followed by detailed instructions on how to perform every portion of the activity. As if being asked to ignore the literal meaning of the word “experiment,” students are expected not to stray from the activity they are intended to complete, and are generally expected to be able to acquire results that demonstrate the relevant physical concept. They are then required to write up a report of what they have done. This sort of activity is what I will refer to here on in as a “traditional lab,” though the details of how they are conducted can vary from college to college, especially those in which faculty have made deliberate attempts to reform them.

I have observed not only a general dissatisfaction among physical faculty with the state of traditional labs, but also a wide of divergence of opinion on what these

activities are intended to do. My discussions with faculty and teaching assistants revealed a variety of opinions on the subject. Suffice to say, laboratory courses *can in principle* be used to:

- demonstrate the physical phenomena introduced in lecture
- verify physical laws
- simulate experiments with certain historical or technical significance
- familiarize students with laboratory equipment
- present topics concerning measurement and uncertainty
- teach students proper laboratory protocol
- simulate certain features of *real-life* lab work

It is generally understood, both by the students and by the instructors, that the laboratory is, in fact, a simulation, and sometimes a very artificial one. A simulation chooses a few features of the real experience to emphasize, while ignoring the rest.

Unfortunately, traditional labs tend to downplay the entire social dimension of doing science. Research on traditional labs has shown that a majority of a student's time in a traditional lab is spent dealing with logistical issues, such as interpreting and carrying out the instructions in the lab manual (Lippmann, 2003). Very little teamwork is required and meaningful discussions about the nature of the activity rarely take place. When lab groups interact, it is typically to divide up the tasks. They do not usually function as a team, as a unit that is more than the sum of its parts. Nor are the students expected to interact with other groups. A laboratory activity can be performed by individual students working in isolation (and they frequently are, during lab makeup week).

It is rather unfortunate that, due to the constraints of the classroom, laboratories reduce the social dimensions of science. A student performing an experiment in social isolation is lacking exposure to two vitally important features of science work: the experience of observing the work of others and the experience of passing on one's work to others. In real scientific research, there are no detailed instructions, and there is not always an accepted answer to work towards. Rather than having the rigid, authoritarian presence of instructors and lab manuals, real experimentation is done in the company of a scientific community. While potential scientists must learn to interact in such a culture, traditional labs do not address this issue. So we designed a new set of labs that would.

### **Scientific Community Laboratories**

#### *SCL-1*

Reforming this laboratory course was part of a four-year research project funded by the National Science Foundation. The original reforms were made by Rebecca Lippmann and Dr. Edward F. Redish, and produced a first-semester set of scientific community labs (SCL-1). Though their primary goal was to create a set of lab activities that placed emphasis on the nature of measurement and uncertainty, they also succeeded in dramatically increasing the amount of social interaction that took place. A chief goal was to get the students to address how making measurements leads to a result, or how it can answer a question.

During the course of this research project, we collected several hundred hours of videotape of students working in the laboratory, in problem-solving tutorials, doing homework problems, and participating in lecture demonstrations. It was through the

observation of these videos that we recognized noteworthy student behavior in the laboratories. These videos made up the bulk of our observational data for many studies henceforth.

Lippmann's dissertation parsed student discourse in the laboratory into three main categories: logistics, sense-making, and off-task. *Logistics* refers to the management of the smaller details, such as figuring out how to put the apparatus together and manipulating equations. *Sense-making* refers to activity associated with understanding the physics, reconciling what is observed with intuition, etc.

Lippmann demonstrates that *meta-cognitive* statements, or those that specifically address what they are doing and thinking about, that inspire frame shifts into sense-making. Shown below in Figure 2 is a time-line of these activities in a traditional lab, and Figure 3 shows a similar time-line for an SCL-1 lab.

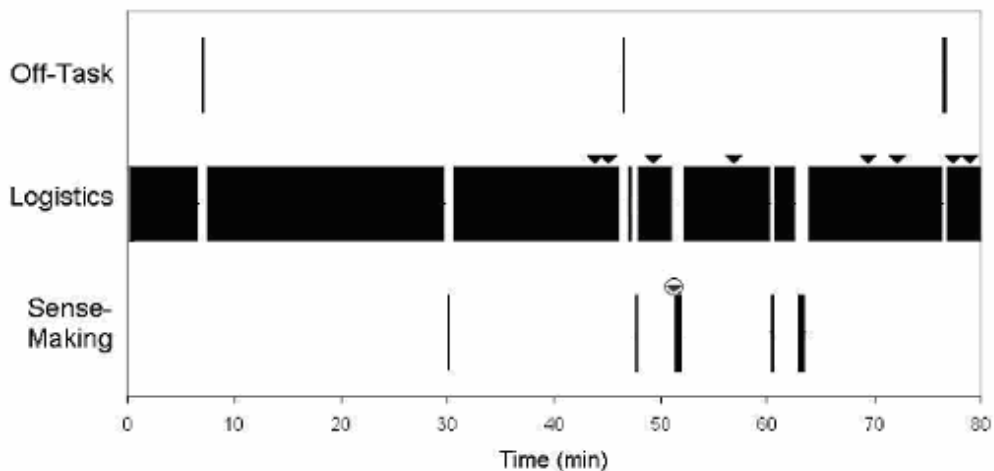


Figure 2. Lippmann plot of student activity in a traditional lab.



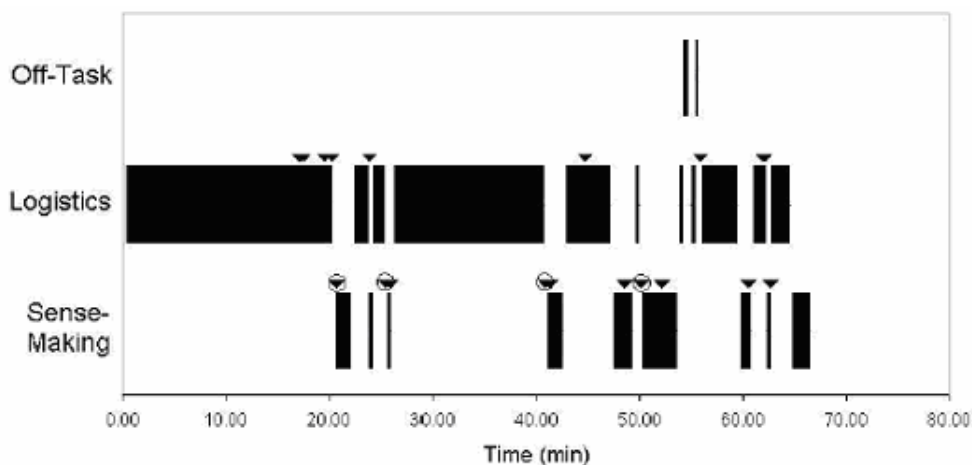


Figure 3. Lippmann plot of student activity in a SCL-1 lab.

Lippmann found that the SCL-1 labs were significantly better than traditional laboratories in inspiring sense-making behavior. It is this kind of discussion that I am referring to when I talk about “meaningful conversations about physics.”

### *SCL-2*

When the task of directing these labs fell into my hands, my colleagues and I continued to make small modifications to them. Inspired by the success of the SCL-1 set, we designed a second semester set, SCL-2 (see Appendix B), to tackle topics of electricity and magnetism, waves and light, and radioactivity. As SCL-1 had focused on topics of uncertainty and measurement, SCL-2 took on the task of data analysis using computer spreadsheet software. For each lab, in addition to the experimental issue, a question is posed about the data that requires the students to invent their own method of data analysis.

The course sequence in which the SCL-1 and SCL-2 labs were embedded was offered once a year for two semesters. Between six and eight lab sections were held each semester from fall of 2001 to spring of 2004, with the exception of spring 2003,

in which twenty sections were held. Some were taught by graduate students specializing in physics education research, and the rest by graduate students in other fields of physics. Each semester, four sections were chosen to be videotaped with the students' permission (see Appendix D). Cameras were installed where they could record groups of four, but also so that they could zoom back and record a whole-class discussion. Microphones were strategically placed to capture the discussion of the target groups in detail. Nearly five hundred hours of videotape was taken.

One suggested limitation of using videotape analysis to study students was the possibility that students would tend to act differently from normal while under observation. We have no reason to believe this phenomenon appreciably altered the data. Sudden moments of self-consciousness, brought on by the fact that the camera loomed twenty feet away, are rare. More often than not, the students would refer to the cameras jokingly. Although a camera is zoomed in a particular group, it is difficult for the subjects to tell who exactly is being filmed. On the other hand, there is ample evidence that students are generally forgetful of the fact that they're being filmed. Students regularly reveal intimate details of their personal lives, speak boastfully of cheating on tests, and sometimes share rude comments about the instructor.

### **Reforming the Laboratory**

The major goal of the LLS project was *epistemological development* – exploring the nature of the knowledge the student were learning and what they had to do to learn it. The project tried to build the idea that physics was about “sense-making” and tried help students reconcile their physical intuition with the physics

concepts they were learning. A chief goal of the lab reform was to have the lab not contradict the message sent in the rest of the class: to make sense of the physics for yourself and not rely on the pronouncements of authority.

In addition to this, Redish and Lippmann interviewed two biology researchers who hired undergraduates to work in their research labs to determine what sorts of skills would be desirable for their incoming undergraduates to possess. They expressed two needs for the students:

- A broader understanding of what an experiment entails, rather than in-depth training in the minutiae of specific experiments.
- Ability to use a basic data analysis computer program (especially Microsoft® Excel®).

With these epistemological goals and practical goals, we formulated a mission statement for the SCL-2 labs (see below) that guided our reform attempts. This statement was made available in the opening pages of the laboratory manual, and we repeatedly pointed the students towards it whenever questions arose concerning what would be required to get a good grade on the lab reports and lab practicals.

## Mission Statement

*You are going to learn three basic things this semester:*

1. **How to recognize relationships.** All the complicated stuff that goes on in a physics lab can be boiled down to a simple premise: if you change one thing, another thing changes too. First we identify *what* changes. Then we try and decide *in what way* it changes. This is what we call “functional dependence.” That’s all physics equations are, really, a precise statement about how changing one thing will affect another thing. In this lab, we will explore many different kinds of physical phenomena and try to figure out *what affects what and how*.
2. **How to make a persuasive case for your data.** In physics, answers don’t just pop up out of the ground, ready to be printed in a textbook. Data from an experiment doesn’t make much sense at a first glance. First you must be able to understand what data *means*. Then you need to be able to *present* this data to others in such a way that it will persuade them that the *conclusions* you’ve drawn from this data are correct. In order to do these things, you must have a good understanding of the limitations of your observations and *how precise your data is* and *how well you can trust it*. For this, we will try to develop quantitative estimates of how accurate our results are.
3. **How to make a computer do the hard stuff.** We will be using the *Microsoft® Excel®* spreadsheet to tabulate data, crunch numbers, and construct graphical representations of our data. Not that we can’t do these things by hand, it’s just that a computer can do it a lot faster, relieving us of a lot of busy-work and leaving us more time for more interesting activities. If you plan on going into research, it is essential to know how to use a computer spreadsheet.

Figure 4. Mission Statement

The following is a list of specific changes made to the labs in order to pursue these goals. They were implemented incrementally over the four years, and corrected as needed.

- Eliminating the lab manuals
- Changing the classroom architecture
- Assigning roles
- Including class interaction
- Encouraging the lab instructors to give the students some space

### *Eliminating the Lab Manuals*

Having a lab manual can be like having an additional member in your group –

at times a threatening leader, rather than an inclusive one. While this “member” may be difficult to understand, it is nevertheless understood by the students that it has the answers in it somewhere. In a traditional lab, the lab manual dominates the conversation at every turn. Students can spend the entire lab period trying to figure out what it’s trying to say, rather than thinking about what they themselves know. Ideally, students are expected to develop a level of autonomy and to interact as a group. The intervening presence of the lab manual can prevent this from happening.

I experienced an interesting event early in the reform effort in one of my own laboratories. The experiment involved lenses, and required the students to go through a number of procedures in order to produce real images, virtual images, etc. Frustrated with the lab manuals for taking all the fun out of what is otherwise an interesting phenomenon to observe (and guided by a whim that only first-year graduate students are reckless enough to act on), I told the students at the beginning of lab to put their lab manuals on the floor – we wouldn’t be needing them. Instead, I gave them a short list of questions on the chalkboard for them to answer, and encouraged them to go about it their own way. Having taken away their main crutch, I half-expected a mutiny. Instead, the students were delighted to be rid of the cumbersome thing. They began to pay serious attention to the equipment they were using, held interesting conversations about the physics, and generally acted in a way that convinced both me and the LLS project leaders that eliminating the lab manual could be a serious step in the right direction of reforming the lab.

In the following semester, when the SCL-1 labs were first conducted, the lab manual was not included. No longer was this silent member going to do all the hard

work for the group. No longer was the manual going to determine *what kind of* experiment to conduct, how to solve the problem, how to plan the experiment, and what to make of the data. These are tasks that the students, as a group, need to learn how to do, and having the manual was robbing them of this experience.

Consequently, the first major reform was to banish the manual from the laboratory.

Without a lab manual to guide them, the students find themselves in an awkward and unfamiliar position. The clues needed to complete the lab can no longer be found somewhere in the text. So where are they? What we wanted was for the students to cease looking for answers from authority, and to start attempting to find the answers themselves. A community of peers, for example, is a tool far more useful than a lab manual, though it takes time and effort to figure out how to operate it. But the question remained: how much guidance should the students be given?

A new list of lab activities was drawn up (see Appendix B). A typical lab activity consists of a short expository passage to provide a physical context and motivation for the task presented. They are often humorous, and intended to send the meta-message that laboratory ought to be fun. Then there is a short question or pair of questions that comprises the goal of the lab. Finally, they are given an activity timetable<sup>4</sup>. Over the course of two hours, the students are expected to design an experiment, collect data, draw conclusions based on this data, and finally to present their conclusions to the rest of the class. An example of such an activity is shown below.

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<sup>4</sup> We expected student's biggest problem would be managing their time. Rather than risk having a significant number of students not complete the laboratory, general time guidelines were given, though one could argue this went against our general philosophy of allowing students to think things through themselves.

The students are not told what kind of experiment would be best, how to design it, or how to construct a convincing argument for their results. The assignment is two-fold: they must do the experiment *and* determine a way to go about doing the experiment. In order to do all of this in the time allotted, a certain level of productive teamwork is necessary.

**Lab 5: Magnetic Force, Part One**

**When you hold two magnets close to one another, they feel either an attraction or a repulsive force between them, depending on their orientation. It appears that the magnitude of this force depends on the distance between the two magnets. But how?**

**Question: How does the force between two magnets change if you change the distance between them?**

<b>Pre-lab discussion</b>	<b>Whole Class</b>	<b>10 minutes</b>
<b>Planning the experiment</b>	<b>Groups of 4</b>	<b>20 minutes</b>
<b>Data collection</b>	<b>Groups of 4</b>	<b>20 minutes</b>
<b>Class discussion</b>	<b>Whole Class</b>	<b>20 minutes</b>
<b>More data collection</b>	<b>Groups of 4</b>	<b>30 minutes</b>
<b>Writing the report</b>	<b>Groups of 4</b>	<b>10 minutes</b>

Figure 5. Sample SCL-2 laboratory handout

### *Changing the Classroom Architecture*

Shown in Figure 6 is a representation of the architectural setup of a traditional Physics 121/122 lab at the University of Maryland. Students work side-by-side with their partners, constantly facing the authoritarian presence of the lab instructor and/or written instructions on the blackboard in front of them. This setup most strongly

resembles a Roman slave galley<sup>5</sup>, and is not the best environment for students to interact in any meaningful way. One must crane one's neck just to see one's lab partner. One sees nothing but other students' backs. We decided to change this setup.

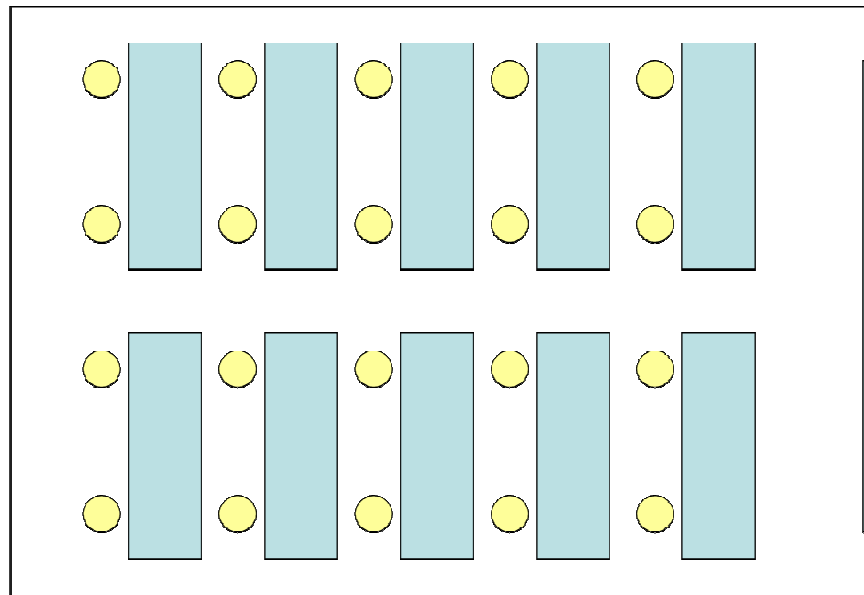


Figure 6. Traditional laboratory architecture

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<sup>5</sup> This is not necessarily an association the students will make for themselves. I, on the other hand, cannot see a traditional laboratory without being reminded of *Ben-Hur*.



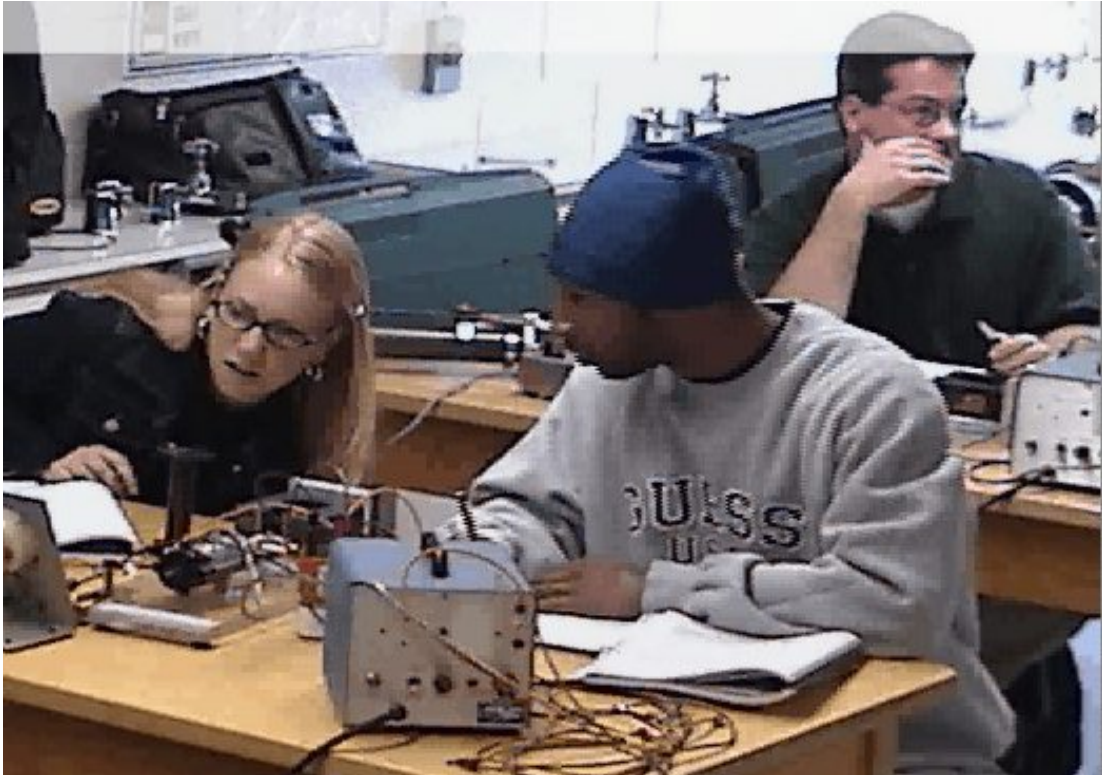


Figure 7. Students in a traditional lab.

Shown below is the setup of a reformed lab. Students work together in groups of four, at a desk small enough for everyone to get in everyone else's face. It is no surprise that a lot more intra-group conversation occurs when you turn them towards each other, or that much more interesting social interactions occur in larger groups. This was demonstrated in Lippmann (ibid.) after this change was made.

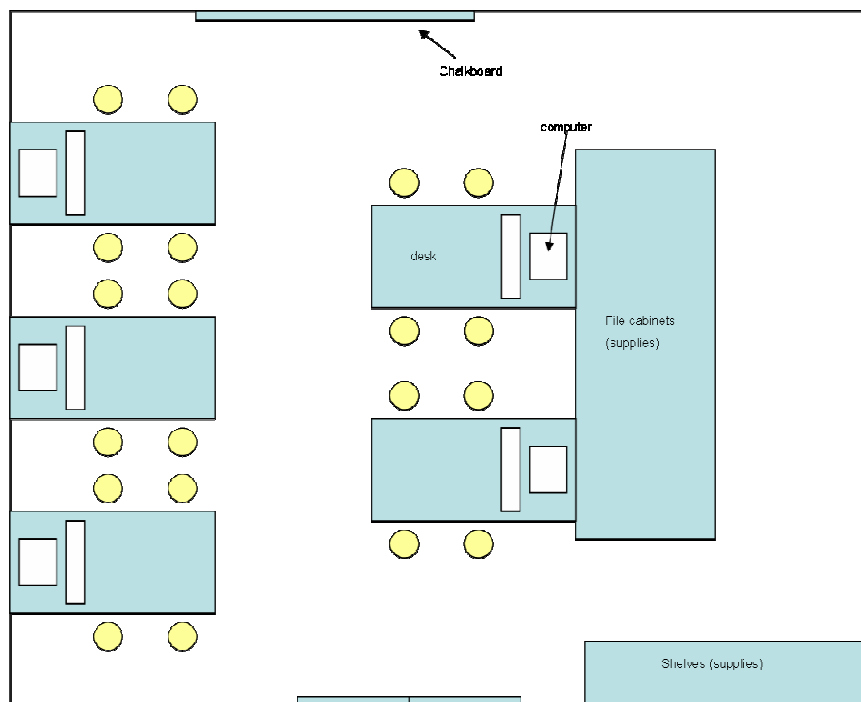


Figure 8. Scientific community laboratory architecture

### *Assigning Roles*

As a consequence of the previous reforms, the groups found themselves with a great deal of work to do. Unfortunately, much time can be wasted when students aren't sure how to divide up the tasks. I observed, as a TA teaching traditional labs, that what frequently occurs is that one student will, for whatever reason, take over the lion's share of the work, with his or her partner doing next to nothing. Even in our reformed labs, with four members to a group, one student sometimes tended to dominate. We decided that it would be necessary to intervene for the sake of guiding the students towards a clearer and fairer division of labor. Inspired by the work of Johnson & Johnson (1993), rotating "roles" were assigned to the four group members:

## Roles

***The Journalist:*** Keeps notes throughout the lab, writes the “Journal” section of the lab report.

***The Data Interpreter:*** Deals specifically with the illustration and interpretation of data.

***The Critic:*** Acts as liaison with other groups, suggests improvements, writes “Evaluation”.

***The Checker:*** Checks the lab report as a whole at the end, makes sure the sections are well integrated and that suggested improvements are made.

Figure 9. Scientific community laboratory roles

It was not our intention to rigidly control the behavior of each student, nor is it our assumption that students are able to operate purely within the confines of such a classification system and produce anything of value. The purpose of assigning roles was to make the cooperative process a bit easier by eliminating the need to spend much time deciding who does what, and, by making the roles rotate, to be sure the students learn all aspects of the lab, rather than choosing to simplify their tasks by becoming specialists. Beginning a large and involved activity with little guidance is extremely difficult. Giving the students a very general idea of what is expected of each individual prevents much awkwardness, and can hasten the natural process by which the members themselves decide how to divvy up the labor.

Another goal of assigning roles was to achieve what Johnson & Johnson (ibid.) refer to as *group interdependence*. While the group is judged by their collective performance, it is best for the students to understand what they are primarily responsible for *individually*, so that they have a better idea where they fit into the group. As a member of a group, one not only has responsibility for one's

own performance, but also a degree of responsibility for the performance of others. This point was articulated to the students early and frequently. Assigning roles also helps clarify what is expected of each group member. The uncertainty of not knowing what one is supposed to be doing can completely hinder creative thought. A brief guideline of where to start can help avoid awkward silences and get them started thinking.

### *Including Class Interaction*

A scientist must be able to interact in a number of different communities. We wanted our students not only to be able to interact constructively with their collaborators, but with the other groups as well. With this in mind, we arranged for a “Class Discussion” segment at the end of the lab period, in which each group presents its data and conclusions, and then is expected to deal with criticisms from the rest of the “community.” The class as a whole, like the group as a whole, can be a valuable tool in the laboratory, a source of information, ideas, and constructive criticism. But like the group, the class also takes effort to figure out how to operate. After all, what does a student have to gain from criticizing his peers, other than to earn their distrust and ire?

The message we wanted to send to the students was that the purpose of interacting in a larger community is not necessary only for the larger community’s sake, but because doing so can help you, or your group, individually. Constructive criticism, after all, should construct something. Plus, if the class as a whole can develop its own dynamics, the way good teamwork can develop in a group of four, students can “use” the class community in the same way that they use the group

community and the other resources at their disposal.

In order to create the need for a vibrant and effective class discussion, we set forth a requirement in the lab report that each group must, by talking to and listening to their peers, develop some concrete ideas about how they could improve their experiment if they were to do it again. Part of the lab report was an evaluation in which the students had to discuss these improvements and how they came to their attention. The underlying message is that they are all in this together. If no constructive class discussion takes place, nobody gets the points. If it does take place, everyone prospers. This, we feel, was an appropriate simulation of a “real” scientific community. Students come to learn that the measure of their work’s quality is not just the judgment of the instructor, but that of their peers. If they are to learn anything from the other groups, they must figure out how to communicate with them as well. Also, a scientific community does not just accept results. Its job is to challenge and refine in order to produce a communal result that is right, stable, and better than any individual or single group can produce for themselves.

#### *Encouraging the Lab Instructors to Give the Students Some Space*

Another major reform of this laboratory was in how the lab instructors themselves were trained to handle these reformed labs. We instructed the lab TAs to give the students more space and autonomy than perhaps they may have been accustomed to giving. This meant perhaps not giving students ideas when they were stuck, not directing the class discussion when nobody seems to have anything to say, or not approving of or disapproving of a weak experimental design a group may not be sure about. The goal was to take those tasks that students naturally associate with

the instructor and to give those back to the students themselves. One way of looking at it is that we refrain from doing for the students what the individual students cannot do, in the hopes that they might construct a well-functioning group that *can* do these things. On the other hand, it is not desirable to remove the TA from the class entirely. Their function as a guide is to raise questions in a way that, hopefully, the students will learn to develop their own “inner TA” and begin asking those questions themselves.

### **The Reformed Labs in Action**

The result of these various reforms was a new class that resembled traditional labs in only superficial ways. The students in these labs spent a great deal of time engaging in lively discussion about the topics most relevant to experimental physics: what the best way to design an experiment is, how to minimize error, how to interpret data, and how to build a convincing case for your argument. These labs required a wide spectrum of different activities - so many of them, that no single person could finish a lab in the allotted time. Developing a well-functioning group is necessary for these tasks.

Naturally, the students were typically quite overwhelmed at first with the new class structure. For the first few weeks, they were frustrated with the lack of guidance. However, after a few weeks, most groups tended to “get it” and become comfortable with not knowing the results ahead of time. When enough of the groups learned to function as units, one could see interesting social dynamics develop in the class as a whole. In a few cases, the students were able to conduct the end-of-lab discussions and debates on their own, with a minimum of instructor interference.

Getting the students to this point was not an easy process.

## **Conclusion**

What we accomplished over the course of the four year project was a radical transformation of the traditional labs. The reformed labs tackle different issues than those of traditional labs, but they have the advantage that the activities, rather than being quasi-individual activities, have a strong social element to them. Cooperation at the group level is necessary, as is cooperation as a class.

What was remarkable was the amount of genuine student interaction that took place in these labs. After a few weeks, many of the groups were engaging in a number of different strategies to tackle the difficult goals we set before them. It was this kind of activity that allowed a group to act as more than the sum of its parts, and generally this led to these students accomplishing the goal of the lab and producing remarkable lab reports. This kind of teamwork, I determined, was worth a detailed study.

## Chapter 4: Introduction to Epistemic Games in the Laboratory

### Introduction

The laboratory activities included in the SCL-1 and SCL-2 labs are more difficult for students than they seem to faculty. In order for a group to complete the lab, a sequence of sub-goals must be accomplished. Initially, the students must determine exactly what the question is asking and what constitutes the answer. Next, they need to formulate a plan of action. Then, they need to construct an experimental apparatus and collect a certain amount of data. Finally, they need to build a persuasive explanation of their data. Each of these steps can consist of a sequence of sub-steps.

Because this activity consists of so many different goals, which typically need to be accomplished in a particular order, the concept of *goal-oriented action* will be important to our analysis of their behavior. Doing a laboratory activity is not supposed to be like cleaning a house, wherein many contributors can “pitch in” and accomplish the task without a sophisticated sense of purpose, cooperation, and synchronization. Rather, they are *sequentially constrained*, in that accomplishing one part of the task will affect what needs to be done next. In the presence of sequential constraints, it is necessary to have a certain amount of central control over what the members do. Productive laboratory group work is characterized by a shared sense of purpose, which can change, as needed, in response to what is accomplished. Understanding how a group functions requires one to consider both what the



individuals believe is occurring, and then on a different level, what elements are shared among the group.

In the previous chapter, I discussed various means of describing and understanding group activity. Since group activity consists of many dimensions of complexity, a researcher has many different lenses with which to view the same occurrences. In this chapter, I discuss the concept of *epistemic games*, which are coherent activities engaged in for the purpose of accomplishing a specific goal. I define and discuss five epistemic games that characterize most of the behavior observed in my data set, and give examples of them from the video transcriptions. These will provide the unit of analysis for considering purposeful activity in the laboratory.

### **Previous Research on Epistemic Games**

In this section, I present two distinct approaches to the subject of epistemic games: the formulation of Collins and Ferguson, which identifies epistemic games as expert strategies for the construction of knowledge, and the formulation of Tuminaro and Redish, which uses epistemic games to describe locally coherent strategies created by students, which are sometimes tacit and unarticulated. By “locally coherent”, I am referring to strategies that consist of a finite set of associated moves, while excluding other moves on the basis of relevance.

#### *Collins & Ferguson: Epistemic Games as Expert Strategies*

Collins and Ferguson (1993) introduced the concept of epistemic games to describe strategies used in science and social studies for the purpose of guiding

inquiry. According to them, the knowledge base used by researchers, i.e. the facts, equations, and concepts accumulated by the community, are not the only resources necessary to perform in the field. Equally important as these components is the means by which they are organized and processed. They describe *epistemic forms* as target structures that guide inquiry, and *epistemic games* as the rules and strategies used in pursuit of these structures.

A simple example of an epistemic game is list-making. In this task, the epistemic form, or the end-product of the activity, is the list itself. Although everyone knows right away how to make a list, up close we can see that this simple activity is governed by implicit constraints and allows the participant to engage in a limited set of sub-activities. As an epistemic game, it has the following components: *entry conditions*, *ending conditions*, and *moves*. The entry conditions are that which signals the need for this particular game. Examples of such conditions would be sending out wedding invitations, planning a trip to the grocery store, or simply bringing several similar objects out of long-term memory into working memory. The ending conditions are that which signals that the game has been completed, or “won.” In making a list, one has completed the game when the target quantity (the list) is acquired, it is complete, no item is repeated, and no item can be divided into a number of items. The moves in list-making would include adding items, deleting items, combining items, splitting an item into pieces, or changing the specifications of the list itself.

An epistemic game is “epistemic” in the sense that it builds new knowledge. In making a list, one can draw upon a variety of sources. If I were to construct a list,

for example, of presidents who served one term in office, I might draw from my recollection of events I myself witnessed (George Bush) or my memory of historical facts (John Adams, Jimmy Carter), and I might have to go hunting in a book for the rest of them. In this case, the epistemic game is a means of collecting information from different sources and constructing a new (for me) piece of knowledge. But it is not necessary for this information to be collected from an outside source. In constructing a grocery list, I can say that each item on that list, and the fact that I need such a thing, was a piece of knowledge I already possessed. Nevertheless, the list itself is considered new knowledge, even though it consists of old knowledge; the organization is new.

Collins and Ferguson describe many such epistemic games used in professional research for the organization of old knowledge into new knowledge such as cost-benefit analysis, stage models, multicausal analysis, and constraint systems. The purpose of illuminating the existence of these games is to demonstrate the importance of the methods, as opposed to the knowledge base, in the acquisition of knowledge, and to suggest that schools place more focus on the teaching of epistemic games, instead of merely drilling students in memorization of the facts themselves, which in many cases can be easily looked up. For instance, students of physics should be instructed in how discipline-specific epistemic forms, such as equations, graphs, Feynman diagrams etc. fit into grander schemes of physics knowledge construction, rather than merely ends in themselves.

*Tuminaro: Epistemic Games as Strategies per Se*

Tuminaro and Redish (2005) use the concept of epistemic games to describe the activities of students engaged in mathematical problem-solving in an introductory algebra-based physics course. Whereas Collins and Ferguson's epistemic games are expert strategies, used by professional researchers and consequently are well thought-out and typically successful, Tuminaro expanded the definition to include *any* coherent strategy. The definition he uses comes from Redish (2004):

*A coherent activity that uses particular kinds of knowledge and processes associated with that knowledge to create knowledge or solve a problem.*

Like Collins and Ferguson's epistemic games, Tuminaro's epistemic games are purposeful, coherent activities. However, since Tuminaro uses these games descriptively, rather than normatively, he includes all emergent strategies, even those that may be unproductive or damaging. He demonstrates the existence of several specific epistemic games being played by students engaged in solving homework problems. While the use of an appropriate epistemic game can lead to new knowledge and a solution to the problem, he also shows how certain games, motivated by incorrect expectations or poor epistemologies, can lead to commonly-made mistakes and endless loops of non-productive behavior.

An important characteristic of the epistemic games proposed by Tuminaro is not just the entry conditions, ending conditions, and allowed moves; Tuminaro observed that games tended to be *exclusionary*. Often a student playing a particular epistemic game would consistently ignore (or even actively resist in response to an instructor's suggestion) certain moves that an expert might consider appropriate for

solving that problem, even though data taken in other contexts showed the student perfectly capable of carrying it out.

### **Epistemic Games as Group Activities**

As previously mentioned, I seek to describe laboratory group-work with a focus on the intended goals of the various activities associated with it. I use epistemic games for this purpose, as they can be defined by these intended goals and by the set of allowed moves, both of which can be observed or inferred through analysis of student conversation. Epistemic games provide a means by which one can make sense of group work. They allow us to address “what the students are playing at” and “what the students are working towards.”

Like Tuminaro, I use epistemic games to describe what students actually do, rather than using them normatively to describe preferred methods. Students in our SCL labs in general do not behave as directed by the instructor, even when a well-defined method is specifically suggested. Simple suggestions to “change their mode of thinking” tend not to be effective. In these laboratory activities, they are given few instructions, and therefore have to rely on their own devices, logic, and methods to apprehend and accomplish the activity. It is this intuitive activity I am most interested in; a judgment of what students should do needs to take these activities into account.

As I mentioned in chapter two, researchers in situated cognition seek to expand the definition of cognition to include group activities. I do not imply that a group can play an epistemic game in the same way that an individual plays an epistemic game. For example, a necessary component of an epistemic game is the

intended goal, or ending conditions. When a group is “playing” an epistemic game, we have no reason to assume *a priori* that each member shares a common goal.

Games can be identified by the characteristic moves, even if the intended goal is not understood. Nevertheless, I use the phrase “playing a game” to imply an understanding of the intended goal, while it is possible for one to “participate” in a game without such an understanding.

I should also mention that epistemic games need to be differentiated from games *per se*. What makes epistemic games epistemic is that they are involved in construction of knowledge. Since a necessary component of an epistemic game is the ending conditions and epistemic form, i.e. the intended goal, we can also say that epistemic games are *purposeful* activities. One may argue that people are *always* engaged in purposeful activities, unless they are acting randomly, and in which case the randomness is most likely the intended goal. Indeed, just about any activity can be described in terms of intention. However, not every activity has as its goal the building of knowledge. Hence, epistemic games are differentiated from other activities in that they are *epistemically purposeful*.

In the following section, I propose five epistemic games that describe the observed behavior of groups of students in the laboratory. They were formulated through a process of closely examining video footage in order to ascertain the overarching goal of the activity, and to identify the set of activities and knowledge elements being used and the general strategy being applied to use these tools in the pursuit of their goal.

<b>Collins &amp; Ferguson Epistemic games (1993)</b>	<b>Tuminaro Epistemic Games (2004)</b>	<b>Gresser Epistemic Games (2005)</b>
<ul style="list-style-type: none"> <li>• List-making</li> <li>• Compare and contrast</li> <li>• Cost-benefit analysis</li> <li>• Primitive elements</li> <li>• Cross-product or table</li> <li>• Tree-structure or hierarchy</li> <li>• Axiom systems</li> </ul>	<ul style="list-style-type: none"> <li>• Mapping Meaning to Mathematics</li> <li>• Mapping Mathematics to Meaning</li> <li>• Physical Mechanism Game</li> <li>• Pictorial Analysis</li> <li>• Recursive Plug-and-Chug</li> <li>• Transliteration to Mathematics</li> </ul>	<ul style="list-style-type: none"> <li>• Evaluative and Concretizing Plan-Making</li> <li>• Equation Bridging</li> <li>• Recursive Equation Bridging</li> <li>• Strategic Mapping</li> <li>• Exploration</li> </ul>

Table 1. List of epistemic games across three contexts.

### **On the Process of Constructing Epistemic Games**

Over the course of this research project, around 400 hours of laboratory activity was captured on videotape. For this particular project, 35 hours were selected for viewing, and they depicted a number of groups engaged in three specific laboratory activities. The lab instructors had recommended these specific groups on the basis of their relative articulateness; the lab activities were chosen because we felt

that they represented the biggest challenge for planning, designing, and making sense of the physics involved.

Initially I had hypothesized that the productivity of the groups depended most heavily on the students' individual personalities, and that success in a lab group depended on complementary *combinations* of such personalities. Four laboratories were viewed several times and transcribed, and with this data, I attempted to categorize the students using a number of classification frameworks, including those of Shepardson (1996), Richmond & Striley (1996), and Belbin (1981). The goal was two-fold: determine whether or not the group was operating in a productive way, and identify what roles were being played out by the participants.

The main difficulty facing this analysis was an observed lack of stability within the groups. A group of students that appeared to be cooperating constructively one minute might all of a sudden start spinning their wheels in an unproductive activity. Students who appeared to be leading during one clip would be found, several minutes later, taking orders or not participating at all. And in one case, the incessant banter of one pair of students seemed to be distracting and intimidating to the rest of the group was observed later, in another context, to be helping keep a vital discussion alive. How does one go about categorizing this kind of behavior, when the context seems to be the determining whether it is helping or hurting the group? It became clear, as more and more videos were watched, that the context itself might be the component of group work worth closer analysis.

One thing, however, was certain: the roles we had assigned to the students, inspired by Johnson & Johnson (1989, 1993) were not being assumed in any



meaningful way. The chief goal of these roles was to assist the students during the getting-to-know-you phase, so that each student would have something specific to do. But a secondary goal was to nudge them into a group configuration that we believed would be productive. A good group, we theorized, must have at least one member consistently bringing the discussion around to address what data would be collected, while another member must be responsible for coordinating the various members' work. But we did not observe, for example, a "data-interpreter" consistently dealing with data, nor did we observe the other members refraining from data-specific issues. Rather, the groups seemed to, at times, go into "data mode", wherein each member would assume some of this role's responsibilities. Modes seemed to be a powerful influence on the groups' activities.

It was frustrating, not being able to identify these patterns in individual student behavior. But this led us to question, if observable personality traits and interactions are transitory, what exactly does remain constant? Reviewing the same laboratories led to me to hypothesize that the students operated within "modes" lasting on the order of a few minutes at a time, and that these modes could be the way in which the students were apprehending and dealing with the laboratory task at hand.

Epistemological framing describes how a student might "interpret" a task, and how this interpretation leads to the activation of specific sets of knowledge, skills, and behavior appropriate to that context. This is a productive tool with which to describe these observed modes and why shifts in focus and behavior were so common. But the activity observed was even more structured than just that. These modes, when observed closely, appeared to be characterized by systems of unspoken

rules and the pursuit of a common goal, which was sometimes unspoken as well.

This is what led to the decision to use epistemic games to describe laboratory group work as locally coherent behavior.

The task of formulating epistemic games began with determining what the goals, or perceived end-games, of the students were. In rare instances, the students explicitly state what they are attempting to do, but in most cases this must be inferred from the conversation. Another obstacle was in the fact that many games do not play out to conclusion. Nevertheless, observing what the students are trying to determine and what sorts of events lead them to “move on” give strong evidence as to what the goals of the games are. When a block of activity is identified and a goal is determined, the next step is to figure out what moves are being used and what moves are not. Through this process, many potential epistemic games were constructed to describe what was being observed.

But epistemic games can not be of much use to us if we must invent a new one to describe every instance of locally coherent behavior. It is only useful if a finite number of games can be used to describe most of what is seen in the laboratory.

After watching many laboratories, some games were modified and some were determined to be the same game and combined. After five well-defined epistemic games were identified, those we will explore in this chapter, most of the locally coherent behavior we observed in lab could be described by one of these games. This convergence suggests that the students have a limited range of games at their disposal<sup>6</sup>, that they do not merely play a new game every time a new situation rears its head. In this thesis, we have taken as our goal to identify a few important and

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<sup>6</sup> At least insofar as they can be observed using the methodology described herein.

frequently recurring games and to explore their characteristics and effects on the group behavior.

### Evaluative and Concretizing Plan-Making

The first game we will examine I call *Evaluative and Concretizing Plan-Making*. This is typically a very productive game for students choosing an experiment that answers the lab question, and it serves as a standard to which other games can be compared.

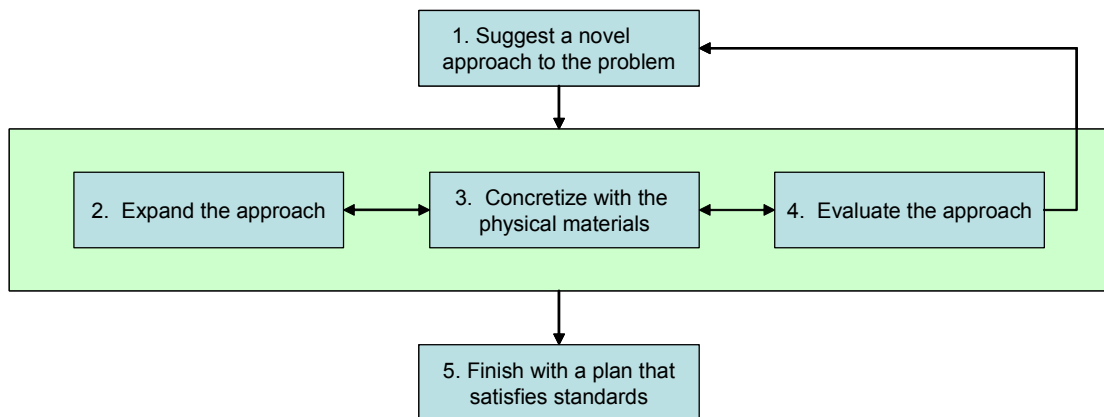


Figure 10. Schematic diagram of students' moves with *Evaluative and Concretizing Plan-Making*

This game begins when a suggestion of a novel approach to the problem is made by one of the students. The goal of this activity is to construct a plan on how to proceed through the experiment, using this suggestion as the central idea. We can say that a *round* of this game lasts as long as this suggestion is *in play*, or as long as the suggestion is being acted upon.

The initial idea which starts the game is typically a quick suggestion, rather than a complete plan. It serves to focus the conversation and thought onto the same

issues. We can identify this opening move when a student makes a statement that begins with, “What if we did...” or “Let’s try...” This is how one signals to the group that one wants to play this particular game.

We can tell that this game is an example of “locally coherent behavior” not just by the actions engaged in, but by those actions excluded from the activity. When a round of Evaluative and Concretizing Plan-Making begins, the game includes discussion about the idea put forth. Statements that are not concerned with the idea in play are interpreted by the other group members as moves to end the game. If these statements are not ignored, they initiate another round of the game focusing on another idea, or signal the end of the game.

There are three classes of moves appropriate for this game. The first is labeled on Figure 9 as “Expand the approach.” These are moves that, in general, add to the idea in play. This would include fleshing the idea out and adding detail to it. The second class of moves is labeled “Concretize with the physical materials.” These moves are attempts to make the idea realistic by applying it to the materials they have available. The importance of this class of moves is most obvious when a group *isn’t* considering how to practically apply their idea. Concretization suggests an implicit goal that the plan they are working towards cannot be merely a theoretical solution to the problem, but it must be physically realized. The third class of moves is labeled “Evaluate the approach.” Evaluating involves testing the idea against the group’s sense of what constitutes a good, complete plan. Examples of this kind of move would be questioning whether or not the plan is doable, realistic, or easy, or able to yield the data necessary for the assignment. The extent to which an idea is evaluated

varies from group to group, as does and the character of these evaluations. The evaluative moves also suggest a more subtle dimension to the intended goal of the game. The idea is to construct a plan that not only is physically realized, but satisfies certain standards the group members consider essential before moving to the next step or game.

The epistemic form of this game is the plan of the experiment. That which makes this game unique, however, are the features of this plan, specifically that it is a plan that both satisfies certain criteria as set by the group members and has been demonstrated with the physical materials as realistic. This plan is technically not a complete and detailed plan of an experiment, since the students frequently follow up this game with further tests, such as appealing to the lab instructor for approval or the physical implementation of the plan. We can think of a group's plan as having several levels of completeness, and within *Evaluative and Concretizing Plan-Making*, the goal is to construct a plan that satisfies a certain collection of tests. In short, the idea must be complete enough, realistic enough, and devoid of problems to the extent that the group is ready to commit to the idea and move on to the next stage (and game).

#### *Two examples of Evaluative and Concretizing Plan-Making*

We can observe an instance of *Evaluative and Concretizing Plan-Making* in the following transcript of a group of students (labeled as "Group 1" in Appendix A) engaged in laboratory activity #5 (see Appendix B). The goal of this activity is to determine how the force between two magnets depends on the distance between them. The group has at its disposal a spring, a force probe, and various other

materials. Magnets are provided to the group after they check in with the instructor with a plan on how to proceed.

**Lab 5: Magnetic Force, Part One**

When you hold two magnets close to one another, they feel either an attraction or a repulsive force between them, depending on their orientation. It appears that the magnitude of this force depends on the distance between the two magnets. But how?

Question: How does the force between two magnets change if you change the distance between them?

Pre-lab discussion	Whole Class	10 minutes
Planning the experiment	Groups of 4	20 minutes
Data collection	Groups of 4	20 minutes
Class discussion	Whole Class	20 minutes
More data collection	Groups of 4	30 minutes
Writing the report	Groups of 4	10 minutes

Figure 11. SCL-2 “magnet lab”

In the following excerpts, the statements are coded to correspond to the boxes in the game diagram.

1	<p><b>BELINDA:</b> But if you can measure... if you can do the spring the first one, and then put a second one... and then you can look at how much the spring changes, the length of the spring, and come up with a force that way.</p>
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She is suggesting they attach one magnet to the spring and hold the other magnet a distance away, allowing the group to measure the displacement of the spring.

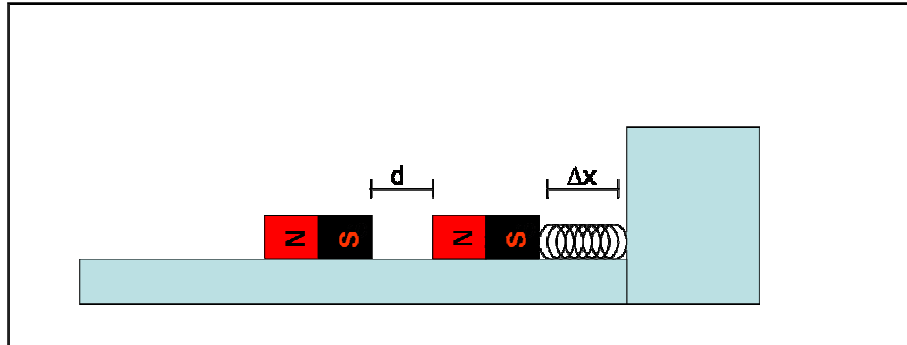


Figure 12. Idea setup

This is a novel approach that has not been discussed before by this group in the lab period. Her statement begins this round of Evaluative and Concretizing Plan-Making.

2	<b>DORIA:</b> And just say like, force is $X K$ .
4	<b>BELINDA:</b> But, yeah, cause $K$ is constant.
4?	<b>DORIA:</b> Right.
4	<b>ANGIE:</b> He said we're looking at relative <sup>7</sup> . So we don't have to know exactly what it is, we're just looking for relative.
2 or 1 3	<b>BELINDA:</b> So, force equals $\Delta K \dots \Delta C \dots K$ is going to be constant anyway, so and we're relatively speaking. Hook up your spring, and at the bottom you have a magnet. Then you hold the magnet at different lengths... away.. from whatever...
	<b>DORIA:</b> Whatever the change...
3	<b>BELINDA:</b> This'll be measured... oh no, this'll be measured.
	<b>DORIA:</b> Right.

Doria and Angie are now working within Belinda's idea-space. They explicitly

<sup>7</sup> This refers to an earlier comment by the lab instructor that they need only to determine functional dependence, not the absolute force value.

validate the idea (“Yeah”), add to the idea (“And just say like, force is  $K X$ ”), and describe the benefits of the idea (“So we don’t have to know exactly what it is, we’re just looking for relative.”) Belinda also takes the idea forward further.

3/4	<b>BELINDA:</b> The change in spring. How easy will that be though? We need a pretty pliable spring. Not something taut, cause if it’s real taut you won’t be able to see a difference.
	<b>DORIA:</b> Right. (Angie leaves)
3	<b>CONSUELA:</b> Are we going to hang it... hang it down...?
4	<b>BELINDA:</b> Yeah, I think it needs to be. Because the spring will... will have a bigger change when it’s hanging.
4	<b>DORIA:</b> But the magnet’s pretty heavy. We’re going to have to... we can’t have a too flimsy spring, because then it won’t have anywhere to go.
3	<b>BELINDA:</b> That’s the only thing... can we hang it from like... can we hang it from higher? Because, otherwise how are you going to...
3	<b>DORIA:</b> Suck. Well we need to feel how heavy the frickin’ magnets are.

Now the group is making attempts to concretize, or see how this idea will work with the actual equipment. They also are beginning to ask evaluative questions, such as “How easy will that be though?” and clarifying questions, such as “Can we hang it from higher?” and “Are we going to hang it... hang it down?” Notice that the group’s idea is going from a general abstract idea to a very specific, concrete one, as the members attempt to define precisely how it will be implemented.

<b>CONSUELA:</b> That’s what I mean.
<b>DORIA:</b> Are we not allowed to take it?
<b>CONSUELA:</b> We just need an idea, and then he’ll give us



the magnets, he said.
<b>ANGIE:</b> This one doesn't require a lot of force.
<b>DORIA:</b> Oh [TA]... can we have a magnet?
<b>BELINDA:</b> Well can we talk to him about our thing?
<b>DORIA:</b> Yes. It sucks. But I mean...
<b>BELINDA:</b> Oh yeah, we have a question...

Here the group is negotiating the end-game. According to the instructions of the lab, before the group is allowed to receive the magnets they need to present a plan to the lab instructor. Consuela articulates these terms to the group when she says, “We just need an idea, and then he’ll give us the magnets, he said.” This external constraint has shaped this group’s understanding of how one “wins” the Evaluative and Concretizing Plan-Making Game, or more specifically how developed the plan must be before their work at this stage is done. “We just need an idea” implies that the group has an understanding that their plan does not need to be a complete procedure. However, their moves within this game suggest a shared concept of just how developed it must be before they have an idea ready to present to the instructor. It must be fleshed out, concretized, doable, and not too difficult. These are the standards that define an idea that is good enough for them at this stage. In the next stage, the idea is brought before the instructor, who may have different standards by which to judge this idea. The tacit approval of the idea and the sentiment that it is ready to be sent to the next judge is evidence that this game has been “won.”

Another example of Evaluative and Concretizing Plan-Making can be seen in this clip of Group 2, also engaged in this magnet experiment. In this class, the magnets are available to the groups along with the rest of the equipment. However, a

check-in with the instructor is still required before they can proceed with data collection.

4	<b>DAPHNE:</b> So we need to think if this is going to work. I don't see why that wouldn't work. Cause what would be changing is like, make... we'd have this
3	magnet at this distance, this distance, and this distance, and measure how far it would...
4	<b>BONNIE:</b> What are we measuring exactly?
2	<b>DAPHNE:</b> If we change the distance then we're finding the force. I think what he said was, you have to vary one of the two... to figure it out. And I have no idea how you vary the force. I guess by changing the different magnets or something? You can't change the charge of the magnets. So if we measure the distance, then if this force is proportional to this force, then we're measuring the force.

Daphne is referring to an idea that they had been whispering about during the TA's instructions. The idea is to hold one magnet fixed and attach the other magnet to a spring. With this setup, they can vary and measure the distance between the two magnets. When she says "if this force is proportional to this force," she means that the force between the magnets is equal to the force applied to the spring. How they can measure the force on the spring has not been determined or discussed.

3	<b>CATHY:</b> So how would we get the spring first of all to lay like... straight?
2	<b>DAPHNE:</b> We can do it with the one we did last semester.
2	<b>CATHY:</b> And so we would measure how far it... like we would measure the distance of the spring at like...
2	<b>DAPHNE:</b> The change of the spring. The change in distance of the spring.
2	<b>CATHY:</b> All right. It's worth a try.
3	<b>DAPHNE:</b> We can try and see what... let me get the magnets.

3	<b>ASHLEY:</b> I'll get the spring.
3	<b>CATHY:</b> And maybe some silly putty too.

We know from the explicit instructions of the lab that an idea must satisfy the instructor in order for the group to take data, and therefore that an idea must satisfy the group's standards before it will be brought before the instructor. We can think of these as two levels of commitment to the idea. Here we can see a third level. The idea has been suggested by Daphne. Cathy makes an attempt to concretize the idea. Daphne appears to have an idea of how to measure the force. Cathy remarks that this idea is "worth a try," and the group members demonstrate agreement with this by going to get the specific materials. Apparently there is a level of approval they have reached on the idea so far, that it is worth investing the time and effort necessary to collect the materials, presumably so that they may further concretize the idea and determine whether it is doable, appropriate, and easy.

	<b>BONNIE:</b> Okay, I don't quite understand what we're doing. Which is not good, cause I'm the journal person.
2	<b>CATHY:</b> We have to measure both of these, though.
2	<b>BONNIE:</b> Right, but we vary one. Yeah, we have to find some way of measuring force based on the spring. I'm not sure how it works.
	<b>CATHY:</b> Ummm...
3	<b>BONNIE:</b> Those are strong magnets.
4	<b>CATHY:</b> See, I don't think they're so... look... like, I really don't think they're gonna... move a spring.
3	<b>BONNIE:</b> Yeah, once the distance...
3	<b>CATHY:</b> Cause, in order to get the...
3	<b>BONNIE:</b> The other thing is, there aren't going to be a lot of distances, cause one you get it like two inches away or so, it stops...
3	<b>CATHY:</b> Then I guess maybe it moves... So we would

	have to keep... we would have to keep one of them... in place, right? It would have to be like... that doesn't do anything... that doesn't do anything.
3	<b>BONNIE:</b> So we do the other side too, the attraction side ( <b>CATHY:</b> Yeah) So like, turn one around... see how close they can get to...
3	<b>CATHY:</b> It's gonna be really hard because... it's not gonna pull back... it's gonna get to a point and automatically it's just gonna go this way.
	<b>BONNIE:</b> Yeah. So we I guess find this point, like, if you, can you hold it back so far... and it won't do anything...

In this dialogue, Bonnie admits to not understanding the idea in play, while Cathy does seem to understand it so far. At first, Cathy's moves generally describe or expand the idea ("We have to measure both of these, though."), while Bonnie's moves, at first requesting clarification, are generally evaluative ("The other thing is, there aren't going to be a lot of distances, cause one you get it like two inches away or so, it stops...") Eventually, however, Cathy starts making evaluative moves as well.

3	<b>DAPHNE:</b> See, the idea is you tape this on and hold it like... I guess we'd have to hold the other side of the spring fixed, wouldn't we?
	<b>BONNIE:</b> *laughs* That spring is...
3	<b>DAPHNE:</b> We wanted a stretchier one cause it's gonna be... it won't... if the spring isn't stretchy enough then these probably won't even come together.
	<b>BONNIE:</b> Oh, yeah, I know.
3	<b>DAPHNE:</b> But we have to hold this side fixed, don't we?
	<b>BONNIE:</b> Yeah.

As the other groups return with the equipment, we see more attempts at concretization.

As in the previous example, this group is operating within a narrow idea-space representing the idea Daphne has put into play. What they do with this idea can be classified as pushing the idea forward through explanation and expansion, determining how to physically realize the idea, or evaluating the idea against certain standards. The game of Evaluative and Concretizing Plan-Making proceeds with these moves until either the idea satisfies the group, at which they can commit to this idea and move on to another activity, or the idea is abandoned. This is what we hoped they would be doing at this particular point in time: thinking about how an experiment produces a result.

### **Equation Bridging**

In general, the epistemic form that guides behavior through a complex activity such as a laboratory experiment, which requires the organization of many different ideas and actions, will be a plan of how to design the experiment and organize information. In general it will be a collection of things that the group is able to do, and a general understanding of how those things might lead to the goal of the experiment. In the previous game, students begin with a general idea, and proceed to build a detailed plan around it. It is a game by which the players attempt to navigate from what they know to what they need, and in the process, accumulate the list of actions and concepts necessary. But this is not the only approach available to the students.

*Equation Bridging* represents a method of solving a problem that is much simpler than Evaluative and Concretizing Plan-Making. In this game, the intended goal is to find a single equation that will yield the target quantity or quantities. It

suggests an expectation much like the “plug and chug” approach to problem-solving (Tuminaro, 2003), in which the goal of the exercise is to find that particular equation into which obvious things can be put in and the “answer” drops out. Unlike plug and chug, equation bridging includes experimentation as a source of information, rather than relying exclusively on what’s present within the equations. This equation is the epistemic form, an artifact that acts as a “bridge” between what the students already know or can determine easily and the target quantity.

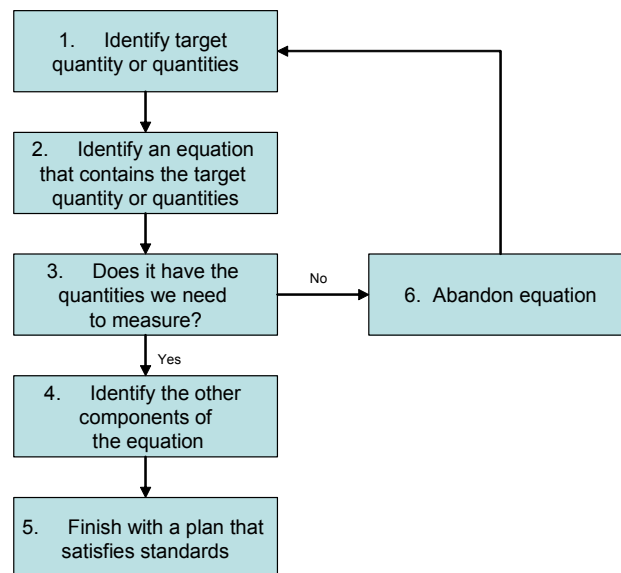


Figure 13. Schematic diagram of students’ moves with *Equation Bridging*

In order for this game to begin, the target quantity or quantities must be identified. Equations are then suggested on the grounds that they contain the target quantity, rather than how closely they seem to relate to what’s going on physically. “Getting” the target quantity, then, is a game of determining the other components of the equation. If they cannot be determined, or if the equation turns out to be inappropriate for the task, it is abandoned. In this event, the game is played again

with another equation until what they believe to be the correct equation is discovered, or until the game is abandoned.

*An example of Equation Bridging*

Here we see Group #1 playing Equation Bridging in the magnetic force experiment. This example occurs before the previous clip in which this group utilizes Concretizing and Evaluative Plan-Making.

	<b>BELINDA:</b> We can measure the area of the magnet.
	<b>DORIA:</b> But how do we measure...
	<b>BELINDA:</b> Pressure...
2	<b>ANGIE:</b> But it's not... pressure times area...
3	<b>CONSUELA:</b> It's magnetic force...
2	<b>BELINDA:</b> Oh yeah, it's $E Q$ .
3 2	<b>DORIA:</b> No, but that's electric. Force of a magnet is just $F$ equals $Q V B \sin \theta$ . There's no distance in it.
	<b>BELINDA:</b> Where are you coming up with that?
	<b>DORIA:</b> It's in the book. And it's in... haven't you learned it for MCATs yet?
	<b>BELINDA:</b> No.
	<b>DORIA:</b> Really?
	<b>BELINDA:</b> Really.
	<b>DORIA:</b> That's the hardest stuff.
	<b>CONSUELA:</b> Oh gosh.
	<b>BELINDA:</b> Hey when do you get your scores back?
	<b>CONSUELA:</b> I know, that's what you guys just said, and I was like oh yeah...
2 3 4	<b>BELINDA:</b> All right so $F$ equals $Q V B \sin \theta$ . What is this? Equal to $M V^2$ over $R$ . What's your $R$ ? Your radius?
3	<b>DORIA:</b> That's like the... because... well you see... not between two magnets. That's like... magnetic field caused by centripetal...
4	<b>BELINDA:</b> What is... what is $B$ ?
4	<b>DORIA:</b> $B$ is the field strength of the magnet.
	<b>BELINDA:</b> But how are we going to measure any of that?
	<b>DORIA:</b> Yeah, I know. So I don't know how it depends on distance.

<b>CONSUELA:</b>	How the hell are we supposed to do this?
<b>BELINDA:</b>	All right. If you like...
<b>DORIA:</b>	I feel like it should be the same as like...

This group has attempted this game with four separate equations:

1.  $F=PA$
2.  $F=Eq$
3.  $F=qvB \sin(\theta)$
4.  $F=(1/r) mv^2$

Angie suggests the first equation,  $F=PA$  (force equals pressure times area), and it is abandoned quickly on the grounds that the  $F$  in it doesn't apply to magnetic force. It seems to have been activated as a result of Belinda pointing out that it is possible to measure the area of the magnet. With force as the target quantity and area as an acquirable quantity, this equation, which had been used in a previous semester, is activated, and then quickly thrown out. This equation had been used in the previous semester, and the students quickly judge that it isn't the right *kind* of force.

Belinda proposes the second equation,  $F=Eq$  (force equals electric field times charge), which had been introduced recently in the course. It too is judged inappropriate on the grounds that it applies to "electric force" rather than "magnetic force."

The third equation,  $F=qvB \sin\theta$  (force equals charge times velocity times magnetic field times the sine of the angle between the velocity vector and the magnetic field vector), is suggested by Doria, who implies that she had discovered it through studying for the MCAT's, which are standardized tests that potential medical school students take during their junior year. I should point out again that this laboratory activity had been purposely assigned prior to the introduction of



magnetism in lecture. The students were intended to explore magnetic force phenomenologically, using prior physics knowledge and skills. The students were not expected to have any knowledge about magnetism at their disposal. Doria brings in this equation, which the other students are unfamiliar with, and it is accepted as valid, for the time being.

Belinda suggests the fourth equation,  $F=(1/r)mv^2$  (force equals mass times velocity squared divided by radius) seemingly as a response to the third equation. It is plausible that she is familiar with a problem in which a charged particle moves in a circle under the influence of a centripetal magnetic force (we will later examine games in which a problem is mapped onto a previous problem.) Whether this is the case or not, this fourth equation is put on the table and the group members set up about trying to determine what the various components are and how they can be measured.

Compared to Evaluative and Concretizing Plan-Making, the rules of Equation Bridging are simple. The goal is to find an appropriate equation that transforms *knowns* (such as the area of the magnet) into the target quantity, which is unknown. One starts a round of this game through the suggestion of an equation, which at the very least must contain the target quantity. If the equation is appropriate, i.e. it gives them the “right kind” of target quantity, the equation stays in play. If the other components of the equation are known, or the methods by which they can be determined are known, the game is won. If the equation fails their test of appropriateness, or contains unknown variables, either the group abandons the equation and begins a round with a new equation, or the game itself is abandoned for

a different one, which is what we will see in the next section.

One hypothesis of what is going on here is that the equation bridge could be seen as “the answer;” that is, the students are still viewing the lab as trying to demonstrate a known result, and they are trying to decide what that result is. Since this result is given to them by authority, they tend to use authoritative resources rather than their own sense-making. Another, and more appropriate, equation that students might seek is an equation that would allow them to measure one of the two quantities they are trying to relate. Thus, “ $F=-kx$ ” in the previous discussion allowed them to see that measuring the stretch of a spring might permit them to infer the force that the second magnet was exerting on the first.

Unfortunately, the goal of this epistemic game is inappropriate for the activity. They are attempting to find an equation that essentially answers the lab question for them, one that states the relationship between force and distance, while perhaps reducing the experimental goals to something trivial, like calculating a constant. The purpose of the lab, however, is to construct this relationship using experimental data. Even if this game were won, the most it would do for them is give them a theoretical answer that they could work towards. It would not avoid the necessity of designing an experiment. It is plausible that the students may have been playing this game in order to determine the “right” answer before starting.

Equally damaging to the students in this instance is that Equation Bridging, as an epistemic game, excludes certain activities as viable moves. The knowledge base they are accessing is the equations that can be found in the textbook, the students’ notes, class materials, or from memory. They are *not* trying to make sense of the

relationship between distance and force by intuition or through sense-making. They are not, as in Concretizing and Evaluative Plan-Making, thinking about how an experiment might yield the information they need. A basic idea that students may come up with is, just by thinking about the magnets themselves, that the force must be the strongest when they are right next to each other and diminishingly smaller as they get further away. This obvious fact says quite a bit about what sort of equations might relate force and distance. But since the students are stuck in a well-defined game of brainstorming equations and manipulating them, they do not access the common sense ideas that would help them. It is the *goal* guiding the behavior, rather than the behavior itself, that is inappropriate. This supports the idea of using epistemic games to describe and explain what students are doing.

It should be noted that this is the same group that engaged in Evaluative and Concretizing Plan-Making earlier in this chapter. It is interesting to note that, although this group is capable of interpretive and sense-making moves, they are choosing not to do this here. This group's choice of games is discussed in more detail in chapter six.

Another example of Equation Bridging:

<b>CHUCK:</b> Wasn't force mass times velocity?
<b>BRANDON:</b> Mass times acceleration.
<b>ALLISON:</b> We can see when at.. like at what height it... flipped over.
<b>BRANDON:</b> That's good.
<b>ALLISON:</b> Like here, feel it. Where exactly... does it go over. And then for here... oops, sorry. For here, like, where... it comes out.
(enter Django with spring)
<b>BRANDON:</b> There's $K X$ squared. You just brought $K X$ squared to the table. Thanks.
<b>DJANGO:</b> Hooray, but we don't know the spring constant!

This group has identified force as the target quantity. Chuck recalls force being “mass times velocity” (a common error), and is corrected by Brandon. Now, they do not discuss how one might go about measuring acceleration. Rather, Allison, who is clearly not merely looking for relevant equations (and hence not participating in the game), distracts Brandon momentarily with a physically realizable idea. Then Django arrives with a heavy duty spring, causing Brandon to identify it as “K X squared.” It is possible that Brandon has recalled the equation of energy stored in a spring ( $E = kx^2$ ), but more likely, since they are looking for equations with force, that he has made another common error, thinking that  $F = kx^2$ . Django is quick to note that this equation contains an unknown (and perhaps unknowable) quantity,  $k$ , the spring constant. Brandon believes they do not need this piece of information. As far as he is concerned, this game is over.

### **Recursive Equation Bridging**

Equation Bridging is intended to be an easy solution to the problem of determining unknowns. Rarely in these labs will there be an activity for which thinking up the correct equation accomplishes a significant part of the task. They were designed to avoid such easy solutions. Nevertheless, a mathematical equation is frequently such a solution in standard homework assignments (see *Plug and Chug* in Tuminaro). While a single equation may not be the solution for the entire task, it frequently constitutes part of the solution, in conjunction with other equations, reasoning elements, and ideas.

Recursive Equation Bridging resembles Equation Bridging in many ways. As shown in Figure 13 below, the moves and move structures are nearly identical. One feature, however, is unique to Recursive Equation Bridging. In the event that an appropriate equation has been found but not all of the components of this equation, aside from the target quantity, are known, the possibility exists to continue the game by choosing a new target quantity, among the quantities which are unknown, and repeating the process.

The reason I classify this as a different game lies in the fact that it implies different intentions on the part of the players. Equation Bridging is intended as a one-step solution. Recursive Equation Bridging may require many steps, some sophisticated mathematical calculations, and a more complicated conceptual understanding of their solution. In Equation Bridging, the equation itself *is* the solution, while in Recursive Equation Bridging, the solution is an organization of different equations. The latter requires a much higher degree of active participation on the part of the players.

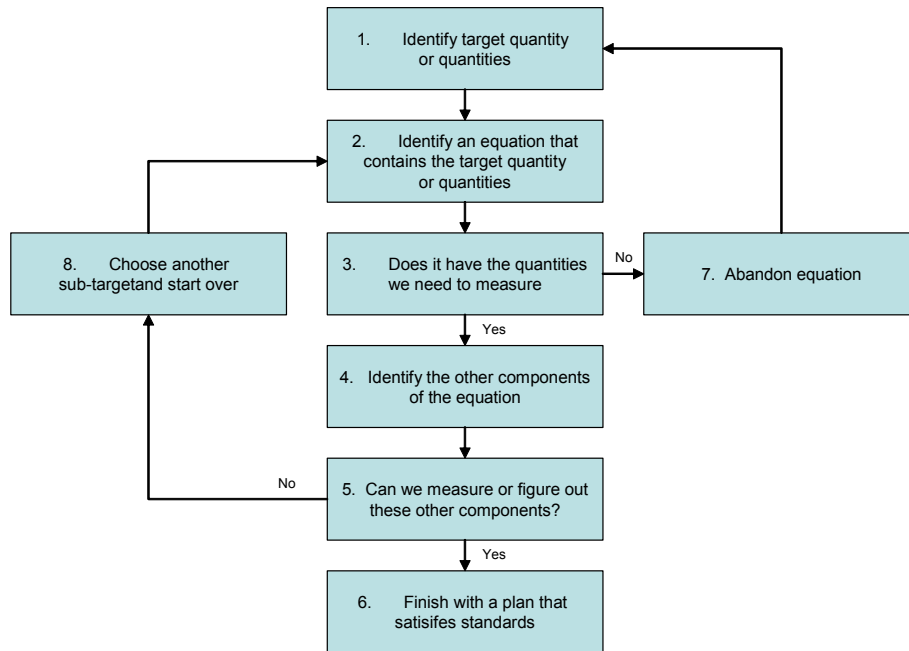


Figure 14. Schematic diagram of students' moves with *Recursive Equation Bridging*

*An example of Recursive Equation Bridging*

After four rounds of Equation Bridging, our Group #1 is going to make an attempt at Recursive Equation Bridging:

4	<b>DORIA:</b> B equals...
4	<b>BELINDA:</b> What is mu right there?
4	<b>DORIA:</b> Mu... is that thing... what is it called?! (slaps book) Mu is the permeability of free space, and we don't really have to know what it is.
5	<b>BELINDA:</b> Oh, so it's a constant.
5	<b>DORIA:</b> Right.
4	<b>BELINDA:</b> So good. So we know constant times what, current?
	<b>DORIA:</b> Yeah.
5	<b>BELINDA:</b> We don't know... how are we gonna measure current?! This is bad.

In a previous excerpt the group had identified F, or force, as the target quantity (see Figure 14 below, step 1). With Equation Bridging they were able to

relate  $F$  to other things by using the magnetic force equation in SI units (step 2). This being the fourth unsuccessful attempt to relate  $F$  to terms they can measure or know, they identify a new target quantity ( $B$ ) within that equation and attempt to play Recursive Equation Bridging (step 3), which yields the Biot-Savart Law. When they determine that this game has neither revealed  $F$  in terms of what they can measure or find out, the game ends unsuccessfully.

Goal: <b>Target quantity</b> = <i>In terms of quantities we know or can find out</i>	
1) Target quantity	$\mathbf{F} = ?$
2) Result of Equation Bridging	$\mathbf{F} = q v \mathbf{B} \sin(\theta)$
3) Result of Recursive Equation Bridging	$\mathbf{B} = \mu \mathbf{I}$
4) What was not determined	$\mathbf{I} = ?$

Figure 15. Two attempts to solve a problem using game strategies.

### Strategic Mapping

In the previous examples of games, students attempted to formulate an approach to a problem presented to them. They use both internal resources, such as memorized formulae and intuition, and external resources, such as textbooks, notes, and instructions from the TA. These games are similar in structure, the idea being to *build* a plan from an initial idea. Sometimes, however, it is not necessary to build a new plan when a plan previously encountered will suffice.

Tuminaro (ibid.) proposes a game entitled *Transliteration to Mathematics*. The theory behind this game is based on research on problem-solving that suggests students attempt to apply previously used techniques to a new problem, even without

a conceptual understanding of these techniques (Ben-Zeev, 1998). Indeed it is easy to recognize that a problem *looks like* something familiar based on shared features. The act of “transliterating” involves only the mapping of quantities from the current problem to the problem one is already familiar with, as opposed to “translating,” which involves consideration of meaning.

Students play a similar game in the laboratory that I call *Strategic Mapping*. This game has a structure that looks like the reverse of the games we have already discussed. Rather than building up a plan from small ideas and pieces, the structure of the plan is suggested as an initial idea, and this is borrowed from an example that the players have seen previously. As in previous games, the epistemic form is the plan itself. The game begins with the recognition of a target quantity, followed by a suggestion of a previous solution pattern. With this pattern as a guide, certain features of the plan are already assumed. If they have gone through a similar problem, at the very least they know that the mathematics and computational tasks are within their grasp. The goal is to successfully map the current problem onto the previous pattern. The moves within Strategic Mapping can be seen in Figure 15.



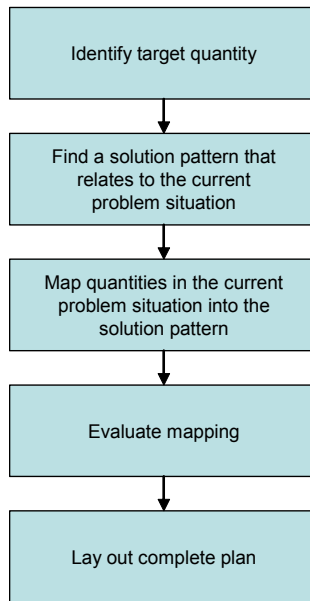


Figure 16. Schematic diagram of students' moves with *Strategic Mapping*

### *An example of Strategic Mapping*

Strategic Mapping can be extremely difficult to identify if the moves are not made explicit by the players. The feature of this game that differentiates it from other games is in the nature of the idea suggested. A student playing this game may not necessarily come out and say that the idea he has put in play is part of a solution pattern he has already dealt with. Unless the intentions are verbalized, one cannot be entirely certain that this is the case. Nevertheless, with enough understanding of the previous problems the students have dealt with, one can sometimes infer that this is the nature of the student's activity. In the following two examples, students suggest approaches that are strongly analogous to a homework problem that had been assigned recently. I posit that these students have this example in mind, and are actively trying to map the current problem onto this familiar example.

Two hard rubber spheres of mass  $\sim 10$  g are rubbed vigorously with fur on a dry day. They are then suspended from a rod with two insulating strings. They are observed to hang at equilibrium as shown in the figure on the right, which is drawn approximately to scale. Estimate the amount of charge that is found on each sphere.

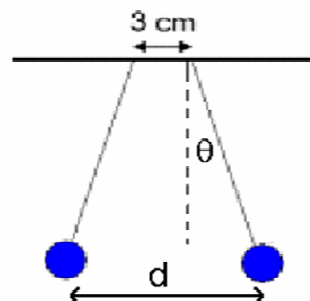


Figure 17: Previously used homework problem

The following is the solution to this problem presented by the course instructor:

Let's estimate that the charges we have placed on each sphere is the same and equal to  $Q$ . They might be different, but the spheres are identical and we presume we have rubbed them the same way, so they are likely to have similar charges. How can we figure out how big the charges are? Let's look first at the picture. The balls are not hanging straight down. Why not? Because there is an electric force between them pushing them outward. Presumably, the stronger the electric push, the farther out the balls would hang, so the angle must tell us something about the strength of the electric force. If we knew the electric force and if we knew the distance between the balls, we could calculate the electric charge from the electric force law,  $F = kQ^2/d^2$ . We can estimate the angles and the distance from looking at the figure. Therefore, our chain of reasoning is as follows.

- Figure out the angles and distances from looking at the picture.
- Figure out the magnitude of the electric force by using a free-body diagram and the condition that the force on each ball must balance.

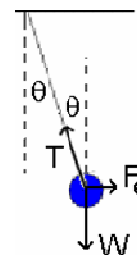
Figure out the magnitude of the charge from using Coulomb's law.

From the figure, we can estimate that the distance  $d$  is about 8 cm. This means that the sides of the triangle with the angle marked  $\theta$  are about 2.5 cm  $[= (8 \text{ cm} - 3 \text{ cm})/2]$  and 10 cm. (I did this by eye. Better estimates might be done by measuring with a ruler, but since we are only estimating — that is, we only want accuracy to one significant figure — this should be OK.) This gives us that  $\tan \theta = \text{opposite/adjacent} = 2.5/10 = 0.25$ . We can get the hypotenuse by the Pythagorean theorem to be

$$c = \sqrt{a^2 + b^2} = \sqrt{(2.5 \text{ cm})^2 + (10 \text{ cm})^2} = \sqrt{106.25} \text{ cm} = 10.3 \text{ cm}$$

From this we can get the sine and cosine of the angle as well ( $\sin = 2.5/10.3 = 0.24$  and  $\cos = 10/10.3 = 0.97$ ).

Now we need to create a free body diagram and balance the forces. This is shown in the figure at the right. We don't know either the tension nor the electric force, but by balancing the up forces against the down and the left forces against the right we get two equations for our two unknowns and can solve for everything. It works like this.



$$F_{up} = F_{down} \qquad F_{left} = F_{right}$$

$$T \cos \theta = mg \qquad T \sin \theta = F_e$$

$$T = \frac{mg}{\cos \theta}$$

$$F_e = T \sin \theta = mg \frac{\sin \theta}{\cos \theta} = mg \tan \theta$$

Since we know the mass of each sphere is  $10 \text{ g} = 0.01 \text{ kg}$ , the weight is  $W = mg = 0.1 \text{ kg} \times 10 \text{ N/kg} = 1 \text{ N}$ . The tangent of the angle is about 0.25 so our electric force must be about 0.25 N. Assuming both charges are equal to  $Q$ , we get

$$F_e = \frac{k_c Q^2}{d^2} \qquad Q^2 = \frac{d^2 F_e}{k_c} = \frac{(0.1 \text{ m})^2 0.25 \text{ N}}{9 \times 10^9 \text{ (N-m}^2\text{) / C}^2} \approx \frac{1}{4} \times 10^{-2-10} \frac{\text{N-m}^2}{(\text{N-m}^2) / \text{C}^2} = \frac{1}{4} \times 10^{-12} \text{ C}^2$$

Taking the square root, we get that the charge is about  $0.5 \mu\text{C}$ .

Figure 18: Solution to previously used homework problem

In this problem, the force between two charged objects is determined indirectly by observing the angles at which the strings hang. Students generally don't know how to measure force directly in the laboratory, however, measuring angles is straightforward.

In this clip, Group Three has been attempting to come up with ideas. A recurring problem for them has been the presence of friction. This is clearly an important part of this group's standards; several ideas have been dismissed so far due to their inability to eliminate the effects of friction. As you will see, a discussion about this topic leads to the suggestion of a setup that is extremely similar to the homework problem:

<b>ALLISON:</b> I think that... what we need to do is... mark a spot where one magnet is gonna start out at. And bring the other one closer...
<b>BRANDON:</b> What if you tape one to the thing...
<b>DJANGO:</b> We need something that...
<b>BRANDON:</b> Can't move.
<b>DJANGO:</b> No friction.
<b>BRANDON:</b> Space?! You want... space?
<b>CHUCK:</b> Let's ice the table over!
<b>DJANGO:</b> We should go to space...
<b>ALLISON:</b> We could... hang something... in the air. There's like... air friction, but that's not... if we hang them.
<b>DJANGO:</b> Yeah, like a... thing where they... like a pendulum kind of thing?
<b>CHUCK:</b> Yeah.
<b>DJANGO:</b> We need string! (leaves)
<b>ALLISON:</b> If we have like...
<b>BRANDON:</b> I don't understand this pendulum idea.
<b>ALLISON:</b> I'm trying to explain it to you now. It's so you have... two things like hanging, and then you bring them like... they're on a string, so there's no...
<b>BRANDON:</b> Oh, so M G will be the same on them.
<b>ALLISON:</b> What?
<b>BRANDON:</b> If they weigh the same, M G will be the same if they're both on the string... bring the strings closer together.
<b>ALLISON:</b> To weigh them?
<b>CHUCK:</b> Do we have anything to hang them to weigh them from though?
<b>BRANDON:</b> Bring the strings closer together.
<b>ALLISON:</b> To weigh them?
<b>CHUCK:</b> I mean, to hang them from.
<b>BRANDON:</b> We could make something.
<b>ALLISON:</b> Well, we'll make a little contraption.
<b>BRANDON:</b> We could make something using a box... cardboard box.

Allison's idea was immediately identified by Django and Chuck. Brandon seemed to understand the gist of it after a short discussion. Because there seems to be so much of an understanding of what this idea was about, in the absence of meaningful discussion of how it works and how it will yield the target quantity, is

evidence that this homework problem prototype is a shared concept within the group. It did not need to be mentioned explicitly. Since they know they have done this problem before (or have been responsible for it) they seem to accept that it is a valid approach. What they focus on, rather than details of the calculation, is how to simulate this previous example, i.e. how to map the present problem, with the materials they have at their disposal, onto this pattern, which is understood to be valid. Consider the lines:

<b>ALLISON:</b> We could... hang something... in the air. There's like... air friction, but that's not... if we hang them.
<b>DJANGO:</b> Yeah, like a... thing where they... like a pendulum kind of thing?
<b>CHUCK:</b> Yeah.

“Yeah, like a...” suggests that this reminded Django *of something else*. He has seen this before.

### **Exploration**

Some activities in the laboratory appear to lack the kind of structure seen in other games. Frequently a group will be observed playing around with the materials, without an apparent plan of action. However, this kind of behavior is far from random, even if an observer perceives it as being so. “Playing around” serves a very real and very important purpose: to aid in the brainstorming of ideas.

I propose *Exploration* as a game that describes activities contributing to the creation of ideas by investigating the features of the laboratory materials. While the group is not working from a blank slate (they may have some ideas about what long-

term strategies they can marshal), this activity is not narrowly focused on a single idea as other games are. Students frequently engage in this game when they realize they lack the know-how to engage in more complicated games devoted to constructing a plan. Without an understanding of how the materials behave, students cannot imagine what the equipment will do when subjected to certain conditions. They also lack the ability to concretize. Exploration helps to build this set of information.

The moves associated with Exploration are shown in Figure 18. Entry conditions are merely that the players have equipment to work with. Participants explore the equipment, point out its relevant features, and hold short discussions about these features. What ends this cycle of exploration is when an idea emerges and the players are ready for the minimum level of commitment that will drive this idea into another game. From here, the idea is “in play.”

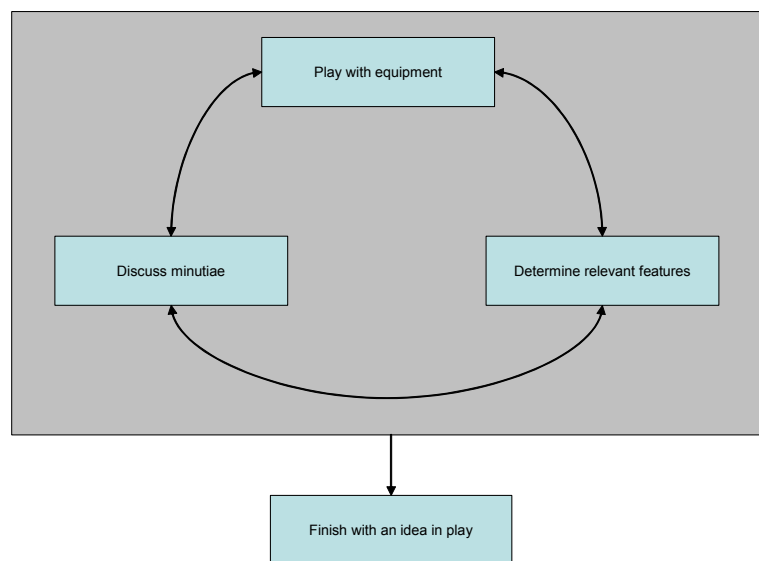


Figure 19: Schematic diagram of students' moves with *Exploration*

*An example of Exploration*

Here is a group at the very beginning of the lab period. As seen previously, they had an idea on how to proceed and acquired the magnets and materials. At some point, this previous idea was abandoned, and now they are engaged in Exploration:

<b>CATHY:</b> Then I guess maybe it moves... So we would have to keep... we would have to keep one of them... in place, right? It would have to be like... that doesn't do anything... that doesn't do anything.
<b>BONNIE:</b> So we do the other side too, the attraction side (CATHY: Yeah) So like, turn one around... see how close they can get to...
<b>CATHY:</b> It's gonna be really hard because... it's not gonna pull back... it's gonna get to a point and automatically it's just gonna go this way.
<b>BONNIE:</b> Yeah. So we I guess find this point, like, if you, can you hold it back so far... and it won't do anything...
<b>DAPHNE:</b> See, the idea is you tape this on and hold it like... I guess we'd have to hold the other side of the spring fixed, wouldn't we?
<b>BONNIE:</b> *laughs* That spring is...
<b>DAPHNE:</b> We wanted a stretchier one cause it's gonna be... it won't... if the spring isn't stretchy enough then these probably won't even come together.
<b>BONNIE:</b> Oh, yeah, I know.
<b>DAPHNE:</b> But we have to hold this side fixed, don't we?
<b>BONNIE:</b> Yeah.
<b>DAPHNE:</b> We can tape it to the paper...
<b>ASHLEY:</b> This is just trying out.
<b>BONNIE:</b> Idea number one.

As you can see, the previous idea of how to arrange the magnets and spring has not been abandoned; yet, they are not exclusively focused on it. The line, "This is just trying out" suggests the shared frame of understanding in this group. They are not committed to any idea. They are merely seeing what the materials can do. Their

discussion is not about the broad plan for acquiring the target quantity, but rather about details concerning the equipment: the stretchiness of the spring, the orientation of the magnets, etc.

Exploration differs from other games, particularly Evaluative and Concretizing Plan-Making, in the open-endedness of its goal. They are not working towards something specific. Rather, they engage in this game in the hopes that a goal will come to light in the process.

## **Discussion**

These five epistemic games describe the coherent activity observed in our reformed laboratory sections, which is to say, in a specific socio-cultural environment. They are by no means an exhaustive list of such activities. Just as Collins and Ferguson illustrate epistemic games observed in expert settings and Tuminaro illustrated those manifested in physics problem-solving, these games represent an arsenal of coherent skills used for particular activities. The purpose of laying out these games as such is to have a vocabulary with which to talk about coherent activity in this environment. A game, which typically lasts on the order of two or three minutes, will be our unit of analysis for the treatment in chapter six. In general we are concerned with what factors guide group behavior in the learning environment of labs. Now that we have a way of classifying this behavior, let us now examine how these games are played, what inspires their use, and what they can accomplish for the students.



## Chapter 5: Epistemic Games as Distributed Cognition

### Introduction

In the previous chapter, we examined how student activity can be parsed into segments of coherent, purposeful behavior known as epistemic games. There is a clear advantage to considering these games as a unit of analysis when describing individual student behavior; they give us a means by which to answer the question, “What is this student doing?” that says something about the purpose and the procedure of the activity. As we have seen, a *group* of students can also engage cooperatively in these epistemic games. Therefore, it is desirable to use a similar analysis to describe what is going on *within the group*, so that we might be able to answer the question, “What are these students doing *as a group*?”

In chapter four, epistemic games were introduced as cognitive activities, while in chapter two, cognition was presented as a process occurring within the nervous systems of individual human beings. Consequently, one may conclude that epistemic games are *individual* activities that take place in the human mind. However, in many of the examples shown previously, we see games being played by groups of individuals. Group game-playing is not merely several individuals all engaged in the same cognitive game. One can participate in a game without having an understanding of its goal, or without having been present at the initiation of the game. The cognitive labor can even be distributed among the individuals in a group so that a long-term game might be played without each individual being aware of all its components.

But how can this be, if epistemic games are cognitive activities that take place inside the nervous systems of individuals? How can we attribute cognitive properties to a network of individual nervous systems? For many researchers, the social character of cognition is so powerful that they are inclined to expand the domain of *cognition* to include social activity of all kinds. Such a radical paradigm shift may not be necessary for our purposes.

In this chapter, I will review Hutchins' (1995) concept of *distributed cognition*, which regards the cognition of social networks separately but analogously to the cognition of individuals, without denying the existence of or deemphasizing the importance of the latter. By using the concept of distributed cognition, I will attempt to expand the domain of epistemic games to include the group activities observed in our reformed labs, but at the same time acknowledge the fundamental distinction between cognitive action centered in the nervous system and social activity distributed across a network of individuals and including cultural influences and artifacts. Epistemic game-play is not necessarily an isolated individual cognitive activity. In the physics laboratory, it can also be a tool situated within a larger system, one which includes individual minds, group interaction, and physical equipment.

### **Situated Cognition**

Distributed cognition is one of several branches of the school of thought known collectively as *situated cognition* (Lave & Wenger, 1991; Lave, 1988; Brown & Duguid, 1992). The general claim of situated cognition is that cognition itself cannot be studied in isolation as a phenomenon bound by the human brain. Instead,

knowledge is *situated* within a specific socio-cultural environment. In order to understand how people engage in learning, sense-making, and other cognitive processes, one has to take into account social interaction, cultural artifacts, and other features of the outside world.

One can think of socio-cultural effects doing for educational psychology what friction does for physics. One can understand a great deal by studying a mind in isolation, however, when that mind is placed in the real world, the effects of friction are enough to drastically affect its properties. Rather than merely correcting previously existing theories with socio-cultural effects, researchers in this field place them at the center of attention, stressing that the knowledge is context-dependent, rather than universal. From the perspective of situated cognition, an introductory physics laboratory is a specific, unique socio-cultural environment, with a myriad of real-world complications that one might be tempted to ignore, such as social hierarchies, time constraints, and personal agendas. In order for a study to have “ecological validity,” or to reflect a real-life situation, these effects must be considered relevant features of the socio-cultural context.

### **Edwin Hutchins and Distributed Cognition**

Psychologist Edwin Hutchins, who was mentioned briefly in chapter two, founded the school of thought known as *distributed cognition*. This approach is Vygotskian in its attempt to emphasize the importance of the socio-cultural environment to cognition. Situated cognition attempts to reconcile the cognitive with the socio-cultural by asserting that knowledge can be distributed amongst individual

minds, interactions, and cultural artifacts in a way that this system can operate, in many ways, like a human mind, but with capabilities individual minds lack.

Like most advocates of the socio-cultural approach, Hutchins laments the trend in cognitive science to de-emphasize the importance of culture and the environment. “The computer was not made in the image of the person,” he says in his work *Cognition in the Wild*, “The computer was made in the image of the formal manipulations of abstract symbols. And the last 30 years of cognitive science can be seen as attempts to remake the person in the image of the computer.” (p. 363)

The field of artificial intelligence has indeed figured prominently in modern cognitive models. The metaphorical connection between the mind and the CPU is strong, and works both ways. Just as computer terminology is used generously to describe cognitive processes, researchers use computer programs to simulate cognitive models. D’Andrade (1995) demonstrates that the common thread in competing cognitive models is the concept of cognition as *computation*, or, the manipulation of symbols. Hutchins does not disagree with the premise that the human nervous system does indeed engage in computation. However, he points out that it does more than just that. Cognitive models deemphasize the importance of the *input*, the “stuff” upon which the nervous system computes. Unlike a computer, whose primary functions are generally pre-wired and can operate in isolation, the human mind requires constant contact with the so-called outside world, and while it comes pre-wired with a number of vital functions (like eating and breathing), more complicated functions, such as communication through language and mathematical skills, are learned through contact with socio-cultural influences. These functions are

what Vygotsky called “higher mental functions,” which are social in nature, rather than strictly genetic. These skills are not intuitive (though as Steven Pinker points out in *The Language Instinct* (1994), evolution has done a smashing job of preparing our bodies so that they can be easily adopted<sup>8</sup>), but rather internalized from our interactions with the outside world.

Rather than refute the concept of cognition as computation, Hutchins runs the ball the other way. If, he argues, we can describe a human nervous system as cognitive on the grounds that it can compute, why not expand our definition of “cognition” to include other systems that can also compute? He makes a strong biological argument for the loosening of this definition. There is no unitary entity in the human body to which we can attribute individual cognition. Cognition is made up of a massive network of neurons, from the mysterious matter in the brain to the sensory nerves criss-crossing the body. But where is the boundary that defines what this system *is* and *isn't*? Hutchins quotes Gregory Bateson (1972) to illustrate this problem:

*Suppose I am a blind man and I use a stick. I go tap, tap, tap. Where do I start? Is my mental system bounded at the handle of the stick? Is it bounded by the skin? Does it start halfway up the stick? But these are nonsense questions. The stick is a pathway along which transforms of difference are being transmitted. The way to delineate the system is to draw the limiting line in such a way that you do not cut any of these pathways in ways which leave things inexplicable.*

Unfortunately, this argument blurs a traditional line separating the science of the body from the science of the rest of the world. Perhaps this separation truly is

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<sup>8</sup> For example, vocal communication, and the physiological structures associated with it, evolved because it is a desirable trait. On the other hand, no human being will learn English (or any other language, for that matter) if raised in social isolation. The *physical ability* to speak is genetic, whereas the *cognitive ability* to speak a particular language depends on socio-cultural interaction.

made only out of convenience. I argue that there is still considerable merit to regarding the “mind” and the “environment” as separate, if only for the reason that the study of hands and the study of sticks require vastly different tools and models. Perhaps when this is no longer the case, we can disregard the boundary. Until that time, let us use it.

So why use the cognitive model to describe extra-corporeal events? Here is where Hutchins makes his strongest points. We in fact live in a world in which there exist networks of human beings engaged in joint computational tasks. Says Hutchins:

*Thus, a particular kind of social organization permits individuals to combine their efforts in ways that produces results...that could not be produced by any individual ...working alone. This kind of effect is ubiquitous in modern life, but it is largely invisible... The skeptical reader may wish to look around right now and see whether there is anything in the current environment that was not either produced or delivered to its present location by the cooperative efforts of individuals working in socially organized groups.*

The first half of *Cognition in the Wild* describes two such systems: the system of navigation aboard an amphibious helicopter transport in the United States Navy, and the system of navigation wielded by canoe sailors in a non-literate Micronesian society. As Hutchins explains, “in a computational sense, all systems of navigation answer the question, ‘Where am I?’ in fundamentally the same way.” As individuals, we engage in this computation continuously. The brain is pre-wired to be able to assess its own position by considering the direction of and distance to familiar objects. Navigation crews are engaged in basically the same computation, only the computational process is *distributed* amongst a broad system.

A navigation crew consists of as many as a dozen men acting together to compute the ship's position. If we consider this computation to be a type of cognition, it is clear that it is not occurring strictly within the nervous system of any one individual. The cognitive process is distributed among many nervous systems. Also, a great deal of computation is being done by inanimate objects. For example, the chart from which the sailors work embodies information and facilitates computational processes. In theory, a human brain could store all the information that exists in a navigational chart, but why bother? One could, in theory, do all basic mathematics in our heads, but why bother? In this system, not only is cognition distributed amongst the human beings present, but amongst the cultural artifacts at the group's disposal.

A system of distributed cognition can engage in computations far more complicated than those done by individual brains in isolation. The idea of two people "putting their heads together" means more than doubling the computational power. Social-cultural interactions seem to give rise to a social "being" with outstanding computational power. Now we could, in theory, trace all the components of a system of distributed cognition back to biological cognitive processes. A navigational chart, for example, was constructed by combining many pieces of knowledge carried by individuals, just as language was compiled slowly by many contributors, all individual brains. But breaking down knowledge as a cultural artifact into its constituent pieces would be unnecessarily complicated, like studying the vibrations of individual atoms in order to understand which direction your car will go if you turn the steering wheel to the left.

A system of distributed cognition, as Hutchins describes it, consists of individual nervous systems (whose inner workings are complex and not entirely understood, but by no means ignorable), interactions between these individuals, the environment, and cultural artifacts, both abstract (like language and math) and concrete (like charts and compasses). The “cognition” engaged in by such a system is analogous to that engaged in by individual minds, though Hutchins takes care to point out how, for example, group memory and group learning can differ from individual memory and learning. I present an example in the quote from Otto von Bismarck: “Only fools learn from their mistakes. I’d rather learn from other people’s mistakes.” Through participation in a system of distributed cognition, von Bismarck might thus be able to expand his ability to learn from mistakes, just as he might make mistakes which benefit those around him. Though an individual acting in isolation might go through the slow process of learning by trial-and-error, Hutchins illustrates how mistakes made in the navigation environment frequently serve as learning experiences for the rest of the crew. Because of the spread of information, the system of distributed cognition is far more efficient at this type of “learning.”

### **The Lab Group as a System of Distributed Cognition**

The notion of distributed cognition perfectly describes the manifestation of epistemic games in the laboratory. These games can and are played by individuals. Tuminaro shows ample evidence of individuals engaged in these activities either in near isolation or by offloading some of the computational effort to a marker board or calculator. In chapter four, we saw that it is not so easily to distinguish between an individual playing a game and a game being played by a group. Also, as Bateson



pointed out, the line between what's going on in the head and what's going on with the tools we use is not so distinct either. It would, of course, be tremendously difficult to describe every group action we observe in the laboratory in terms of the individuals engaged and the cognitive processes that are obscured behind their skulls. On the other hand, the "group behavior", though admittedly composed of individual behavior, is relatively easy to observe. Let us use Hutchins' concept of distributed cognition to consider the *system* consisting of the students, their interactions, their tools, and their environment, and by doing so, talk about epistemic games as *both* individual cognitive processes *and* group activities engaged in by the system of distributed cognition.

It should not be too much of a stretch to regard a group as an entity. In fact, we subconsciously do this every time we remark, "this group knows how to use the oscilloscope" or "my class didn't understand Newton's third law." But rather than use a strictly social formulation for understanding group activity, as many Vygotskian researchers do, let's keep cognition in the nervous system and just consider them to be part of a larger, more complicated network of nervous systems, made up of living, breathing organisms which are our colleagues, and the long-dead organisms that contributed to the tools we use to communicate and make computations.

### **The Scientific Community as a System of Distributed Cognition**

Science itself is an example of a system of distributed cognition. We speak of the "scientific method" as a procedure that one can engage in; however, nobody really does science in isolation. At the very least, one uses cultural tools, such as language

and logic, to make observations and describe the world around us. We may draw upon the observations and descriptions made by others.

Professional scientists, in fact, are far from isolated. They use tools and techniques constructed by scientists before them, and produce information that will be used by others. Modern research groups consist of many scientists working together, each doing a part of a larger computational process, perhaps not even fully aware of every detail of the whole plan. By engaging in scientific research, whether one is aware of it or not, one is acting within an enormous system of human beings, a system which collects observations and processes them *almost like* a sentient being with extraordinary computational ability. Redish (1998) refers to the “culture of science”- the set of processes by which communities of scientists build a *community consensus knowledge base* or *community map*. This refers to the collection of information that is distributed throughout the minds of individuals and embodied in cultural artifacts. It is understood that the knowledge within individual brains exists in different quantities and forms, but that the collection of all minds is an emergent phenomenon that evolves and grows, much like an individual mind.

By now it is conventional wisdom that students are able to learn quite efficiently when they are acting in a group of peers. The right kinds of social environments, in which certain nervous systems cooperate with other nervous systems and the appropriate cultural artifacts, give rise to an emergent phenomenon that strongly resembles an individual cognitive system. The introductory physics laboratory is an environment in which we expect for students to work together in configurations that allow the groups to accomplish more than the sum of their parts.

We want for a lab group to function as a system of distributed cognition, not just as a collection of individuals. We want them to develop a community of interaction that plays a part in the process of doing science. And as part of this, we hope that these groups can play epistemic games, though somewhat differently than they might play them as individuals

It should be noted that the primary purpose of an introductory physics laboratory is *not* analogous to the primary purpose of a navigation team. The purpose of the latter is to determine where the ship is and where it is heading. The purpose of a laboratory group is *not* primarily to produce the experimental results, but to provide an environment in which the individual students can learn how to conduct experiments, and this includes having an understanding of the broad picture, something which an individual sailor may not have. Our lab groups differ from navigation groups in that the group-work is not an end in itself, but a means by which individual students can learn.

Individuals can engage in epistemic games. Systems of distributed cognition can also engage in epistemic games. Armed with this framework, let us now go back and reexamine the epistemic games as they occur in the laboratory, and observe the nature of these games when engaged in by a strong network of minds.

## **Chapter 6: How Epistemic Games are Played in the Laboratory**

### **Introduction**

I now have the tools to describe what groups of students are doing as they try to design and analyze their experiments in lab. I give examples in chapter four to show that students engage in blocks of coherent activity describable as epistemic games. In chapter five, I use the perspective of distributed cognition to suggest that epistemic games may describe not just a cognitive activity of an individual, but also one engaged in by groups of individuals working with a shared understanding of procedure, and ideally, of purpose as well.

In this chapter, I present case studies of two lab groups. The first lab group works extremely well as a team, in that they communicate productively and share a general sense of purpose. In another way of speaking, they align their individual behaviors in a way that it makes sense to describe their activities as “group epistemic game-playing.” We will follow this group through a half hour of lab activity, identify the types of epistemic games and activities they engage in, and discuss the nature of these games, how they are initiated and negotiated among the group, and what these activities accomplish for the group.

The second group I observe does not appear to engage in these same kinds of activities, and consequently, is not able to progress through the activity the way the first group does. I examine this group and attempt to understand why this group cannot engage in gameplay, what sorts of social interaction are missing, and what social interactions perhaps hinder the ability of the group to work together effectively.

The goal of this analysis is to demonstrate what the students are *doing* in lab, and to distinguish between the components of productive activity and unproductive activity. Understanding the social interactions and individual actions that accompany productive teamwork will give allow us to make more informed judgments about what makes for a “good” lab group and what sorts of skills a poor lab group is not using.

### **Case Study: Group 1**

Group 1 was observed previously in chapter four, engaging in Equation Bridging and Recursive Equation Bridging. Here I examine this group in more detail. The magnetic force lab (shown in full in Appendix A) is a four-hour activity; I explore the first half hour of this activity. This is an interesting portion of the lab, since it is the time in which the group first apprehends the task, interprets the question they must answer, examines the materials available, and constructs a plan on how to proceed.

Shown below in Table 1 is a timetable for 22 minutes of this group.

Time	Transcript	Game Playing	Outside Interaction	Other	Off-task
0:00	1-4	Equation Bridging			
0:15					
0:30					
0:45					
1:00	1-27				
1:15					
1:30					
1:45			Discussion w/ student from another group		
2:00	2-3				
2:15			Assimilating		
2:30					
2:45					
3:00	2-25	Recursive Equation Bridging			
3:15					
3:30					
3:45					
4:00	2-40	Evaluative and Concretizing Plan-Making			
4:15					
4:30					
4:45					
5:00	3-15				
5:15					
5:30					
5:45					
6:00	3-33				
6:15					
6:30					
6:45				Logistics	
7:00	3-47	Evaluative and Concretizing Plan-Making			
7:15					
7:30					
7:45					
8:00	4-25				Off-task
8:15					
8:30					
8:45					
9:00	4-39		Discussion with other groups (offscreen)		
9:15					
9:30					
9:45					
10:00	4-43		Assimilating		
10:15					
10:30					
10:45					
11:00	5-16			Floundering	
11:15					
11:30					
11:45					
12:00	5-31	Evaluative and Concretizing Plan-Making			
12:15					
12:30					
12:45					
13:00	6-8	Evaluative and Concretizing Plan-Making			
13:15					
13:30					
13:45					
14:00	6-28				
14:15					
14:30					
14:45					
15:00	6-46			Equipment Logistics	
15:15					
15:30					
15:45					
16:00	7-15	Evaluative and Concretizing Plan-Making			
16:15					
16:30					
16:45					
17:00	7-42				
17:15					
17:30					
17:45					
18:00	8-14		Discussion with TA		
18:15					
18:30					
18:45					
19:00	8-45				
19:15					
19:30					
19:45					
20:00	9-13				
20:15					
20:30					
20:45					
21:00	9-37				
21:15					
21:30					
21:45					
22:00	10-12				
22:15					

Table 2. Timetable of student activity in Group 1, Experiment 6

The activity has been divided into four types:

- **Game Playing** – These are segments of activity that are described using the epistemic game terminology provided in chapter four. Each segment is labeled with the type of game being played. Notice that time blocks associated with a game generally range from one minute to five minutes.
- **Outside Interaction** – This includes discussions between the group and the lab instructor (labeled ‘TA’ in the transcripts) or between the group and other students (labeled ‘S’ in the transcripts). This also includes what is labeled as *assimilation*, or discussion that is specifically geared towards considering or making sense of what has just transpired in a discussion with the instructor or other students.
- **Other** – This category describes other activity that is outside the framework of epistemic games.
- **Off-task** – Even the best groups go through periods of discussion that seem to have nothing to do with the topic at hand.

The chart scales by time, so that one can see the relative lengths of each block.

I do not repeat large segments of text here in the chapter. The full transcript appears in Appendix B. The second column of Table 1 contains transcript references (e.g., 6-8 refers to page six, line eight).

### *Equation Bridging*

This game, which lasts about a minute and a half, was detailed in chapter four. The goal of equation bridging is to find an equation that “bridges” quantities that are known with the target quantity required for the lab activity, in this case, the magnetic force. The students are observed searching through the notes, the textbook, and their own memories for equations that contain the quantity  $F$ . When one is suggested, they determine if this is an appropriate equation (i.e. does it refer to *magnetic* force) and whether it can actually bridge the target quantity to known quantities. These are the *allowed moves* of the game. We see this game played from 1-4 to 1-38.

Of the four members of the group (Angie, Belinda, Consuela, and Doria, named alphabetically counter-clockwise from the front-left of the table, for those with access to video), we observe that at least three (Angie, Belinda, and Doria) are making moves characteristic of this epistemic game. They suggest equations and evaluate each others' equations when they are suggested. This is an excellent example of a *shared game*, shared in the sense that a majority of the members are aware of the basic structure of the game. The dialogue shows the students suggesting equations and then evaluating them in terms of whether or not it has the right ingredients, while the physical meaning of the equation is almost an afterthought. But the general structure of the game involves making suggestions, dissecting the equation, and evaluating it in terms of what it has and what it doesn't have. The students do little else. For example:

<b>BELINDA:</b> Pressure...
<b>ANGIE:</b> But it's not... pressure times area...
<b>CONSUELA:</b> It's magnetic force...
<b>BELINDA:</b> Oh yeah, it's $E Q$ .
<b>DORIA:</b> No, but that's electric. Force of a magnet is just $F$ equals $Q V B \sin \theta$ . There's no distance in it.

Because this group began playing this game before the hour started (and therefore before the camera began rolling), we unfortunately don't observe the initiation of this game. Furthermore, there is no explicit discussion of the purpose of this game, suggesting that either (a) the goal of the game was stated or alluded to before the start of this transcript, (b) the game had been played before and its goal is unspoken, or (c) the understanding of the purpose of this game is not shared among



all the group members. Explanations (a) and (b) seem most plausible; the fact that the dialogue is so focused towards the goal of finding the “right equation” makes (c) highly unlikely.

In this game we see a basic example of the group acting as a system of distributed cognition. Equation bridging is by no means being played entirely in the head of one individual. Moves are shared by at least three of the group members. Equations are suggested, evaluated, and discussed by several members. Plus, the knowledge base of this game, being the body of equations from which they are brainstorming, is not entirely located inside the head of one member, or even in the heads of the members of the group. Rather, some of this information exists in the textbook (a cultural artifact, written by physicists, encompassing information contributed for a large number of sources) and from the notes (a more localized cultural artifact, constructed by the students from the information assembled by the instructor of the course). Equation bridging, which seemed simple at a first glance, is actually quite complicated. It is being played by a distributed cognitive system, consisting of nervous systems and artifacts, but most importantly by the interactions between student and student, and between student and artifact. These interactions are the core elements of the epistemic game.

#### *Discussion with student*

This group’s game of equation bridging is interrupted by the entrance of a student from another group, who asks, “What’s acceleration? It’s like one half... delta X... the one formula... like I know acceleration is delta V over delta T but...” It is common in these labs for a group that is stuck to consult another group for help.

Partly in order to inspire this kind of interaction, the lab instructors are encouraged to be reluctant in giving away answers.

As observers, we lack the context to see how this question fits into what this other group is doing, and for that matter, the same is true of Group 1. It is not necessary for them to understand if this student has a particular epistemic game in mind. They have been asked a question and they know what kind of answer is being solicited. There is no evidence that Group 1 is aware of the purpose of this question. If this visiting student is playing an epistemic game, this exchange is evidence that one can participate in this game *without* an understanding of the purpose or procedure. Group 1 is *participating*, but not *playing*.

<b>BELINDA:</b> Oh V... It's $D = V_0 T + \frac{1}{2} A T^2$ .
<b>DORIA:</b> That one?
<b>S:</b> $D = V_0 T + \frac{1}{2} A T^2$ .
<b>BELINDA:</b> So like, you could get rid of, yeah, it's the V initial, so if V initial is zero you can get rid of that and $D = \frac{1}{2} A T^2$ .

This student draws our group into an activity, perhaps an epistemic game, and in doing so brings them into her system of distributed cognition.

This interaction lasts from 1-39 to 2-6. After the student leaves, Belinda goes off-task. However, Consuela is inspired by this interaction to consider the ideas brought to the table, in this block of activity labeled *Assimilation*:

<b>BELINDA:</b> I was at the gym yesterday, and all of a sudden like right here started... like touch it and it really hurts...
<b>CONSUELA:</b> What are they doing? They're doing the...

They're measuring the... that doesn't work though, right? They're measuring acceleration, but what is that gonna do? Force equals...
--

<b>BELINDA:</b> Well force is $A \dots$ force equals $M A$ .
--

<b>CONSUELA:</b> So they're using mass.
---

This activity could now lead directly into a new game inspired by the external interaction, but it doesn't do so right away.

### *Recursive Equation Bridging*

The next block of activity we have also discussed in chapter four. The group continues to discuss equations, playing a variation on the Equation Bridging game that we have defined as Recursive Equation Bridging. Unable to “make something happen” with just one equation, they now attempt to string equations together. In this game, the magnetic force equation and the Biot-Savart Law are combined in order to bridge magnetic force with known quantities. They are unable to do this, being left at the end of the game with  $I$ , the current, which they do not know how to measure.

These events suggest that there is a lack of conceptual underpinning here. Although the difficulty of measuring current is discussed, nobody seems to notice that such an equation must be inappropriate for the present situation, where there *is no current*<sup>9</sup>.

This is evidence that the students are not strongly applying their sense-making skills to this game. That useful skills are not used during this time period (particularly skills we can see them doing at other times) suggests that epistemic game-play is not merely the selection of certain skills, but the suppression of others. When there is an epistemological framing of a situation, the decision that “this game is about  $X$ ” unfortunately seems, in this instance, to also mean that “this game is not about *not X*”.

---

<sup>9</sup> The idea of an Amperian pseudo-current, which is discussed in some older texts, has not been considered in this class.

The upside of framing is that you don't have to consider everything at once; a downside of framing is that possibly useful components are left out of the frame.

Signs of frustration have begun to show, with Belinda's going off-task to talk about her day at the gym, and the following lines:

<b>CONSUELA:</b> How the hell are we supposed to do this?
<b>BELINDA:</b> We don't know... how are we gonna measure current?! This is bad.
<b>BELINDA:</b> But how are we going to measure any of that?
<b>DORIA:</b> Yeah, I know. So I don't know how it depends on distance.

These statements give more detail to the type of frame Belinda is in. Determining whether a component can be measured or not comes late in the Recursive Equation Bridging game. Belinda seems frustrated that they are led to consider equations based solely on whether they have  $F$  or not, only to determine later that the equation will not be helpful.

#### *Evaluative and Concretizing Plan-Making*

Until line 2-41, the group has appeared to act with at least a shared sense of procedure. But here there is a sudden shift in activity. Belinda suddenly has a burst of inspiration that seems to be cued by the interaction with the student from the other group. The issue of motion and the relation to force has been raised and now recognized:

<b>BELINDA:</b> That one. And then you could do $V_f$ squared equals $V_o$ squared plus $2 A D$ . But if you're ooooooh...!
---

What is this "oooooh" all about? Rather than following up with the assimilation, she appears to be suddenly inspired by another idea that has popped into her head:

**BELINDA:** What if we... okay... because if we're holding the magnets... like say we connect the one to a string... and we had them dangle \*gasp\* we had it dangle off this thing (motions to force probe).

**DORIA:** Can we look at that?

**BELINDA:** (brings force probe down) So, you tie up the string, right?

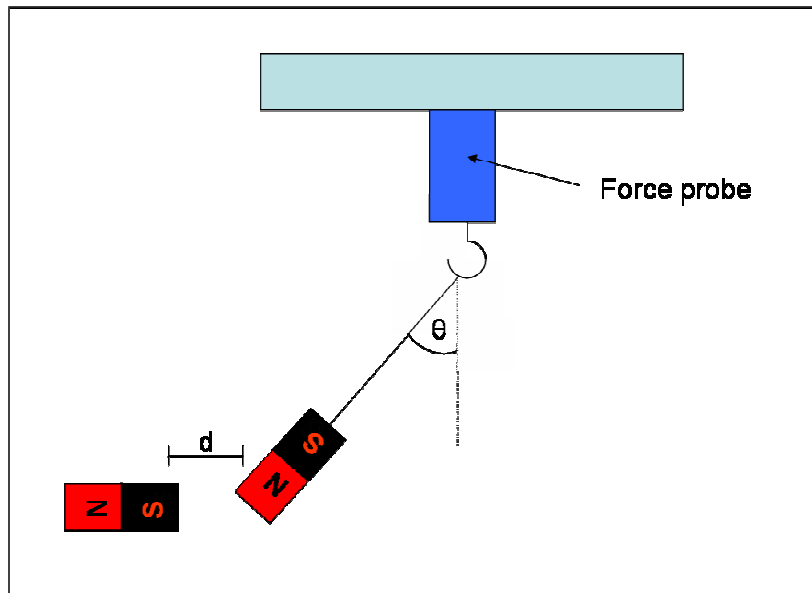


Figure 19. Belinda's idea

Suddenly everyone stops making moves associated with Equation Bridging and Recursive Equation Bridging. What ensues we have described as a round of Evaluative and Concretizing Plan-Making that lasts from 2-41 to 3-45, or almost three minutes.

What is interesting about this shift is the almost seamless transition the students make *as a group* from one type of coherent behavior to another. Doria and Consuela go along with Belinda and proceed to make moves that add to, evaluate, and concretize the idea Belinda has set forth. I posit four reasons for this:

- Mutual frustration with equation-related games they failed to win.

- Realization that a one-equation or multi-equation solution to the whole problem does not exist.
- Trust in Belinda as the dominant personality of the group.
- Familiarity with the game of Evaluative and Concretizing Plan-Making.

Notice that there is no meta-cognitive discussion associated with this shift. Nobody comes out and says that what they are currently doing isn't working. Belinda doesn't explicitly suggest that they try another method. But clearly there is a change of some sort. Suddenly everyone is discussing the materials and how to accommodate Belinda's idea concerning the possibility of hanging the magnet from a string connected to the motion detector, and bringing the other magnet up next to it. They are no longer discussing possible candidates for equations. Physical realization, long ignored, is suddenly in the forefront.

One possibility, based on examples seen in other groups and Belinda's sudden "oooooh" moment noted earlier, is that Belinda has recalled the pendulum homework problem (see Figure 16). Perhaps in her mind she is attempting to play the game of Strategic Mapping. Without an explicit statement, we cannot know for sure this is what she is doing. However, it raises an interesting possibility: that this group, while clearly playing Evaluative and Concretizing Plan-Making as a unit, may consist of individual members who have different interpretation of their goal. To Belinda, the goal might be to map this situation onto the homework problem, while to Doria and Consuela, the goal may be to construct a plan from scratch using this idea, which, for all they know, Belinda has made up on her own.

*Logistics*

Unfortunately, the group does not manage to construct a plan around Belinda's idea. From line 3-34 on, we see the shared activity start to break down. They have gotten stuck. Angie suggests another shift:

<b>ANGIE:</b> Who's the critic? Who's critic?
<b>BELINDA:</b> You are! You're evaluation. That's critic.
<b>CONSUELA:</b> Oh yeah.
<b>ANGIE:</b> Am I supposed to ask other people?
<b>BELINDA:</b> If you have...
<b>DORIA:</b> Umm..

Angie then leaves to go consult another group for ideas. This is explicitly stated as one of the tasks of the person taking this role (see Appendix B).

The statement, "Am I supposed to ask other people?" implies that this is not merely an idea that Angie has produced out of the blue. "Supposed to" implies that *this is something they do* whenever they reach points like this. The behavior of the other group members suggests that consulting another group is an accepted move.

This exchange is interesting because up until now we have been regarding the group as sharing an understanding of localized events. They appear to have a strong shared understanding of what moves are associated with each game, and sometimes it appears that they have a shared understanding of the activity's goal. Angie's move to consult other groups, however, suggests that there might also be a strategy-of-strategies that could be shared by the group members, or an idea of where to go next if one game or activity should fail.

### *Game Conflict*

From 4-6 to 4-25, Belinda attempts to revive the game of Evaluative and Concretizing Plan-Making. The group follows suit and attempts to flesh out her idea and realize it with the physical materials. But this too falls apart. At 4-26, Angie leaves to consult other groups, and Belinda goes off-topic again.

Here we can observe a bit of conflict regarding how to proceed. Angie believes that the next move should be to consult other groups. Doria, as evident in the video, is leafing through the textbook, commenting, “You know... this book just sucks. I don’t get it!” The fact that she is consulting what was previously the source of equations suggests that Doria is inclined to return to one of the equation-related games. Belinda, on the other hand, remarks, “I wanna look at materials,” and leaves the table. This suggests she is inclined to play Evaluative and Concretizing Plan-Making, which begins normally through the discovery of some feature of the materials. It is unclear what Consuela thinks.

What is going on here? This group seems perfectly capable of game-playing with a shared procedure with a few different games. And yet, there is clearly a difference in opinion on what needs to be done next. The group members appear to be framing the situation differently. For Angie, the key to progressing forward is figuring out what to do from another group. For Belinda, an idea will present itself by examining the materials. Doria is still convinced there’s a piece of the puzzle they need somewhere in the textbook or in the notes. Consequently, the group separates. Rather than working as a coherent unit, they become four individuals working in



isolation. We should not assume *a priori* that this is a bad thing. A divergence may be exactly what is needed here.

*Assimilation/Floundering*

Upon Angie's return in line 4-45, there is a brief discussion through which her experience is assimilated by the group. Angie points out that another group was going to measure the acceleration of a magnet as it is attracted towards the other one, but that it was decided it would be impossible to measure, it being such a small interval of time to measure.

Until line 5-23, the group doesn't seem to be working together as a single unit at all. Statements are all over the place:

<b>CONSUELA:</b> So using a spring would be too messy because of those...
<b>ANGIE:</b> Yeah, I think it would be, I think would complicate it too much.
<b>CONSUELA:</b> How else are we supposed to like...
<b>BELINDA:</b> All I know is that we'll need a ruler of some sort. I came up with that.
<b>ANGIE:</b> All I know is that... we didn't have pre-lab discussion.
<b>BELINDA:</b> He said that we're gonna do a lot of thinking for this experiment.
<b>CONSUELA:</b> Can we at least have them... I feel like it would be easier... I want to see the magnets.
<b>BELINDA:</b> If we can control the distance...
<b>ANGIE:</b> They did give us the protractor.

Each group member seems to be thinking about something different. The conversation is unfocused and serves no observable purpose. And most importantly, it doesn't appear that anyone is really listening to anyone else. Ideas are mentioned, and rather than causing seamless transitions to coherent activity, they merely hang in

the air, only to get swept away by the next utterance. This is not students working as a group. The system of distributed cognition has temporarily disintegrated.

*Evaluative and Concretizing Plan-Making*

This dry period does not last very long. Angie makes the statement: “What if we did it this way?” and manipulates the materials. Her idea is to lay the magnets on the table and to attach one to the force probe. Suddenly the group springs into action as a unit again. They are once again playing Evaluative and Concretizing Plan-Making. Angie’s statement is understood by the group as an explicit initiation of this game. They are familiar with the activity.

Inspired by this return to a familiar game, Belinda, in line 6-9, tries to start another round of this game: “What if we measured... all right... we have the thing hanging and we held it out for like five centimeters... see how fast they come together.” Belinda wants to measure the time it takes for the magnets to snap together. The attention of the group is temporarily turned to this idea, which Angie and Doria proceed to dismiss on the grounds that it is not possible to measure this small of a time interval<sup>10</sup>.

What is interesting about this segment of video is that it demonstrates just how productive a group can be when everyone recognizes a familiar epistemic game. Just before Angie’s suggestion, the group was floundering with no shared sense of purpose or procedure, and accordingly, nothing was happening. Then, an explicit attempt is made by a group member to start a game everyone is familiar with, and suddenly there is genuine communication and the group can again be recognized as a

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<sup>10</sup> This would be hard to implement. Since the force varies over the distance that the magnet travels, it requires an integral over the unknown varying force.

single unit working within shared constraints. The video depicts a shift in attitude. They are doing the same things again, presumably with the same end-purpose in mind.

*An Idea in Play*

In line 6-16, Angie makes the following request:

**ANGIE:** Turn the box off and turn it back on.

The “box” she is referring to is the piece of hardware that interfaces the force probe equipment and the desktop computer. This equipment was used during tutorial sessions in the previous semester, so we can assume that the group members are familiar with what the force probe can do. Until line 6-45, the group attempts to get the force probe working. Something is wrong with the equipment (as you can see later on in the class hour, the wire just wasn’t plugged in all of the way, resulting in no input) and by line 6-41, they have given up trying to make it work on their own, and are calling the instructor over for assistance.

This group has *partial knowledge* of how the force probe works. Why does it not seem to bother them that they cannot get the equipment working? One possibility is that the group has the understanding that, in matters of technical detail, their system of distributed cognition includes the lab instructor. Though the instructors have been consistently denying the groups their participation in more theoretical matters, like working through the mathematics or thinking of an idea, they typically help out when a piece of equipment does not work, since it was not our intention to make students spend significant amounts of time trying to figure out what’s wrong with the equipment, the way we might force them to work out a kink in their idea, for

example. This is because the goal of the lab is to get them to think about how an experiment tells you something, not how to work particular equipment. It is interesting to note the sorts of things the students consider are appropriate to request assistance with. They have run into *many* problems in this lab already, but this is the first time they have asked the instructor for advice.

Also important to notice is that the moment Angie ordered Belinda to check out the box, the group begins to concretize almost exclusively. They run with Angie's suggestion. Belinda, being in front of the equipment, uses the equipment to show how the idea can be implemented. Not being able to understand how the box works, however, prevents them from going forward with the idea.

*Game-shift*

Something interesting happens in line 7-4. The group suddenly becomes extremely interested in a conversation going on across the room (which the camera, unfortunately, was not able to capture). Belinda, as evident in her facial expression in this line, thinks she has just witnessed something important. She immediately asks about Hooke's Law, demonstrating that she has observed a group using a spring rather than the force probe, and has perhaps seen the instructor validating this idea.

<b>BELINDA:</b> (oooh face)
<b>DORIA:</b> What?
<b>BELINDA:</b> What's Hooke's Law?
<b>DORIA:</b> Force equals negative $K X$ .
<b>BELINDA:</b> We probably wouldn't know the.. we wouldn't know the $K$ of the spring.
<b>DORIA:</b> Right.
<b>BELINDA:</b> But if you can measure... if you can do the spring first one, and then put a second one... and then you can look at how much the spring changes, the length

of the spring, and come up with a force that way.
<b>DORIA:</b> And just say like, force is $X K$ .
<b>BELINDA:</b> But, yeah, cause $K$ is constant.
<b>DORIA:</b> Right.

Belinda has proposed another round of Evaluative and Concretizing Plan-Making, with the idea of using a spring as a measurement of force (see Figure 11). Suddenly, the group is no longer discussing how to get the interface box to work, but rather, how to improve upon Belinda's idea. There was no explicit declaration that they were dropping the previous idea, though the frustration, due to not being able to get the interface box to work, was visible. The group, understanding perfectly well how to play this game, moves quickly into it. They play this game for nearly two minutes, with an emphasis on concretizing with the materials, until they decide to consult the instructor.

*Discussion with TA*

From line 8-13 to line 10-21, the group has a discussion with the lab instructor. Belinda, the group's consistent spokesperson, proceeds to describe the group's plan to him, which is to hang one magnet from a spring and to bring another magnet near it at different distances, and through the displacement of the spring, they can determine the force between the magnets:

<b>BELINDA:</b> Well, this is what our idea is thus far. So, we're thinking that, we hang the spring... it's right here... we hang the spring. And at the bottom of this would be our magnet. Then we would control the distance that... we would take another spring and like put it five centimeters... within ten centimeters, twenty-five centimeters, and at each different distance, we can
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measure the distance of the spring, how much it goes down. Because according to Hooke's Law, which is this, if we use the same spring, relatively speaking, we don't need to know the spring constant.

**ANGIE:** (?)

**BELINDA:** I don't know. So we don't need to know this. So we can kind of verify that the change in the spring distance as the one magnet on the bottom is attracted to the other one we hold up against it would kind of approximate the force between the two?

As for the constant that appears in Hooke's Law, Belinda sweeps this under the rug on the grounds that they are "relatively speaking." She suggests that the force of the magnet on the spring would "approximate" the force between the magnets. The instructor replies that it does more than approximate. That's what it is. Perhaps by "approximate", Belinda meant that what was measured would be proportional to the force they are looking for, not necessarily equal to it. In this case she would be correct. It would be very difficult for the instructor to understand this double-meaning, even if it was understood by the other group members, leading to a potentially damaging miscommunication.

The instructor tacitly approves of the idea so far, but raises the issue of how the group might change the distance between the magnets. This group's plan is the most common approach to this particular lab problem, though the biggest problem with it is the inability to find forces at several different distances, since many data points are necessary to see a relationship between the magnet and the force. The instructor, concerned about time constraints, tells them that another group has faced this problem already, and solved it by placing the pages of a book between the magnets, and then varying the number of pages used. The instructor made this

suggestion in order to encourage the group to use this method. The group understood it as a tacit approval.

*How the experiment pans out*

The group continues to run with the idea of measuring the force via Hooke's Law, but they reject the instructor's suggestion to use sheets of paper and, by the time the class discussion comes around, they have not been able to resolve this problem. This class discussion was conducted purposely to bring about the sharing of ideas, with the understanding that most groups did not yet have a complete plan on how to approach the experiment. This group listens to several plans, agrees that one in particular is a good approach, and then goes with that for the duration of the lab period. To see how this approach works out, see Appendix C.

*Long-term strategy of strategies*

In the first half hour of this laboratory activity, we see the group engaged in a three different epistemic games in the pursuit of their goal, namely Equation Bridging, Recursive Equation Bridging, and Evaluative and Concretizing Plan-Making. We have seen appeals to authority (textbook, notes, and instructor), appeals to peers (consulting other groups), the recall of previous information (homework problems), and sense-making (imagining what the magnets on strings will do). By examining these epistemic games, we can attempt to understand why the students chose certain games rather than others, and what may have guided the progression through these activities.

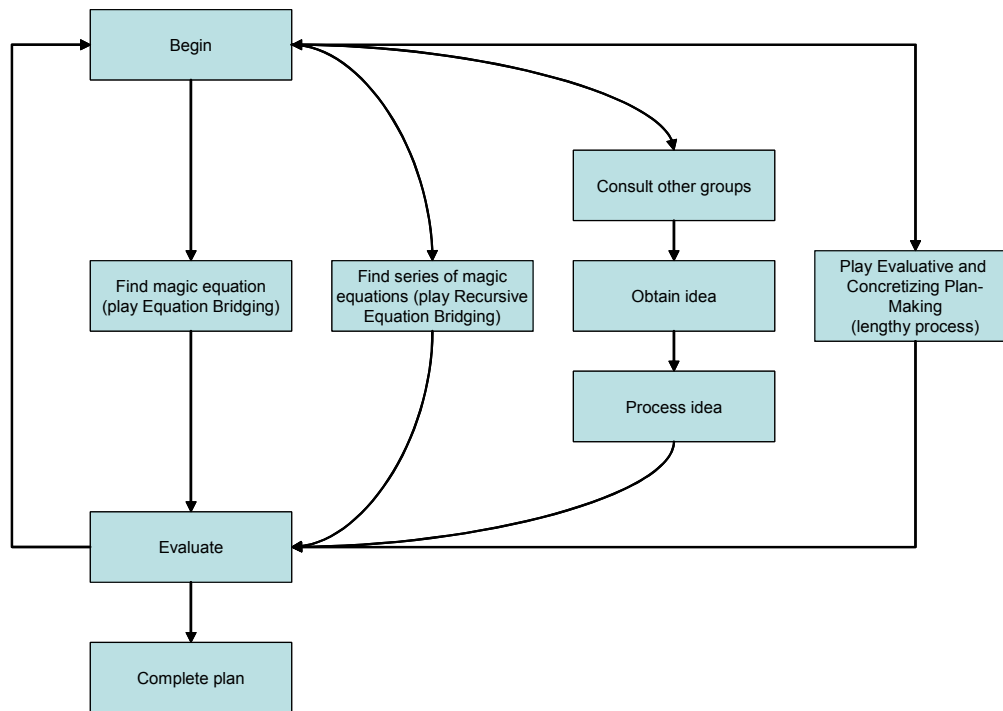


Figure 21. The evolution of group activity.

The activities that the students engage in, as shown in Figure 18 appear to increase in complexity over time. The first activity we see is the *Equation Bridging* epistemic game, the goal of which is to find one equation that connects what the students know with what they need to determine. Students engage in this activity frequently when doing homework problems, sometimes paradoxically spending hours on this simple activity, when a more complicated strategy (i.e. thinking about the problem) may take less time. Presumably that relevant equation, the key to everything, exists in the textbook, and finding it will be a quick one-step solution to the problem.

When Equation Bridging fails to produce the single equation they need, they then attempt to play Recursive Equation Bridging. This game involves more steps; one equation will not make everything fall into place. It involves a bit more



mathematical manipulation, but like Equation Bridging, will not require sense-making or any serious thought about the materials they will be using.

The attempts at Equation Bridging and Recursive Equation Bridging both failed to move the group further towards their goal. Angie then suggests that the next step ought to be to consult other groups. On one hand, this is still looking for an easy solution, in that it will be someone else providing the creative effort. But unlike the previous epistemic games, consulting another group requires these students to engage in sense-making, not just to understand what the other groups might be doing, but to evaluate whether or not it is an approach worth trying. We observed this group reject one idea they got from another group, and then abandon this activity altogether. This is one of the reasons the lab is designed to encourage this kind of activity, rather than providing them with an instructor-approved solution.

What next, now that no shortcuts have been found? Here is where the group begins to investigate the materials at their disposal so that they might play Evaluative and Concretizing Plan-Making. They start small, suggesting very basic ideas that will require a great deal of concretization and elaboration before they can become full-fledged experimental plans. Since this is a lengthy process, it makes sense that the group would take a gamble on the easy solutions before deciding to participate in this game.

The general pattern seen is that the students move from activities requiring few steps and little sense-making to those requiring more steps and more sense-making. A group that has many strategies at its disposal may choose to exploit the easier options first. Therefore, if a group is observed engaging in an unproductive

activity, it may mean they are taking a gamble that this approach will yield a quick solution, before going on to more sophisticated approaches. This is what I call the group's "strategy of strategies."

It should be noted that this strategy includes an "Evaluate" stage, in which the group evaluates the appropriateness and effectiveness of their method. This evaluation is not usually explicit, but we assume they have some reason for rejecting a method (which could be that they realize that they don't understand how to implement it.)

#### *Tuckman stage model analysis of Group 1*

The Tuckman model proposes that groups evolve by passing through four distinct stages: *forming*, *storming*, *norming*, and *performing*. Using this model, we can describe to first-order the general atmosphere of the group. However, there are two difficulties with this model: (1) the group appears to move in and out of phases within the course of this lab, rather than slow progressing linearly through each phase, and (2) the model tells us nothing specific about how the group is confronting the task at hand.

We could rightfully say that, for the most part, this group seems to be in the process of *performing*:

Finally, the group attains the fourth and final stage in which interpersonal structure becomes the tool of task activities. Roles become flexible and functional, and group energy is channeled into the task. Structural issues have been resolved, and structure can now become supportive of task performance. This stage can be labeled as *performing*. (Tuckman 1965, p. 78)

The roles given to the students are certainly now flexible. No student seems to be concerned exclusively with the tasks assigned to them, though they seem aware of

these tasks and comfortable with accomplishing them, whether they fall under their domain or not. Other non-spoken rules, such as leadership, also seem to have become flexible. Belinda remains the de facto spokesperson, but that doesn't stop other group members from taking the reins. And though Belinda does appear to take the lead quite often, the other members do so as well. For most of the laboratory, there seems to be little role-related conflict. The group seems quite capable of putting their skills together in the pursuit of a single task.

But then there is the period of time labeled "floundering" on the timeline. During this few minutes, the group cohesion breaks down. Each member has a different idea of what needs to be done at the moment. They do not discuss this divergence of opinion openly, nor do they agree to separate temporarily to pursue different objectives, as a *performing* group might be expected to do. Rather, they break off and do their own things. Following this is an unproductive conversation with each group member trying to get their ideas out, and simultaneously ignoring the others. From these few minutes, it seems more like they are storming:

The second point in the sequence is characterized by conflict and polarization around interpersonal issues, with concomitant emotional responding in the task sphere. These behaviors serve as resistance to group influence and task requirements and may be labeled as *storming*. (Tuckman 1965, p. 78)

It could be that the obvious frustration on the part of the group members may be due to the breakdown of group cohesion. What is certain, however, is that the group is not *performing*.

Tuckman's original stage model is insufficient to explain how the group, normally in a performing stage, would suddenly revert to storming for several minutes. At the very least, a nonlinear model would be required. But the fact that

this shift in group attitude took place on such a small time scale casts doubt on the practice of describing these behaviors as “stages.” Rather, it could be said that the group has the ability to respond to a task in any of the ways described by the model, and that it is the tasks they are confronted with, and the social negotiation used to determine how to behave, that really matters. For this reason, the framework of epistemic games is better equipped to deal with these short-lived modes than a traditional stage model.

### **Case Study: Group 3**

The previous example showed a group that engaged in a variety of activities and epistemic games. There were a few pitfalls and unproductive stretches, but in general there was a high level of coordination between the group members. They worked together, most of the time, as if with a shared sense of purpose of procedure. But this is not always how lab groups behave. Some groups fail to communicate in a way that activity can be well-coordinated. In this section, we will see another group (Group 3 in Appendix A) engaged in the SCL-2 magnet lab, and they do not engage in group epistemic game-play. Consequently, they do not progress towards a goal in the way we would hope they would.

In the opening moments of this lab, Allison shares an idea with the rest of the group:

<b>ALLISON:</b> All right. I was thinking... could we... have something in the middle, like... a paperclip or something, for instance? And measure, like the further... what?
<b>CHUCK:</b> I thought we were just doing two magnets.
<b>ALLISON:</b> We are doing two magnets but with the... like, with the distance it's going... to... what was I saying? I don't know, like, I feel like... you can feel the

force... oh, no, I'm wrong. Never mind.

Allison's first statement looks a lot like the kinds of statements that students in Group 1 use to initiate a round of Evaluative and Concretizing Plan-Making. She has an idea of a possible physical setup, and is putting it on the table for the other students' feedback. The rest of the group does not follow suit. Chuck's comment suggests that he doesn't comprehend what Allison is suggesting, or that he has framed their present task in a completely different way.

In Evaluative and Concretizing Plan-Making, the group would respond with clarifying questions to determine exactly what is being suggested, followed by an attempt to flesh out the idea into a plan. Instead, Chuck's question shuts down Allison. For reasons unarticulated, she abandons this idea. What kind of epistemic game she might have been playing within her own mind is impossible for us to determine from this transcript. However, the conversation suggests that there was no understanding in the group of *what kind* of activity was going on. Allison seems to think that it is the time for making new suggestions. Chuck seems to think they've already decided on a general approach.

Now that we have seen successful attempts at Evaluative and Concretizing Plan-Making, one can imagine where this comment might have led a group with that strategy. Had they shared the understanding that the goal is to take an idea and mold it into a plan by asking clarifying questions, adding pieces, and constantly evaluating it, they could very well have devised a plan from this idea, using paperclips to vary

the distance between the magnets<sup>11</sup>. However, the group does not share an understanding of purpose or procedure, so the comment falls on deaf ears.

After this exchange, Brandon suggests an idea that also fails to get the kind of productive response necessary:

<b>BRANDON:</b> I have an idea. We can put some kind of weight on the top of (them) and make 'em go in slow motion. It's harder, but then you'd have to know what the force of friction was.
<b>CHUCK:</b> No friction! (laughs)
<b>BRANDON:</b> Yeah. Why do you think that (?)
<b>ALLISON:</b> To see if...
<b>CHUCK:</b> Wasn't force mass times velocity?
<b>BRANDON:</b> Mass times acceleration.

Brandon's suggestion is that they put the two magnets on the table top and put some kind of weight on top of them so that, rather than snapping together quickly, they will go slowly enough to be able to measure the velocity or acceleration. In theory, this is a plausible suggestion, though in practice it would be hard to implement. A group playing Evaluative and Concretizing Plan-Making might run with this idea for some time, before discovering, through concretization, that doing this will not slow the magnets down nearly enough to allow for a reasonable measurement of velocity or acceleration. But this group will never find that out, because they do not respond as if this is a specific strategy for making a plan. Rather than talking about how the idea might be implemented, the other students respond almost conversationally.

In fact, Chuck's comment reveals a bit about his epistemological framing. "No friction" comes off as a shared private joke. In introductory physics courses,

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<sup>11</sup> This could, however, modify the force if the clips were magnetizable.

word problems are frequently presented in a way that the student is instructed to ignore secondary effects, such as wind resistance and friction. Consequently, “no friction” has become synonymous with the contrived world of ideal, hypothetical problem situations, having little to do with the real world. By mentioning this, Chuck reveals how he is framing the present activity: that they are trying to treat a real-world problem with a physics-world scenario and rules. It is very likely that the humor Chuck sees in this statement implies an inconsistency between the two views in his mind. At any rate, this idea is not pursued by the group.

<b>ALLISON:</b> We can see when at.. like at what height it... flipped over.
<b>BRANDON:</b> That's good.
<b>ALLISON:</b> Like here, feel it. Where exactly... does it go over. And then for here... oops, sorry. For here, like, where... it comes out.
<b>BRANDON:</b> There's $KX^2$ . You just brought $KX$ squared to the table. Thanks.
<b>DJANGO:</b> Hooray, but we don't know the spring constant!
<b>BRANDON:</b> We don't need to.
<b>ALLISON:</b> Is there any way to attach them to 'em?
<b>DJANGO:</b> Tape.
<b>BRANDON:</b> What's the idea?
<b>DJANGO:</b> I don't really know.
<b>BRANDON:</b> You just got the stuff. This is tough.
<b>DJANGO:</b> I know.
<b>ALLISON:</b> I think...
<b>CHUCK:</b> We're trying to answer the question, "how does the force between two magnets.
<b>DJANGO:</b> How about, this is attached to one side, and this is attached to another, and that magnet pulls it... till... there's not enough force... the spring...
<b>BRANDON:</b> You don't want...
<b>DJANGO:</b> Where's the other magnet?
<b>CHUCK:</b> "How does the magnetic FORCE between 'em depend on the distance?"
<b>DJANGO:</b> (?)
<b>ALLISON:</b> We could do... I don't think that we should use the springs.
<b>BRANDON:</b> Springs don't make sense right now.

**CHUCK:** "How does the magnetic force BETWEEN two magnets depend on the distance BETWEEN them?"

We can see that there is a basic shared understanding that, at the present moment, it is appropriate to make suggestions; they are essentially starting from scratch. Allison puts forth another idea. She holds one magnet up on its side and brings the other magnet closer to it until the force is great enough to knock it over. This time, Brandon approves of the idea, though nobody seems to know what to do with it. It is possible that Allison herself is playing a game like Evaluative and Concretizing Plan-Making in her own mind. She wants to run with this idea, expand it, flesh it out, and concretize it with the materials. Or she could be engaging in Exploration, messing around until an idea surfaces. Without verbalization, it is hard to tell. The rest of the group does not do what she does, and their responses distract her. Without a common goal, they fail to communicate in a way necessary to use this idea, and rather than stick with it, they are distracted by another idea.

Django has been looking for equipment, which suggests that he frames this activity differently than Brandon. His purpose is to brainstorm ideas by considering the equipment one can use (or perhaps to play Exploration). When he brings over a spring, Brandon responds that Django has "just brought  $K X^2$  to the table." Neither Brandon nor Django understand "what's the idea." For the rest of this clip, each student seems to be doing his or her own thing. This is somewhat different from Group 1, which also went through a stage wherein each member went off to do her own thing. In Group 1's case, the members diverged for a few minutes, and



eventually came back together. For Group 3, this divergence is the rule, rather than the exception.

It was noted previously in chapter four that this was an instance of Equation Bridging. The group briefly considers three equations:

$$\begin{aligned}F &= mv \\F &= ma \\F &= kx^2\end{aligned}$$

And though two of these equations are incorrect, the group did not see a way of physically realizing these equations, and took the ideas no further.

These students are interacting in a way that does not allow for true cooperative group-work. Allison has several ideas, but they are not acted upon. Brandon is generally responsive to the ideas of others, but does not share their sense of purpose. Chuck seems to purposely impede any progress they might make through his quips. Django seems to be content with the fact that he is the materials go-fer, and that other people will be responsible for the brain-work. This all would be fine if done for a short period of time (as we saw in Group 1), but in this case it goes on for a considerable chunk of the lab period. One could imagine different ways that a group might coordinate for these tasks. They might engage in Evaluative and Concretizing Plan-Making to deal with the ideas suggested by Allison and Brandon. Or they might engage in Exploration with the materials, as Django seems inclined to want to do. Either way, a coordinated team effort would accomplish more than the uncoordinated activity we see here. Without a shared sense of purpose, good and bad ideas alike are lost.

Later on, we see that the group continues to have trouble as a result of not being able to work with a common purpose:

<b>BRANDON:</b> I don't understand this pendulum idea.
<b>ALLISON:</b> I'm trying to explain it to you now. It's so you have... two things like hanging, and then you bring them like... they're on a string, so there's no...
<b>BRANDON:</b> Oh, so M G will be the same on them.
<b>ALLISON:</b> What?
<b>BRANDON:</b> If they weigh the same, M G will be the same if they're both on the string... bring the strings closer together.
<b>ALLISON:</b> To weigh them?
<b>CHUCK:</b> Do we have anything to hang them to weigh them from though?
<b>BRANDON:</b> Bring the strings closer together.
<b>ALLISON:</b> To weigh them?
<b>CHUCK:</b> I mean, to hang them from.
<b>BRANDON:</b> We could make something.
<b>ALLISON:</b> Well, we'll make a little contraption.
<b>BRANDON:</b> We could make something using a box... cardboard box.
<b>ALLISON:</b> So like...

The “pendulum idea” Brandon is referring to is the idea that they can hang both magnets from springs, thus eliminating surface friction. It is possible that Allison is trying to play something like Strategic Mapping by comparing the current situation to the homework problem discussed in chapter four. However, it is never articulated that this is the goal. And since the other group members are not in on this activity, even if it is an example of an epistemic game, it is not a shared game.

The group does not appear to have a shared understanding of what to do with this idea. Django, for example, continues to think about this activity in terms of getting materials. He hears the suggestion, and immediately runs off to get the string. Brandon is attempting to make sense of the suggestion in terms of the mathematics

involved: “If they weigh the same, M G will be the same if they’re both on the string...” This direction would be appropriate to take, since this idea is not yet in a form that it works out on paper. Chuck and Allison, unfortunately, are not discussing the math like Brandon is. They are more concerned with the physical implementation of the idea. Chuck asks, “Do we have anything to hang them, to weight them from though?” and then the rest of the group starts talking about how to design the actual apparatus.

In this example, we see that the group by no means has a shared goal. They seem to respond to each others’ comments as they come along, the conversation shifting every few lines, rather than focusing on a single strategy. There seems to be no understanding of what specifically they are doing and no concept of what is appropriate right now and what is considered “changing the subject” or “shifting the frame.”

Later on in the lab, this group does eventually develop a shared goal and coordination, but it takes a long time to happen. These clips were presented to demonstrate not that this group lacks the ability to work together, but that they accomplish little when they do not.

### *Tuckman stage model analysis of Group 3*

This group is more difficult to describe using Tuckman’s analysis. While Group 1 seemed to activate different stages in response to different contexts, Group 3 seems not even to follow a consistent stage for even a short amount of time. Instead, the lack of cohesion within the group has prevented these stages from manifesting at

all; each member appears to have a different idea of what is going on and how to operate within the group.

Take, for example, the issue of group leadership. At a first glance, Brandon seems to be the *de facto* leader of the group. Conversation is constantly directed towards him, as if for his approval. His statements lead to new conversations, in contrast to those made by Allison, which are frequently ignored or shot down. But Brandon does not seem to be making any particular effort to assume leadership. His leadership is more like Richmond & Striley's (1996) *inclusive* type, rather than *persuasive* or *threatening*, as can be seen by his attention to, and approval of, Allison's ideas. Though one can only speculate as to whether or not Brandon is aware of his status as team leader, if there was a period of *Forming*, during which his dominance was established, or a period of *storming*, in which his leadership was challenged, this is no longer going on, as far as Chuck and Django are concerned. Allison, however, is not in the same place. She makes obvious and numerous attempts to take over temporary leadership of the group. As far as leadership is concerned, Allison appears to be *storming*, while the rest of the group is beyond that stage.

So while Brandon seems comfortable with his leadership role, and while Allison *storms* by herself, Chuck and Django play out their own roles as well. Chuck consistently acts as a comic relief; Django understands that his duty is to be the materials gofer, a role that absolves him of any need to think. So while one hand, there are elements of their roles that seem well-established and recurring, the "structural issues" mentioned in Tuckman's analysis are far from resolved. If

Allison's comments are omitted from the transcript, this group appears to be Performing, albeit unproductively. Chuck, Django, and Brandon seem comfortable with their roles vis-à-vis each other. But throw Allison into the mix and there is role conflict and discord. This situation is not easily explained through the Tuckman model.

Group 3 illustrates further inadequacies of the stage model, which fails to accommodate a group wherein the members are acting non-uniformly. Epistemological framing, on the other hand, can describe this situation. There is a shared understanding between the male members of this group of what is the appropriate way to move forward, and Allison does not share this frame:

<b>ALLISON:</b> All right. I was thinking... could we... have something in the middle, like... a paperclip or something, for instance? And measure, like the further... what?
<b>CHUCK:</b> I thought we were just doing two magnets.
<b>ALLISON:</b> We are doing two magnets but with the... like, with the distance it's going... to... what was I saying? I don't know, like, I feel like... you can feel the force... oh, no, I'm wrong. Never mind.

We see here that the shared frame, so often an enabling tool, is in this case blocking a productive member from participating.

The Tuckman model also assumes that with the progression of a group through the four stages, the group's productivity increases. Group 3 is, in some ways, *performing* through flexible roles, however, rather than enabling them to efficiently tackle the task before them, it is hindering them by suppressing the challenges presented by Allison. But through epistemic games we can see that many locally-

coherent activities are in fact unproductive and undesirable. Performing, as in working together towards a common goal, is not always going to lead to productivity.

## **Discussion**

These two case studies demonstrate what a shared epistemological frame can do for a group – and what can result from the lack thereof. The chief difference between Group 1 and Group 3 is in the former’s ability to share an understanding of the purpose of their activity. When this sharing occurs, the students are able to cooperatively make use of a small range of skills in a manner that is tacitly (or even explicitly) understood.

Group 1 was capable of coming together in the pursuit of a number of locally-coherent epistemic games. Within their shared frame was an understanding of the purpose of their activity and the types of moves appropriate to this activity. Shifts from one epistemic game to another occurred typically without explicit vocal direction, suggesting that these games were well-understood within that group. We see that Group 1 engaged in a sequence of games that generally increased in complexity with respect to cognitive steps. It is appropriate, then, to regard this group as a functioning system of distributed cognition, in which manipulations of ideas are carried out jointly by the group, and not within the head of any one member. This is made possible through the shared epistemological framing of the group and the epistemic games they have developed.

Group 3 was generally unproductive, and as we could observe, many good ideas failed to bloom because of their inability to work together in the way that Group

1 did. We do not see structured games taking place, nor do we see evidence of a shared perception of the task. Instead, we see a group wherein each member operates without meaningful mutual interaction. This cannot be regarded as a system of distributed cognition; it is little more than the sum of its parts. And consequently, the group was incapable of handling the task set before them, which was intended to be completed by a functioning group, not by individuals.

## Chapter 7: Conclusion

### Overview

The goal of this study was to determine how students cooperatively take on tasks in the physics laboratory. By including the cognitive and the social perspective, I have approached this topic with a net broad enough to catch both the contributions of individual students and the emergent phenomena within the group itself. We have seen that groups of students can engage in structured, locally coherent cooperative activities that can be extremely productive in the construction of knowledge in the lab environment. We have also seen that groups can engage in these activities, and frequently switch between them, without stating explicitly what they are doing.

Chapter four presents epistemic games, which are a powerful tool for categorizing and analyzing cognitive behavior geared towards the building of knowledge. A great deal of what happens in the laboratory can be illustrated through the terminology of epistemic games, and five frequently occurring games are presented. In order to expand the concept of epistemic games to describe not just individual cognitive activities, but shared group activities, we present in chapter five the framework of distributed cognition, which allows individuals to play a part in a larger cognitive system that includes not just minds but interactions, social factors, and cultural artifacts. Thinking about a laboratory group as a large computational system consisting of interacting minds allows us to talk about epistemic game-play as a social phenomenon, as well as a cognitive phenomenon. Finally in chapter six we



see how the games are played in the laboratory and how successful game-play can assist a group's performance.

### **Research Findings**

Now that we have determined how to parse student activity, we can see student activity from a new vantage point. From this perspective, we can see the social dynamics that can lead to a shared epistemological frame and productive group work, as well as social dynamics that can hinder cooperation. We also gain some insight concerning what might be going on in a group that is not articulated by the students or obvious from an observer.

We have learned that students engage in locally coherent epistemic games, with specific goals and specific sets of behavior appropriate for them. Through studying video transcript, we see that these epistemic games typically last on the order of a few minutes, and can be played either by an individual or by a group of individuals. Though it is not necessary for each group member to be entirely aware of the end goal of the activity, a shared understanding of the appropriate moves leads to an emergent phenomenon analogous to the epistemic games an individual might play, only tremendously more effective.

Students who share an understanding of the epistemic games at their disposal are capable of a high level of productivity, as we have seen with Group 1. They can approach the laboratory task in several different ways, without having to engage in lengthy discussions *about* what they are doing. In general, the conversations we

observe in groups engaged in shared game-play are richer and more productive than those we observe in other groups.

As we have seen with Group 3, when a group does not engage in shared epistemic game-play, the students tend to work at cross-purposes. One can say that the group is only as productive as its most dominant member, who performs the cognitive labor on his or her own. This is not the kind of behavior we are seeking to promote.

We have seen that social interactions play an important role in the selection, negotiation, and carrying out of these epistemic games. Though detailed explanation is not necessary in order for a group to converge on an epistemic game, this occurrence requires a shared epistemological frame. It is necessary for the members to be able to understand what is going on when someone proposes a new game to play. Ignorance about what the other group members are doing will cause students to work as individuals, not as a unit.

Knowing that students engage in these games and understanding the nature of them can be helpful for a lab instructor. It is essential to know what sorts of strategies the lab groups might be attempting to use. Awareness of the existence of these strategies helps an instructor to answer the question “What are the students doing?” by observing certain verbal clues.

Finally, we have seen that it is useful to consider a laboratory group as a system of distributed cognition. Each student brings his or her own skills and ideas to the table, and a group that can communicate well will be able to function as a single computational unit that makes use of all of these resources. The virtues of teamwork

come about not just through the summation of individual skills, but through the emergence of group behavior irreducible to the sum of individual minds.

With these labs, our research group had intended to get the students thinking about a number of things. We wanted them to learn to make connections between the physical concepts they were learning in lecture and the experiments in lab designed to probe them. We also wanted them to think about experiments in terms of design, specifically, having goals, proposing ways to reach those goals, and evaluating their proposals on the basis of how well it would work (and incidentally for this study on how certain it allowed them to be of their results.) Understanding the extent to which these particular goals are achieved, and also what needs to be focused on to make them achieved more effectively and more often, requires the kind of analysis demonstrated in this thesis. Group epistemic games gives us a method of identifying the goals towards which the students are working and the strategies they are employing in the pursuit of these goals.

### **Suggestions for Future Research**

Our work is far from done. We have some tools with which we can make sense of group-work, and there is still more to be learned about epistemic game-play and distributed cognition. Hopefully the questions I raise here will be addressed in future research projects.

First of all, how do shared understandings develop? The path from four total strangers to one well-oiled laboratory group must be a rocky one, filled with trial-and-error. It would be helpful to make a lengthy case study of one group, starting with their first experience together, and tracing their progress throughout the year. Perhaps

there are definite moments where the group comes to an explicit understanding about what these strategies are and how to execute them. Or perhaps the evolution is unspoken and gradual.

Next, we would like to determine which of these epistemic games should be encouraged, and which (if any) are unproductive enough to be discouraged. It has been our stance throughout this work that there is a time and place for any of these strategies. What may be productive in one context might be unproductive in another. A dead-end strategy might bring to light some fact that inspires another strategy or completes a piece of another abandoned idea. Many researchers mentioned in this thesis insist on an optimal way for laboratory groups to act. From our perspective, however, groups need to negotiate their strategies on their own. The strategies that do not yield the answer can be just as important as those that do. Nevertheless, it would be to an instructor's advantage to know if there are strategies that do nothing but harm, and to be able to identify it and discourage it.

Further research might examine epistemic games in other contexts. The laboratory activities studied in this dissertation were designed with a specific pedagogical and research agenda. But there exist many reformed laboratories, tutorials, and classroom activities that also attempt to foster an increased level of group work. It would be enlightening to see what sorts of group epistemic games emerge in those environments, and how they relate to those found in this study. It would also be possible to examine non-academic work environments, such as a corporate office or a town hall meeting, and see what sorts of group strategies emerge.

## **Piano Quartet Redux**

We know instinctively that there is strength in numbers. I saw it in the eyes of the four young pianists, as they glanced at each other for encouragement, feedback, and signals. Comparing these faces to those of the terrified solo performers convinced me that something special was happening in the group that couldn't be done alone.

With this study, I set out to explore what makes a group different and what makes up this thing called "teamwork." Teachers know that students can learn a great deal from each other, and that teamwork, aside from being a means to an end, can be a powerful learning environment. Working together is not just about combining manpower. It is about learning how to interact with others, learning how other people think, and if you are lucky, learning more about yourself.

## **Chapter 8: Suggestions for Laboratory Instruction**

### **Introduction**

The things we have observed in these laboratories indicate that there is something unique about our reformed labs. Group learning may occur in other classes, but normally it is heavily guided. Students who are majoring in science will eventually get the chance to work in laboratory environments, but it will also be under the guidance of more experienced others. The SCL labs give students the opportunity during the school years to engage in mostly unguided scientific inquiry in a community of one's peers. It is intended to be a place where students can pick up some of the skills, both technical and social, necessary to do science.

During the four years in which my colleagues and I offered these labs, we have learned a great deal about how one can successfully implement major reforms to an ailing laboratory course. As I have demonstrated in this dissertation, it is indeed possible to create a laboratory environment in which students engage in meaningful discussions about physics, learn to work together as a team unit, and in doing so, tackle projects far larger in scope than those offered by traditional labs. In this chapter, I present details on our reform effort and suggestions for instructors who may wish to get involved in a similar reform project, based not only on what we see in our research, but on my own "teacher's instincts." These are conjectures and could serve as a framework for the development of future research.

## **Suggestions for Laboratory Reform**

As mentioned previously in chapter three, the reforms that led to the development of the scientific community laboratory sets were inspired by specific needs of our class population and specific perceived failings of our traditional laboratory curriculum. I do not claim in general that what has worked for us will work for all physics departments. However, we have learned enough about the reform process to be able to provide general advice about what may and may not work. It should also be noted that our reforms progressed primarily through trial-and-error. We had eight semesters and over a hundred different sections to work with, and we were able not only to make incremental changes at the beginning of each semester, but we had the control to be able to make changes during the semester as well. Our experience was full of noble failures and unexpected successes. In the end, however, we were satisfied with the result, and hope that our experience may help others in reforming their own labs.

### *Class population concerns*

There are many different ways to approach a laboratory section, just as there are many different topics to choose from. A guiding principle in any lab reform should be the specific needs of one's students. No one kind of lab is ideal for everyone, and the more relevant the labs are to the student population, the more effective they will be.

The target population for the scientific community labs was mainly pre-med students and biology majors. During our preliminary planning, we consulted with professors from the biology department and asked what sorts of laboratory skills they

would like their students to have. A chief concern of theirs was students not being able to understand the broad picture of experimental research. This is what first opened my eyes to the idea that perhaps traditional laboratories, in their attempt to provide simulations of real experimental work, were focusing on the minutiae and ignoring the substance of experimentation. Indeed, when students engage in a dozen “experiments,” but never have the opportunity to plan their own experiment or debate results with others, they run the risk of not understanding at all what scientists are really doing in the lab.

Deciding which components of experimentation should be simulated by the introductory lab, and which can be omitted, is important and should be done with an understanding of the needs of one’s student population. These needs can change from year to year. The last thing a lab reformer wants to do is design a lab whose skills may not be at all relevant for the students. Right now it is typical for biology majors, engineering majors, architecture majors, and pre-meds to take an introductory physics laboratory. It is a mistake to take a narrow viewpoint that the physics lab exists solely to teach about physics experimentation. Rather, it is an opportunity (sometimes a student’s only one) to learn about experimentation *per se*.

### *Significance of experiments*

Traditional laboratories typically deal with topics that have just recently been introduced in lecture. The idea is that, after the students learn the theory behind a concept, then they get a chance to *see* it. This makes a lot of sense from a teacher’s perspective, since it assists in the narrative flow of the course. However, this is entirely contrary to how research is done. If students are in the laboratory doing



nothing besides verifying something they have already been told is true, they are missing out on the act of building knowledge *based on observation*, which is the chief significance of doing an experiment. They must have the opportunity to explore topics without an *a priori* understanding of what the answer is.

This formula need not be followed. It can be reversed with positive results. The scientific community laboratories were designed specifically so that “the answer” of the experiment was not known in advance. This meant either giving them topics that were not specifically covered in lecture, or introducing topics in laboratory first and in lecture afterwards.

The merit to this latter approach is that the students are doing experiments for the same reason real scientists would do them. There is some phenomenon that they don't understand and the purpose of the experiment is to explore this phenomenon, make sense of it, and attempt to model it. This approach is far more representative of “real research” than the traditional way. Furthermore, it can change the narrative structure of the lecture in a positive way. When a new concept is introduced, the instructor can point out that the class has already explored it in the real world. The experience gives the students something concrete upon which to apply the more theoretical and mathematical components of the concept.

Tackling a topic first in laboratory gives the students the impression that what they are doing *means something*, that this is the activity by which the concepts in the textbook were built. Giving them the punch-line first and the joke second, as in traditional courses, robs the experiment of its deeper significance.

### *Difficulty level of experiments*

When considering the kind of laboratory activities to present, one must take care to aim for an appropriate level of difficulty. An experiment that is too difficult may cause widespread demoralization and the failure of students to *get* the purpose of the experiment, or it may result in one lab instructor having to do the experiment nine or ten times, resulting in nothing more than a lengthy demonstration. On the other hand, if laboratories are too easy, the students will be bored and will not find cause to engage in genuine discourse about what is going on. Ideally, one would seek activities that are well within the capabilities of the students, yet still present a genuine challenge.

At a first glance, the SCL labs seem to be quite difficult in terms of how much needs to be done within a small period of time. In just under four hours, a lab group must design an experiment, take data, formulate a conclusion, present results to their peers, evaluate the other students' experiments, and write up a lab report. Although we do not expect cutting-edge experimental techniques, the volume of work necessary to complete these labs is considerably higher than in a traditional lab, where the experiment is pre-designed and the instructions are provided. This is the chief reason we chose to give them labs spanning two weeks.

What makes these activities doable for the students is the enhanced productivity that results from social interaction. Students work in groups of four rather than in pairs. At the very least, physical and mental labor can be divided up amongst the members. But more importantly, having a larger group of students

significantly increases what the students can accomplish. It means a larger pool of ideas. It can mean the emergence of more sophisticated epistemic games.

In traditional laboratories, it is quite common for students, when confronted with a difficult activity, to run out of time. Lab instructors normally grant the students extra time to finish. This can have extremely bad effects on the students' expectations. If they know they'll be given the time necessary to finish, students will never consider the practical decision of how to design an experiment *with specific constraints*, time being one of them. We have found it desirable to keep to a strict timetable with the labs, and to continuously remind the students that it is preferable to go with a design that isn't "perfect" than to go with a design that cannot be finished within the time allotted. This is how real science research is done. Nobody is given infinite time and infinite resources to do an experiment. While it is desirable to do the best experiment one can, it is of utmost importance to do something realistic.

A good rule-of-thumb would be that students working together in larger teams can do considerably more than they would working in pairs. A laboratory designed should not be afraid to present the students with difficult tasks and lengthy assignments, so long as the students are assured that they are not being graded on an all-or-nothing basis.

#### *Negotiating reforms with the students*

Not all of the changes made to our labs were done between semesters; some were implemented incrementally during the semester in order to address specific problems that emerged. Some were accepted easily by the students, while others took

some effort to implement. But in general, we observed an interesting pattern over the semesters in the students' behavior as a result of the reforms.

Initially, the students were surprised at how difficult the laboratories seemed to be. Based on their previously laboratory experiences, they expected something entirely different. Being thrust into a new environment with unfamiliar rules can be distressing for students. It seemed that any radical change to the structure of the lab, even those which made the activities easier for the students, was initially met with fear and frustration. This phenomenon can be a major barrier for a serious course reformer. Student morale is important for an instructor, and widespread frustration can be construed as a failure, and perhaps discourage further attempts to reform and lead back to traditional ways that, while sometimes unproductive, the students are at least familiar with.

I do not suggest that a lab reformer ignore the plight of frustrated students. Quite the opposite in fact; nothing is more important to a curriculum reformer than honest feedback from the students. The challenge then, if one seeks to change the course in positive ways, is to negotiate these changes with the students.

First of all, it is desirable to be completely honest and up-front with the students about what is happening. Let them know that this laboratory is going to be different than those they are familiar with. This might be a challenge, since teachers have a tendency to exaggerate just how different things are going to be “with them.” Nevertheless, the students must be reassured constantly that it is okay to feel a little bit “lost” during the first few weeks of a new type of course. Secondly, do not be afraid to make your intentions clear to the students. If the underlying purpose of the

laboratory is to teach them how to deal with experimental error, remind them of this fact frequently. We published a “mission statement” (see Appendix B) in which the three main goals of the laboratory were stated explicitly for the lab instructor to point the students to in case the issue of “why are we doing this” is raised. Finally, from our experience, it took from three to five weeks for the students to get comfortable with our reformed labs. This may seem like a long time to suffer uncertainty (and we would love to figure out how to decrease this time), however, the patience pays off. The subsequent weeks of lab, after the students had grown accustomed to the new rules, were extremely productive. It doesn’t hurt to let the students know that it might take a little while to get comfortable with your reforms, but that, in the end, they might enjoy these new labs far more than the traditional ones.

### *Feedback*

The only thing worse than having students openly express hostility towards a reformed class is having them do it secretly. When trying out something new, it is vitally important to stay in touch with how the students think. In my experience, anonymous feedback, while potentially painful for the reformer, is the best method for assessing how the students are taking things. It helps for two reasons. First, if there is a widespread problem among the students with respect to the laboratory, one can rectify the problem before the students become frustrated to the point of not caring. Second, if the students get the impression that the designer of the labs genuinely cares about their opinion and will be responsive to their needs, they will be more willing to go along with the new setup. A laboratory reformer might find an

honest and forthcoming class of students to be a valuable resource for ideas on how to improve the course.

### **Suggestions for Laboratory Design**

Let us now take a look at some of the components of lab curriculum that one might decide to tinker with when designing or conducting a reformed lab.

#### *Equipment*

In a sense, the laboratory equipment is what makes a lab. It's what sets it apart from other courses. We found that in traditional labs, the *purpose* of the lab frequently seemed to be learning how to use specific equipment. One introductory lab sequence featured two labs in which the students mainly learned how to operate an oscilloscope. The actual physics being explored with the equipment was secondary. My general opinion is that laboratory can be an appropriate setting for the students to learn how to use lab equipment, but that the manipulation of these tools should in general take a backseat to the conceptual goal of the lab.

An example of this being an issue occurs in SCL-2. In this set of labs, the students are encouraged to use the Microsoft® Excel© spreadsheet for the tabulation and manipulation of data. This program was selected specifically because of its similarity to many of the more sophisticated data analysis programs typically used in biological research. A show of hands proved that about half of my class had had previous experience with the program. In each section, lab instructors made sure that no single group of four students was without an experienced Excel© user. We did not want the chief purpose of this lab to be learning how to use the features of this

program. However, we did deem it important for every student to have laboratory experience with a spreadsheet program. The SCL-2 labs included lab practicals in which included a test of basic spreadsheet proficiency.

In each experiment, use of the spreadsheet was encouraged. We introduce sophisticated equipment not for its own sake, but to make tasks easier for the students. If the equipment does indeed make a task easier, the students will choose to use it on their own, and that is exactly what we observed.

Our general policy was to allow students to use sophisticated equipment if and only if they had a reasonable understanding of how it worked. Most of the equipment at their disposal was hardware store junk, everyday objects with no fancy technological function. More complicated equipment, such as force probes and motion detectors, were allowed only after the students had learned how to use them in another part of the course. Regular laboratory time was never devoted to the teaching of new equipment; rather, it was intended for the students to work with what they understood, and to seek new equipment on their own.

What it is important to avoid is a situation where the students are “doing” without “understanding.” If, for example, students use a spreadsheet’s curve-fitting algorithm to construct a best-fit line, chances are they have no idea how this is being done. We required that our students be able to explain how things were done, and encouraged them to stick with what they understood, rather than using tools whose significance was not understood. If students become accustomed to using equipment they don’t truly understand, this shuts off their sense-making abilities, which we consider to be vitally important in doing laboratory work. From a design perspective,

any equipment that the students are allowed to use should be either within their abilities to understand or very near that. This means not providing them with black boxes, which they need only to press this button or that button to get results. The idea is to give them access to equipment that expands their cognitive abilities and doesn't do the thinking for them.

### *Architecture*

How the classroom is arranged can seriously affect student performance. Our traditional labs are typically arranged as in Figure 7, with the students arranged in rows. This arrangement is not ideal for communication between students. One might as the very least consider rearranging the classroom so that group members are facing each other. What you want is communication between the students, so that they might act together as a single unit. This cannot be done if they are not physically able to see each other and converse easily. The scientific community labs were conducted in a room arranged as in Figure 8, with groups of four. The seats were close enough together for students to be able to converse privately within a group, but close enough to other groups so that inter-group conversation could take place without anyone leaving their seat. We found this to be an excellent arrangement for maximum communication within and between groups.

### *Grouping*

In theory, a laboratory instructor has the ability to assign groups however one pleases. We considered many different ideas for how to arrange groups. For instance, it seemed like a good idea to create diverse lab groups by matching "A"



students with “D” students, separating friends, and mixing males with females. These noble intentions, however, were not executed for technical reasons. Gathering the necessary information to assign the groups for hundreds of students proved to be too difficult a task to be accomplished before the first lab. The students were allowed to form their own groups, as it is done in traditional labs.

This turned out to be a good way to group students. The most important factor in what makes a good group is how well they communicate. From my observation, students know better than the instructor who they might communicate best with, and will arrange themselves along those lines. I found that the best lab groups were those with members who had worked together before or were friends outside of class. Basically, it was students who already knew how to relate to each other who found it easiest to engage in sophisticated epistemic activities in the laboratory. Breaking these students up would force them to start all over in that respect.

An important issue facing any laboratory course designer is how one goes about arranging the students in the classroom in order to foster positive group-work. One is normally constrained by campus and department protocol when it comes to how many students total should make up a class, and possibly by other factors, both economical and social. Our particular conditions varied from semester to semester, and as a result we were able to observe a variety of arrangements to compare and contrast.

A team has to be of a size so that in most cases all students will be engaged with the work. Johnson & Johnson (1993) suggest groups of three or four. Our

preferred number of students to a group is four. A group of four has enough students to encompass a broad collection of ideas and enough hands to be able to multitask when an activity requires many different things to be done at once. Groups of three frequently had more trouble with the division of labor and finishing the lab on time. Also, groups of three tended towards social arrangements by which one student took control and called all the shots. In foursomes it was more likely to see temporary leadership, rather than permanent. Groups of five seemed to be as productive as groups of four, though not more, leading one to believe that some cognitive power is wasted in this arrangement. Indeed, it seemed that shy students were less likely to participate in groups of five. It is easier to fade into the background in a larger group.

This is not to say that students cannot be productive in other numbers. I have observed quite a few diligent trios and efficient quintets, but these were atypical. Groups of four appeared to maximize participation and give the groups enough manpower to tackle a complicated multi-step experiment. Furthermore, consider a traditional laboratory section consisting of twenty-four students working in pairs. Having twelve groups, each at a different point in the activity, makes it tremendously difficult for the instructor to keep tabs on each group. Cutting this down to six allows the instructor to work more closely with each group. He or she is able to spend five or ten minutes with a single group should the need arise.

### *Timing*

The scientific community laboratories (see Appendix B) provided a basic timeline for the students to follow. It is given not necessarily to dictate what the students do, but as scaffolding. We realize that students don't have a lot of

experience in designing their own projects, and that allotting time for activities within certain constraints may not come naturally to them. With the timeline, they have a general idea of how much time should be devoted to each activity. We find that students typically don't follow them closely, but nevertheless appreciate the fact that they exist. Perhaps knowing that one is "on schedule" is important for students emotionally.

If there is a certain time for something to be due, this should be adhered to strictly. If the instructor caves in whenever students need extra time, it will be no coincidence that they'll need extra time *every time*. Designing a project means recognizing and planning around time constraints. So though it may seem draconian, dealing with time constraints is an important lab skill for the students to develop.

### **General Suggestions for Laboratory Instruction**

Whether one is teaching a reformed lab or a traditional lab, one's role as a lab instructor is vital to student learning. However, what we have learned about how students behave in lab recommends instructor behavior that contradicts some conventional wisdom. Here are some suggestions that may improve one's performance in teaching labs.

#### *Facilitation rather than lecturing*

Is it important to take a step back and consider: what is the appropriate role of a lab instructor? Traditionally, the teaching assistants in charge of labs supplement the instructions in the lab manual with suggestions of their own on the blackboard. They make sure each lab group is making progress, and if they are not, they try to get

the group on the right track. A lab instructor can find himself *doing* a lot of a group's experiment for them if they happen to be running out of time or hung up on something they don't understand. And of course, the instruction is there to answer whatever questions the students have.

My general attitude towards this kind of teaching is negative. The students should *never* be given a task so complicated that it requires a teacher to step in and do some parts of it. Anything an instructor does, whether it's validating a student's idea or hooking up the equipment properly, takes away from the student the opportunity to learn for himself. How can a student learn to perform an experiment if an instructor is always there to give her ideas, help her out when she's stuck, fix mistakes, and evaluate the students' actions? It is absolutely desirable for the students to do all these things for themselves.

The general approach I have taken, both as a lab instructor and as a coordinator of laboratory teaching assistants, is to regard the teacher's role in the lab as a *facilitator*, rather than a teacher. This means backing off considerably. Any time a student seeks the help of an instructor, it means, in addition to not knowing how to proceed, that the student doesn't know *how to think about* how to proceed. The proper role of an instructor in this case is not to tell the students how to proceed but to point them in the right direction of how to think about how to proceed. This can mean using some version of the Socratic Method. A few well-placed questions can lead the students to doing what needs to be done, rather than the instructor doing it for them. In a sense, this too is an intervention that "does something" for the students, but ideally we want for the students to develop an "internalized instructor." By this I

mean that when the students grow accustomed to the instructor asking the same questions to them when they're stuck ("What are you doing?", "Why are you doing it" etc.) they begin asking these questions to themselves in anticipation of what they know the instructor would ask.

### *Encouragement of social interaction*

Students come to the laboratory armed with a number of cognitive resources that pertain to social interaction. What they may not have is a good idea of how to implement these skills in this new context. Ultimately, we want them to get comfortable working in their groups and interacting with others. How does an instructor encourage this kind of behavior?

I have found that in the first few weeks of the reformed lab, when students are still getting to know each other and get comfortable working together, they often aren't communicating sufficiently to be able to engage in the kind of sophisticated game-play that we see later on. A lab instructor can encourage this in many ways. When a student asks the instructor a question, the proper tactic might be to pose this question directly to the other group members. They need to see that through mutual participation they can solve many of the problems they run into without resorting to the instructor's aid. Some scaffolding is required to get them accustomed to asking each other questions, brainstorming together, and conducting meaningful conversations in general.

Equally useful is opening a group's eyes to the potential for other groups to help them. If a group is stuck, an instructor can point them towards another group that may have already solved their problem. For social reasons, the students may not

be comfortable with mingling in this way, so it behooves the instructor to remind them that this is perfectly appropriate behavior, and can help them considerably. It is far preferable for one group to make suggestions to another group, rather than for the instructor to provide these instructions, because typically students will not accept the word of their peers as gospel as readily as they do with the instructor. Some evaluation is required and a decision must be made whether or not to accept the advice. This requires a judgment, even if it is tacit. Through this kind of interaction, they begin to see the benefit to working within a social community.

### *Self-governing labs*

Through scaffolding and facilitating rather than direct intervention, an instructor will see groups becoming more and more capable of doing things for themselves, as they learn to properly marshal the skills of the individual members through appropriate social interaction. The better they get at this, the less they need an instructor for detailed guidance.

It is customary in scientific community labs for there to be a half-hour at the end of the lab where each group presents their data, and then the class engages in a discussing about the best way to do this experiment. Normally the presence of a lab instructor is required to get the discussion going. Students are naturally shy in lab. They aren't quick to criticize others, and they dislike receiving criticism. Most of the hard-hitting questions have to be made by the instructor. What I have noticed, though, is that when the attitude of facilitating is maintained, the students need the instructor for this role less and less. By the end of the semester, my classes were able to conduct these end-of-class discussions entirely on their own, without my

intervention. As their incentive, they had to write a section of the lab report based on what they learned from other groups. After many weeks of seeing what kind of behavior is appropriate during a class discussion, they are more than capable of engaging in this behavior by themselves. Critiquing the experiments of others ceases to be an emotionally charged action. Students are capable of doing these things by themselves, and it should be encouraged by the gradual withdrawal of help by the instructor.

*Being aware of epistemic game-play*

In this study, we see that students engage in coherent activities whose goal is to build knowledge as a group unit. An important feature of these epistemic games is that so much of what is going on is non-verbal. This can be very confusing for an instructor who is listening in on a group. It may not be easy to determine in a few minutes what the group is doing and what their goal is.

Instructors have a tendency to focus on correctness of specific activity, rather than on the character of activity and whether it can be expected by itself to produce a good result without need for intervention. Recognizing the existence of epistemic games is a good first step. When students are working together well, they may be engaged in a sophisticated activity that they might find it hard to articulate to you if you ask them what they're doing.

As we saw in chapter six, a group that is not making progress may be stuck in a particular game loop. Through lack of communication, they may not even realize that they are excluding certain reasoning strategies from their arsenal. An instructor can assist such a group by explicitly asking what the goal of their present behavior (if

any) is, or more generally, what it is they are doing. Bringing this subject out into the open may help both instructor and student realize where they are and how to move forward. By recognizing recurring epistemic games, such as Equation Bridging, an instructor can see what sorts of things group *aren't* doing when they *are* doing one thing, and perhaps, with a quick question, they might inspire a game shift.

## **Conclusion**

Through this study, we see the enormous potential for groups to tackle laboratory activities through sophisticated social interaction. An explicit goal of any attempt at laboratory reform can and should be to encourage and foster this kind of teamwork. Real science is conducted through social interaction, and students ought to be introduced to science through a community of their own. Learning how to work as a team is not easy for students. It can take several weeks, but it is worth the patience and effort.



## **Appendix A: Complete transcriptions**

Group One

1  
2  
3 **(0:00)**  
4 BELINDA: We can measure the area of the magnet.  
5 DORIA: But how do we measure...  
6 BELINDA: Pressure...  
7 ANGIE: But it's not... pressure times area...  
8 CONSUELA: It's magnetic force...  
9 BELINDA: Oh yeah, it's  $E Q$ .  
10 DORIA: No, but that's electric. Force of a magnet is  
11 just  $F$  equals  $Q V B \sin \theta$ . There's no distance in  
12 it.  
13 BELINDA: Where are you coming up with that?  
14 DORIA: It's in the book. And it's in... haven't you  
15 learned it for MCATs yet?  
16 BELINDA: No.  
17 DORIA: Really?  
18 BELINDA: Really.  
19 DORIA: That's the hardest stuff.  
20 CONSUELA: Oh gosh.  
21 BELINDA: Hey when do you get your scores back?  
22 CONSUELA: I know, that's what you guys just said, and I  
23 was like oh yeah...  
24 BELINDA: All right so  $F$  equals  $Q V B \sin \theta$ . What  
25 is this? Equal to  $M V^2$  over  $R$ . What's your  $R$ ?  
26 Your radius?  
27 **(1:00)**  
28 DORIA: That's like the... because... well you see... not  
29 between two magnets. That's like... magnetic field  
30 caused by centripetal...  
31 BELINDA: What is... what is  $B$ ?  
32 DORIA:  $B$  is the field strength of the magnet.  
33 BELINDA: But how are we going to measure any of that?  
34 DORIA: Yeah, I know. So I don't know how it depends on  
35 distance.  
36 CONSUELA: How the hell are we supposed to do this?  
37 BELINDA: All right. If you like...  
38 DORIA: I feel like it should be the same as like...  
39 (enter student from another group)  
40 S: What's acceleration? It's like one half...  $\Delta$   
41  $X$ ... the one formula... like I know acceleration is  $\Delta$   
42  $V$  over  $\Delta T$  but...  
43 BELINDA: Oh  $V$ ... It's  $D$  equals  $V$  oh  $T$  plus one half  $A T$   
44 squared.  
45 DORIA: That one?  
46 S:  $D$  equals  $V$  oh  $T$  plus one half  $A T$  squared.  
47 BELINDA: So like, you could get rid of, yeah, it's the  $V$

1 initial, so if  $V$  initial is zero you can get rid of that  
2 and  $D$  equals one half  $A T$  squared.  
3 **(2:00)**  
4 S: Okay.  
5 ANGIE: What is (un)  
6 (student leaves)  
7 BELINDA: I was at the gym yesterday, and all of a sudden  
8 like right here started... like touch it and it really  
9 hurts...  
10 CONSUELA: What are they doing? They're doing the...  
11 They're measuring the... that doesn't work though, right?  
12 They're measuring acceleration, but what is that gonna  
13 do? Force equals...  
14 BELINDA: Well force is  $A$ ... force equals  $M A$ .  
15 CONSUELA: So they're using mass.  
16 DORIA:  $B$  equals...  
17 BELINDA: What is  $\mu$  right there?  
18 DORIA:  $\mu$ ... is that thing... what is it called?!  
19 (slaps book)  $\mu$  is the permeability of free space, and  
20 we don't really have to know what it is.  
21 BELINDA: Oh, so it's a constant.  
22 DORIA: Right.  
23 BELINDA: So good. So we know constant times what,  
24 current?  
25 **(3:00)**  
26 DORIA: Yeah.  
27 BELINDA: We don't know... how are we gonna measure  
28 current?! This is bad.  
29 DORIA: No, this is just to... because the... as  $R$ , you  
30 know, increases,  $F$  decreases. And it should be a linear  
31 relationship.  
32 BELINDA: We have three equations for  $D$ . They are this.  
33 CONSUELA: We could do it that way.  
34 BELINDA: That one. And then you could do  $V_f$  squared  
35 equals  $V_o$  squared plus  $2 A D$ . But if you're ooooooh...!  
36 DORIA: Isn't it plus...  
37 BELINDA: Plus or minus... depends on like... um... this  
38 is used for like, projectile motion. So like the first  
39 half would be... add it and um...  
40 **(4:00)**  
41 BELINDA: What if we... okay... because if we're holding  
42 the magnets... like say we connect the one to a string...  
43 and we had them dangle \*gasp\* we had it dangle off this  
44 thing (motions to force probe).  
45 DORIA: Can we look at that?  
46 BELINDA: (brings force probe down) So, you tie up the  
47 string, right?

1 DORIA: What is that?  
2 BELINDA: It measures the force... of the thing pulling  
3 down on it.  
4 DORIA: Okay.  
5 BELINDA: So you put a string and you... put your weight  
6 on it... I mean your magnet. You tie on the magnet  
7 somehow. Okay? And then, we take the magnet and we'll  
8 just move in... however much...  
9 DORIA: Will it measure that? Or will it measure...  
10 BELINDA: You can measure distance, you can also  
11 measure... well won't it have a less pull, like, hanging  
12 straight will have some weight... if it moves out, you'll  
13 have some weight, M G. If it moves out, we can measure  
14 this, we can find the weight in this direction.  
15 **(5:00)**  
16 DORIA: Can't we just put it below so that we don't have  
17 to measure angles and see how much it stretches? Well  
18 that doesn't really stretch, no that doesn't stretch at  
19 all.  
20 BELINDA: Unless you use a spring.  
21 CONSUELA: Spring.  
22 BELINDA: But I don't think a magnet has enough... do you  
23 think it has enough force to pull a spring? But then  
24 you're dealing with Hooke's Law and stuff.  
25 DORIA: Yeah.  
26 BELINDA: I was thinking like, the string, and then  
27 however much it moves out towards it... we'll have a  
28 distance, and then you'll also know the component of the  
29 weight in the x-... in this direction... that would be...  
30 sine of... no cosine of the angle... M G cosine of the  
31 angle equals... this. X. So you know that there's a  
32 difference between this and this.  
33 **(6:00)**  
34 DORIA: I don't know. Um...  
35 BELINDA: Well that's our... okay, if it's hanging on a  
36 string, right? If you only, if you do a force body  
37 diagram, the only thing really is... it's weight down.  
38 You can sort of neglect the string, I guess. I think we  
39 can neglect it. Maybe not. But then if it moves here...  
40 you have the weight... oh and then now you do have the  
41 tension. Hm...  
42 CONSUELA: That's a lot.  
43 BELINDA: I'm trying to... I don't...  
44 ANGIE: Don't damage it.  
45 BELINDA: I know. I'm trying to think of a way...  
46 ANGIE: Who's the critic? Who's critic?  
47 **(7:00)**

1 BELINDA: You are! You're evaluation. That's critic.  
2 CONSUELA: Oh yeah.  
3 ANGIE: Am I supposed to ask other people?  
4 BELINDA: If you have...  
5 DORIA: Umm..  
6 BELINDA: See here's the thing... we can't hold both of  
7 them, cause you can't measure how much something's gonna  
8 move. So if we let drop one of the string, and we move  
9 the other one.  
10 DORIA: If we drop one?  
11 BELINDA: You're controlling the distance, what? If you  
12 just (un) so it can act on its own. We control the  
13 distance... and as we control the distance, this is gonna  
14 move in some manner.  
15 DORIA: Right.  
16 BELINDA: Which is... how it moves is controlled by  
17 force, right?  
18 ANGIE: But then we have to measure the angle. How are  
19 we going to measure the angle (un) if it'll probably be  
20 going like this (swings pen back and forth)  
21 CONSUELA: Yeah.  
22 BELINDA: Yeah. Well I don't know. How else are you  
23 going to measure... you can't hold the two magnets. And  
24 then you can't measure any...  
25 **(8:00)**  
26 (1 leaves)  
27 BELINDA: My hand really hurts. Look at how dark it is!  
28 That's nasty!  
29 CONSUELA: What happened? In the gym?  
30 BELINDA: Yeah, I was working out and all of a sudden it  
31 really started hurting. Which is weird, I didn't knock  
32 it on anything.  
33 CONSUELA: What were you working on?  
34 BELINDA: I was just doing cardio stuff, I don't know...  
35 CONSUELA: \*laughs\*  
36 BELINDA: I wanna look at materials.  
37 DORIA: \*moans\*  
38 (silence)  
39 **(9:00)**  
40 (more silence)  
41 DORIA: You know... this book just sucks. I don't get  
42 it!  
43 **(10:00)**  
44 (re-enter 1)  
45 CONSUELA: What are they doing?  
46 ANGIE: They were gonna measure acceleration between the  
47 two but... since they attract so quickly, you really

1 can't measure that.  
2 CONSUELA: How the hell are we...  
3 DORIA: How are they going to measure that?  
4 ANGIE: They're not doing it.  
5 DORIA: God um...  
6 CONSUELA: So using a spring would be too messy because  
7 of those...  
8 ANGIE: Yeah, I think it would be, I think would  
9 complicate it too much.  
10 CONSUELA: How else are we supposed to like...  
11 (re-enter 2)  
12 BELINDA: All I know is that we'll need a ruler of some  
13 sort. I came up with that.  
14 ANGIE: All I know is that... we didn't have pre-lab  
15 discussion.  
16 (11:00)  
17 BELINDA: He said that we're gonna do a lot of thinking  
18 for this experiment.  
19 CONSUELA: Can we at least have them... I feel like it  
20 would be easier... I want to see the magnets.  
21 BELINDA: If we can control the distance...  
22 ANGIE: They did give us the protractor.  
23 DORIA: I think if the string is going to be like (un)  
24 BELINDA: Okay, why couldn't we say... measure it in  
25 time?  
26 ANGIE: What if we did it this way?  
27 DORIA: See how much it moves?  
28 ANGIE: Have like the length this way... and we could...  
29 it would be much easier to measure it.  
30 CONSUELA: While it's on the... laying down?  
31 **(12:00)**  
32 DORIA: So if we had a magnet attached. Did they hang on  
33 it?  
34 CONSUELA: With the string attached to it?  
35 BELINDA: But this is gonna... if you don't hang it, it's  
36 not gonna produce.. this is just acting as a... something  
37 holding the string. You could use anything. This will  
38 not measure the force. What if we... wait...  
39 ANGIE: What if we had the magnet attached to a string  
40 and then put it this distance away from another magnet  
41 and how fa... how much it pulls on it? It would measure  
42 that.  
43 CONSUELA: It would measure that?  
44 ANGIE: You would think if it's gonna...  
45 CONSUELA: Pull on that.  
46 ANGIE: Pull on it. But... bring up the old motion  
47 detector.

1 BELINDA: How are you going to hook that up though?  
2 ANGIE: Just... which is it...  
3 CONSUELA: Turn the box off for five seconds and then on  
4 again.  
5 BELINDA: Two.  
6 CONSUELA: Is it two?  
7 BELINDA: Yeah.  
8 **(13:00)**  
9 BELINDA: What if we measured... all right... we have the  
10 thing hanging and we held it out for like five  
11 centimeters... see how fast they go together...  
12 CONSUELA: That's all we have to do?  
13 BELINDA: Then you hold it out ten centimeters, see how  
14 fast they come together. Then fifteen and see... you can  
15 measure...  
16 ANGIE: You can't measure how fast it comes together  
17 because they're so strong that they come together like  
18 that. (slaps)  
19 DORIA: Yeah.  
20 ANGIE: Turn the box off and turn it back on. Judy?  
21 BELINDA: There's no... wait... that'll do it. All right  
22 so... what we... put this... make sure it's like here...  
23 we measure where it starts...  
24 ANGIE: (un)  
25 BELINDA: I'm going to measure how much... if you put  
26 like one at ten, we'll see the first one at ten and then  
27 we can do like... fifteen and see how much it pulls...  
28 **(14:00)**  
29 BELINDA: ...twenty and see how much it pulls... twenty-  
30 five... then keep the first one at ten the first time,  
31 and see how much the pull is.  
32 ANGIE: Start.  
33 ANGIE: It's distance... distance... change the y-axis...  
34 CONSUELA: Can we do it again?  
35 BELINDA: Yeah... I'm pulling at a constant thing right  
36 now.  
37 CONSUELA: Pull it hard.  
38 BELINDA: Okay, I can't pull much harder than that.  
39 DORIA: Well that sucks.  
40 BELINDA: Try it again.  
41 ANGIE: It's 100 Newtons.  
42 CONSUELA: How about don't pull it, and then pull it.  
43 What the hell's..?  
44 BELINDA: Let's ask him.  
45 DORIA: Paul?  
46 **(15:00)**  
47 BELINDA: Uumm...

1 CONSUELA: Try like holding it.... I don't really see a  
2 difference.  
3 BELINDA: Does this only measure how much a spring goes  
4 down? Should it? We should ask him, I think this is a  
5 good idea.  
6 CONSUELA: They're using a spring to do it. Are they  
7 neglecting the...  
8 BELINDA: (oooh face)  
9 DORIA: What?  
10 BELINDA: What's Hooke's Law?  
11 DORIA: Force equals negative  $K X$ .  
12 BELINDA: We probably wouldn't know the.. we wouldn't  
13 know the  $K$  of the spring.  
14 DORIA: Right.  
15 **(16:00)**  
16 BELINDA: But if you can measure... if you can do the  
17 spring first one, and then put a second one... and then  
18 you can look at how much the spring changes, the length  
19 of the spring, and come up with a force that way.  
20 DORIA: And just say like, force is  $X K$ .  
21 BELINDA: But, yeah, cause  $K$  is constant.  
22 DORIA: Right.  
23 ANGIE: He said we're looking at relative. So we don't  
24 have to know exactly what it is, we're just looking for  
25 relative.  
26 BELINDA: So, force equals  $\Delta K$ ...  $\Delta C$ ...  $K$  is  
27 going to be constant anyway, so and we're relatively  
28 speaking. Hook up your spring, and at the bottom you  
29 have a magnet. Then you hold the magnet at different  
30 lengths... away.. from whatever...  
31 DORIA: Whatever the change...  
32 BELINDA: This'll be measured... oh no, this'll be  
33 measured.  
34 DORIA: Right.  
35 BELINDA: The change in spring. How easy will that be  
36 though? We need a pretty pliable spring. Not something  
37 taut, cause if it's real taut you won't be able to see a  
38 difference.  
39 DORIA: Right.  
40 (1 leaves)  
41 CONSUELA: Are we going to hang it... hang it down..  
42 **(17:00)**  
43 BELINDA: Yeah, I think it needs to be. Because the  
44 spring will... will have a bigger change when it's  
45 hanging.  
46 DORIA: But the magnet's pretty heavy. We're going to  
47 have to... we can't have a too flimsy spring, because



1 then it won't have anywhere to go.  
2 BELINDA: That's the only thing... can we hang it from  
3 like... can we hang it from higher? Because, otherwise  
4 how are you going to...  
5 DORIA: Suck. Well we need to feel how heavy the  
6 frickin' magnets are.  
7 CONSUELA: That's what I mean.  
8 DORIA: Are we not allowed to take it?  
9 CONSUELA: We just need an idea, and then he'll give us  
10 the magnets, he said.  
11 ANGIE: This one doesn't require a lot of force.  
12 DORIA: Oh Paul... can we have a magnet?  
13 BELINDA: Well can we talk to him about our thing?  
14 **(18:00)**  
15 DORIA: Yes. It sucks. But I mean...  
16 BELINDA: Oh yeah, we have a question...  
17 (enter TA)  
18 BELINDA: Well, this is what our idea is thus far. So,  
19 we're thinking that, we hang the spring... it's right  
20 here... we hang the spring. And at the bottom of this  
21 would be our magnet. Then we would control the distance  
22 that... we would take another spring and like put it five  
23 centimeters... within ten centimeters, twenty-five  
24 centimeters, and at each different distance, we can  
25 measure the distance of the spring, how much it goes  
26 down. Because according to Hooke's Law, which is this,  
27 if we use the same spring, relatively speaking, we don't  
28 need to know the spring constant.  
29 ANGIE: (un)  
30 BELINDA: I don't know. So we don't need to know this.  
31 So we can kind of verify that the change in the spring  
32 distance as the one magnet on the bottom is attracted to  
33 the other one we hold up against it would kind of  
34 approximate the force between the two?  
35 **(19:00)**  
36 TA: Yeah, it would \*be\* the force. My only question is,  
37 are you going to get enough data points...  
38 BELINDA: Yeah, that's the only thing, I was thinking  
39 like, if, cause if we hang it from here... that's not  
40 good because you can only hold it so far away from each  
41 other... but can we hang it somehow from the ceiling...  
42 or something?  
43 TA: What you have... you're gonna use a spring \*and\*  
44 this? Is that what you said?  
45 DORIA: We don't really have to use that at all.  
46 BELINDA: Well we don't need to use this, we're not  
47 measuring it... something to hold onto the spring.

1 TA: Okay, so, the spring, all right, the displacement of  
2 the spring, you're saying, is what tells you the force.  
3 DORIA: Yeah.  
4 BELINDA: Yeah.  
5 TA: And the distance is the part I'm not so sure about.  
6 How are you going to measure that, exactly?  
7 CONSUELA: The distance?  
8 DORIA: We'll put like, one magnet on the spring, measure  
9 the distance...  
10 BELINDA: No, he's saying how are you going to measure  
11 the difference? Like just with a ruler? Like how  
12 accurate would that be?  
13 **(20:00)**  
14 TA: The distance between the magnets.  
15 BELINDA: Oh, the distance between the magnets? Well  
16 can't we just...  
17 ANGIE: No, go ahead... no no no no, go, go.  
18 BELINDA: Are you asking how we're going to measure the  
19 spring? How to change that? Or just when the spring's  
20 hanging there's a magnet on the bottom, like, to show  
21 that at different distances you would hold the other  
22 magnet like five centimeters away first and see the  
23 difference in the spring, and then ten centimeters...  
24 TA: So it sounds like what you need to happen is you  
25 need this to come to an equilibrium so that you can  
26 measure it.  
27 BELINDA: Right.  
28 DORIA: Right.  
29 TA: Okay. If you can do that, this would be perfect. I  
30 don't know if you can or not.  
31 BELINDA: So wait, why... why wouldn't we be able to  
32 impose an equilibrium? Cause if we move it real fast,  
33 like, if we move the magnets to it...  
34 TA: You can see these magnets.. they... if there's  
35 nothing between them, they, for a short while, become  
36 attracted until they stick together.  
37 **(21:00)**  
38 BELINDA: Okay.  
39 TA: So, you're suggesting that you want a range of  
40 distances over which it's attracting but not sticking  
41 together. It might be difficult to do.  
42 CONSUELA: Yeah.  
43 BELINDA: Yeah, I see what you're saying.  
44 TA: Now, another group is doing something a little bit  
45 different. Instead of telling what (?) they're sticking  
46 them together, and then pulling them and seeing at  
47 what... what stretch they come apart.

1 BELINDA: Makes sense.  
2 TA: So in order to do that, they put something in  
3 between... so if you can put something between them, you  
4 can vary that amount, if you can vary the distance  
5 between them.  
6 BELINDA: Wait, what "amount" are you talking about?  
7 You're varying what amount?  
8 TA: Okay, we want to measure the distance between the  
9 two magnets.  
10 BELINDA: Correct.  
11 DORIA: Right.  
12 **(22:00)**  
13 TA: Say... a hundred pages... and then I measure the  
14 force it takes to pull them apart. Then I take fifty  
15 pages.  
16 BELINDA: Oh, I gotcha.  
17 TA: Because you want to be able to vary that distance in  
18 a measurable way.  
19 BELINDA: But then how are you...  
20 DORIA: How are you measuring the force?  
21 BELINDA: How are you measuring the force?  
22 TA: That's... that's the other part. This is how you  
23 measure the distance. Your spring idea may be sufficient  
24 to measure the force. Because the force will be the  
25 force it takes it to pull apart.  
26 BELINDA: I got you. All right.  
27 DORIA: All right, which thing...  
28 (TA leaves)  
29 BELINDA: So now, how are we going to... the only  
30 question is how are we going to... this is our weight...  
31 how are we going to...  
32 DORIA: Um... we need string.  
33 CONSUELA: You can put like...  
34 BELINDA: This is not a bad one... does it stick to it?  
35 DORIA: Yeah, we'll have to have string and then tape it.  
36 Otherwise it'll fall off.  
37 **(23:00)**  
38 CONSUELA: Where's... is there string?  
39 ANGIE: Not enough that if you were to do something like  
40 that...  
41 DORIA: We need...  
42 CONSUELA: Do we need to weigh it? See we have to do two  
43 different things, like, one thing like that, and one  
44 thing with the spring? That measures the distance and  
45 this measures the force?  
46 BELINDA: Why didn't we get those big magnets? Are those  
47 the only ones left? Are there little ones? Can we use

1 little ones? Let's get little ones. What is she looking  
2 for?  
3 CONSUELA: Strings. So we can make a hook on these bars.  
4 (?)  
5 (Exit 3)  
6 BELINDA: Oh um, they have it.  
7 ANGIE: I'm enjoying myself.  
8 **(24:00)**  
9 BELINDA: So why do we use these big weight... these big,  
10 heavy magnets.  
11 DORIA: Those are the only magnets we have.  
12 BELINDA: No, there's some more over there. Small ones.  
13 DORIA: Oh. So, if we put stuff in between it...  
14 BELINDA: I really don't see how this is gonna work.  
15 DORIA: I don't understand how... how... what are we  
16 measuring...  
17 BELINDA: All right, so like... here you'd have your  
18 spring, right? (DORIA: Right) And you'd have a magnet  
19 (DORIA: Yeah) And you'd have 'em... at the end of the  
20 spring you'd have 'em like this.  
21 DORIA: With something there.  
22 BELINDA: Oooh! Oops, wrong (?)  
23 DORIA: Right.  
24 BELINDA: Right. So hanging off of this... it's gonna  
25 displace a certain amount.  
26 DORIA: Yeah.  
27 CONSUELA: But we don't get to see...  
28 BELINDA: And then... when you... so, that would be  
29 like... your initial displacement. And then when you  
30 pull away, how much force it takes to pull it away.  
31 DORIA: Is the amount it contracts.  
32 **(25:00)**  
33 BELINDA: Yeah.  
34 ANGIE: Stretches?  
35 DORIA: But it's gonna bounce!  
36 BELINDA: This is just annoying to me right now. But the  
37 question... the better question here is if you do this,  
38 right? And then you put two pages in between... so it  
39 should... the spring should be less.  
40 DORIA: Well no, it should be the amount it expands.  
41 ANGIE: Yes. So if you put two pieces of paper in  
42 between... and you have it attached to this, right?  
43 When... (DORIA: When it's just chilling there) the  
44 spring... when you're pulling on it... the amount it  
45 takes... as you're stretching it... hmm...  
46 BELINDA: Well first of all we're definitely not using  
47 them.

1 CONSUELA: We're not using them?  
2 BELINDA: We... we can't! We have to use smaller ones.  
3 **(26:00)**  
4 BELINDA: Look how cheap this little spring is.  
5 CONSUELA: About what? What did she say?  
6 BELINDA: I don't know.  
7 (Enter 1)  
8 ANGIE: (?) two little ones.  
9 BELINDA: Two little ones.  
10 ANGIE: Two little ones don't stick together at all. You  
11 don't believe me?  
12 BELINDA: No, I believe you. Okay well no no, this is  
13 the one we can hang off... we can hang this off the  
14 spring and just move it...  
15 ANGIE: I believe you.  
16 BELINDA: I have no idea what's going on.  
17 **(27:00)**  
18 (TA calls for discussion)  
19 (Group 1 presents)  
20 **(28:00)**  
21 (Group 5 presents)  
22 **(29:00)**  
23 (Group 4 presents)  
24 BELINDA: So the probe is measuring the force.  
25 **(30:00)**  
26 (Group 6 presents)  
27 **(31:00)**  
28 CONSUELA: That's pretty much what we said.  
29 BELINDA: That's pretty much what we were thinking. We  
30 were trying... we were gonna relate it using a spring to  
31 Hooke's Law... and... find the force that way. Just  
32 measuring the differences of the spring. But we hadn't  
33 decided how we were controlling the distance yet... if we  
34 were just... um... if we were going to be putting things  
35 between the magnets or... I... (?) so... I don't know.  
36 Haven't got that far.  
37 **(32:00)**  
38 (TA sums up discussion)  
39 **(33:00)**  
40 BELINDA: Okay, so...  
41 CONSUELA: What did they say they were going to do?  
42 ANGIE: I really like their idea.  
43 BELINDA: Theirs?  
44 ANGIE: Yeah.  
45 CONSUELA: Me too.  
46 DORIA: Theirs?  
47 BELINDA: But where how do you... the distance thing, it

1 seems like it...

2 DORIA: But when you try to uh... exactly... work...

3 BELINDA: Our transducer? This is a transducer, right?

4 Oh my gosh.

5 CONSUELA: Ok, ready? I don't understand, maybe (?)

6 BELINDA: We need to ask... (CONSUELA: Paul!) Paul, we

7 need your help.

8 CONSUELA: Maybe it's the wrong one, like...

9 BELINDA: I get a... I have a (?) about Polish people,

10 which I am, therefore...

11 ANGIE: Try switching ports... try changing the port...

12 try to change the port.

13 BELINDA: It's like cords, it's not a... it's like

14 ripping... I didn't do anything.

15 **(34:00)**

16 BELINDA: All right, I'm changing it to uh port one.

17 That's the only other option. There are two ports.

18 ANGIE: What happened to our screen?

19 DORIA: Our computer sucks.

20 ANGIE: Paul!

21 CONSUELA: What the hell is going!?

22 ANGIE: Paul! This is not (?)

23 TA: All right, who's screaming for Paul?

24 BELINDA: Our computer is on... not helping us... not

25 working...

26 TA: What happened? Oh. Close the windows.

27 BELINDA: The transducer's not even working though.

28 CONSUELA: How come it doesn't let me like open. Oh,

29 there it is. Great.

30 TA: Um, close it out and restart.

31 CONSUELA: Restart.

32 DORIA: We love our computer.

33 **(35:00)**

34 TA: Give me the mouse, will you? Quit. Why aren't you

35 quitting. Close! Quit! Please!

36 BELINDA: Do anything! Oh wait. That reset it. And

37 just end uh, yeah.

38 CONSUELA: Okay.

39 TA: Whatever you did, don't do it again.

40 BELINDA: But it's not work... can you help us try to

41 work it...

42 DORIA: Yeah, it's not working.

43 BELINDA: It was in port two, we moved it to port one.

44 Go back to port... do you want me to go back to port two?

45 Okay, so, when we change it to force, this was still...

46 wait, is it even plugged in?

47 CONSUELA: Because it's not plugged in down there.

1 DORIA: Then it wasn't measuring!  
2 CONSUELA: It was doing something!  
3 TA: You want this in port one, you want that in port  
4 two.  
5 **(36:00)**  
6 BELINDA: You want this in port two?  
7 DORIA: Well then what was it measuring?  
8 CONSUELA: It was definitely measuring something!  
9 BELINDA: This was measuring something.  
10 DORIA: But there was... nothing going on.  
11 BELINDA: All right, let's try this out.  
12 DORIA: We're not measuring acceleration, we're measuring  
13 force.  
14 BELINDA: Just hook it up. All right. Now just say  
15 okay... let's see... wait wait wait.  
16 CONSUELA: Oh duh...  
17 **(37:00)**  
18 CONSUELA: Does this have to be (?) or something? I  
19 don't understand...  
20 BELINDA: I don't think so. Why is this not working?  
21 ANGIE: Why is (?)  
22 BELINDA: All right, first we'll all...  
23 DORIA: Just switch the ports.  
24 CONSUELA: Yeah, try switching the ports.  
25 DORIA: Yeah, switch them.  
26 BELINDA: Let's hang that off the table.  
27 ANGIE: I gotta figure out what's going on.  
28 BELINDA: All right.  
29 DORIA: Try switching the ports.  
30 BELINDA: All right...  
31 ANGIE: Is it going?  
32 BELINDA: See, it only reads the motion probe in the  
33 other...  
34 **(38:00)**  
35 CONSUELA: Then why is it not...  
36 BELINDA: All right.  
37 DORIA: What is going on with our computer?  
38 CONSUELA: Is there something wrong with this?  
39 BELINDA: Click on the question mark. I don't know why.  
40 Zero?  
41 (Enter helper with advice)  
42 CONSUELA: Oh.  
43 BELINDA: Just put ten. Can you highlight it? It won't  
44 delete. And then just go down here. Excellent!  
45 CONSUELA: Do you want to start that again?  
46 BELINDA: Yeah, try that again. And thank you, by the  
47 way. Hopefully that works. Or maybe not.

1 CONSUELA: Wait... it...  
2 **(39:00)**  
3 BELINDA: Here, wait, put this on it.  
4 ANGIE: I'm pulling on it as hard as I can.  
5 BELINDA: I know, it should, yeah, I know, it should.  
6 Let's just see.  
7 CONSUELA: What in the hell, we're not ever...  
8 BELINDA: Put this on the... I don't think that needs to  
9 be there though...  
10 CONSUELA: You don't think?  
11 DORIA: Yeah, what is that... (?)  
12 BELINDA: Here. Don't know. Yep, definitely not  
13 working. Try acceleration. Acceleration and force will  
14 be the same.  
15 DORIA: We don't have to use the computer if we're just  
16 doing the change in X.  
17 CONSUELA: Yeah.  
18 BELINDA: But we're not.  
19 DORIA: We're not? What're we doing?  
20 BELINDA: I thought we (?)  
21 DORIA: Are we?  
22 BELINDA: Oh yeah! This IS measuring.  
23 CONSUELA: Isn't this still... does it need to be  
24 smaller?  
25 DORIA: I mean, I don't.  
26 BELINDA: Okay, we're confused. Our thing is not  
27 working.  
28 **(40:00)**  
29 (Enter TA)  
30 BELINDA: It shouldn't even need the motion detector, if  
31 we're just measuring force here.  
32 TA: First of all, you're way too close to the motion  
33 detector. It doesn't... it won't see it that close.  
34 BELINDA: But... should we even need that if we're just  
35 measuring the force, cause this...  
36 TA: Why are you using it?  
37 BELINDA: We're not.  
38 CONSUELA: We're not.  
39 BELINDA: It said, it couldn't measure without this, so  
40 we were thinking maybe this was it, but we didn't...  
41 TA: It just needs to be plugged in to work.  
42 BELINDA: That's what we thought but it's still not  
43 working with just this.  
44 TA: Here, um, hit zero.  
45 CONSUELA: Here?  
46 TA: Yes.  
47 BELINDA: Slow computer.



1 DORIA: I demand (?)  
2 TA: Okay, now start it.  
3 **(41:00)**  
4 CONSUELA: Oh gosh, what's going on?  
5 DORIA: It's connected though!  
6 BELINDA: Yeah, it's connected.  
7 TA: Is it connected... is it in the right one? Is it...  
8 BELINDA: This one is port two. And the other one is  
9 port one.  
10 CONSUELA: Okay.  
11 TA: Try again.  
12 BELINDA: Whoa.  
13 CONSUELA: Okay, it's working now.  
14 TA: Now it's working. Okay, you need to change the  
15 scale so that you can see the features, but now it's  
16 working. I think it's just a loose connection.  
17 ANGIE: What did you do?  
18 TA: I just... pushed it in and out.  
19 CONSUELA: I think it's when we do... should we set it  
20 up now? How are they... what are they doing... (?)  
21 DORIA: So what are we doing?  
22 ANGIE: Can we try it with this just to see if it  
23 measures enough for us?  
24 CONSUELA: Tell me when.  
25 **(42:00)**  
26 ANGIE: Now.  
27 DORIA: Oh my. That's not gonna work.  
28 CONSUELA: That's like the worst graph I've ever seen.  
29 ANGIE: Maybe we should do the fishing rod thing... how  
30 they're doing it.  
31 DORIA: Do what? Put stuff in...  
32 ANGIE: They're hanging a magnet from a fishing rod and  
33 then (?) seeing how much it attracts to (?)  
34 BELINDA: How are they measuring attraction?  
35 ANGIE: They have one... they have one hanging from a  
36 string.  
37 BELINDA: Off of the transducer?  
38 ANGIE: Yeah. And then... seeing how much like...  
39 BELINDA: The pull is. The string doesn't change  
40 lengths.  
41 ANGIE: The string changes lengths.  
42 BELINDA: It can't... if you have it tied onto there.  
43 ANGIE: You can cut it off and change the length of the  
44 string to change the distance between them.  
45 BELINDA: No... you change the distance, but the string  
46 isn't going to change. It's just the force pulling down  
47 on the string.

1   **(43:00)**  
2   DORIA: You know you'll just... you're not using a  
3   spring, you're using...  
4   BELINDA: Yes. It's a string.  
5   ANGIE: I know. They cut the string to change its  
6   length.  
7   BELINDA: No, I get all that. (ANGIE: Okay then, what  
8   are you talking about?) The string isn't going to move  
9   down, it's just the weight (ANGIE: Yes!) gonna attract  
10  it.  
11  CONSUELA: That's the way they're doing it?  
12  DORIA: Well... will that... the computer measure the  
13  force between them? Or just the force that the weight is  
14  pulling down?  
15  CONSUELA: It's the weight that it's pulling down.  
16  BELINDA: It'll just measure this.  
17  DORIA: Then how is that measuring the force between 'em?  
18  ANGIE: Because if this one is attracted to this one...  
19  BELINDA: The other one is attracted the same way.  
20  ANGIE: ...it's going to pull down more.  
21  BELINDA: All right, let's do this then. You need to  
22  hook us up.  
23  (Exit 1 and 2)  
24  (silence)  
25  **(44:00)**  
26  CONSUELA: So the... we're going to be changing the  
27  distances of the strings, right?  
28  (silence)  
29  **(45:00)**  
30  (group puts together apparatus)  
31  **(46:00)**  
32  **(47:00)**  
33  (inconsequential talk about materials)  
34  **(48:00)**  
35  **(49:00)**  
36  DORIA: You want... this?  
37  BELINDA: We need to make sure that this is ninety  
38  degrees. So how do we do it?  
39  DORIA: Oh, the level?  
40  BELINDA: Protractor or level?  
41  DORIA: Level.  
42  **(50:00)**  
43  ANGIE: Who's doing the journal?  
44  CONSUELA: Do they do the design of the experiment? Or  
45  do I?  
46  BELINDA: You're the journal... wait... you're the data.  
47  Tell me when it's level, try it again. And then, let's

1 see (?)  
2 **(51:00)**  
3 **(52:00)**  
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Group 2

1  
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3 (0:00)  
4 DAPHNE: I guess we have to see like, just, if we hold it  
5 and let it go, will they come together?  
6 CATHY: \*moans\*  
7 ASHLEY: If we hold one stationary, maybe see...  
8 DAPHNE: I was about to say, "Why don't we drop it?" but  
9 it would all fall, so that wouldn't work, would it?  
10 BONNIE: It would magically float apart in the air!  
11 DAPHNE: They wouldn't come together.  
12 BONNIE: It was so strong it would overcome gravity.  
13 DAPHNE: I hate this discussion we always have. I don't  
14 want to hear about all this stuff...  
15 (1:00)  
16 (TA hands out lab notebooks, inconsequential chatter)  
17 (TA instructions)  
18 (2:00)  
19 CATHY: How does the force between two magnets change?  
20 TA: I'm gonna warn you right now, this lab can be pretty  
21 tough.  
22 DAPHNE: The force we would measure if we could test a  
23 spring through the tension... is proportional to the  
24 force pulling it this way, right?  
25 ASHLEY: ?  
26 DAPHNE: Yeah, and then have something attached to  
27 like...  
28 ASHLEY: Wood?  
29 DAPHNE: And then how much this stretches?  
30 (skip ahead)  
31 (8:00)  
32 DAPHNE: So we need to think if this is going to work. I  
33 don't see why that wouldn't work. Cause what would be  
34 changing is like, make we'd have this magnet at this  
35 distance, this distance, and this distance, and measure  
36 how far it would...  
37 BONNIE: What are we measuring exactly?  
38 DAPHNE: If we change the distance then we're finding the  
39 force. I think what he said was, you have to vary one of  
40 the two... to figure it out. And I have no idea how you  
41 vary the force. I guess by changing the different  
42 magnets or something? You can't change the charge of the  
43 magnets. So if we measure the distance, then if this  
44 force is proportional to this force, then we're measuring  
45 the force.  
46 CATHY: So how would we get the spring first of all to  
47 lay like... straight?

1 DAPHNE: We can do it with the one we did last semester.  
2 (9:00)  
3 CATHY: And so we would measure how far it... like we  
4 would measure the distance of the spring at like...  
5 DAPHNE: The change of the spring. The change in  
6 distance of the spring.  
7 CATHY: All right. It's worth a try.  
8 DAPHNE: We can try and see what... let me get the  
9 magnets.  
10 ASHLEY: I'll get the spring.  
11 CATHY: And maybe some silly puddy too.  
12 (1, 2, and 4 leave)  
13 (10:00)  
14 (re-enter 2)  
15 BONNIE: Okay, I don't quite understand what we're doing.  
16 Which is not good, cause I'm the journal person.  
17 CATHY: We have to measure both of these, though.  
18 BONNIE: Right, but we vary one. Yeah, we have to find  
19 some way of measuring force based on the spring. I'm not  
20 sure how it works.  
21 CATHY: Ummm...  
22 BONNIE: Those are strong magnets.  
23 CATHY: See, I don't think they're so... look... like, I  
24 really don't think they're gonna... move a spring.  
25 BONNIE: Yeah, once the distance...  
26 CATHY: Cause, in order to get the...  
27 (11:00)  
28 BONNIE: The other thing is, there aren't going to be a  
29 lot of distances, cause one you get it like two inches  
30 away or so, it stops...  
31 CATHY: Then I guess maybe it moves... So we would have  
32 to keep... we would have to keep one of them... in place,  
33 right? It would have to be like... that doesn't do  
34 anything... that doesn't do anything.  
35 BONNIE: So we do the other side too, the attraction side  
36 (CATHY: Yeah) So like, turn one around... see how close  
37 they can get to...  
38 CATHY: It's gonna be really hard because... it's not  
39 gonna pull back... it's gonna get to a point and  
40 automatically it's just gonna go this way.  
41 (12:00)  
42 BONNIE: Yeah. So we I guess find this point, like, if  
43 you, can you hold it back so far... and it won't do  
44 anything...  
45 DAPHNE: See, the idea is you tape this on and hold it  
46 like... I guess we'd have to hold the other side of the  
47 spring fixed, wouldn't we?

1 BONNIE: \*laughs\* That spring is...  
2 DAPHNE: We wanted a stretchier one cause it's gonna  
3 be... it won't... if the spring isn't stretchy enough  
4 then these probably won't even come together.  
5 BONNIE: Oh, yeah, I know.  
6 DAPHNE: But we have to hold this side fixed, don't we?  
7 BONNIE: Yeah.  
8 DAPHNE: We can tape it to the paper...  
9 ASHLEY: This is just trying out.  
10 BONNIE: Idea number one.  
11 DAPHNE: All right, if we take the... we need scissors...  
12 are there scissors in the um...  
13 BONNIE: Yeah.  
14 DAPHNE: ...thing? Is it stronger if you hold the magnet  
15 like that?  
16 (13:00)  
17 CATHY: What do you mean? You know, I think you have to  
18 just one end, cause it would just attract, you know,  
19 like...  
20 DAPHNE: So it's not like... oh... it might be easier to  
21 do it that way, wouldn't it?  
22 CATHY: But then you have these repulsing at the same  
23 time, like, I think you can only deal with either  
24 attracting or...  
25 DAPHNE: So you can't do it like... oh... doesn't work,  
26 does it?  
27 ASHLEY: This way would do... attract both sides... know  
28 what I mean?  
29 BONNIE: Yeah?  
30 DAPHNE: If you flipped the magnet the other way, you  
31 mean?  
32 ASHLEY: Like, if this is red and this is red...  
33 DAPHNE: But then it attracts both if you line..  
34 ASHLEY: Right, so it's a strong... stronger force,  
35 right?  
36 DAPHNE: It attracts both sides.  
37 BONNIE: Does it though?  
38 DAPHNE: But how are we going to measure that?  
39 CATHY: Yeah, I think we can only pay attention to one  
40 thing at a time.  
41 (14:00)  
42 DAPHNE: But, as long as we keep it constant then we're  
43 keeping the... like if we do it like this... it's  
44 probably gonna be able to stretch the spring better than  
45 if we do it like that. Cause we're measure... we're  
46 trying to figure out the distance, so... if we tape one  
47 end of the spring down... we can tape it to the table...

1 come off easier... so, you know... start like here and...  
2 it's gonna be close, I guess.  
3 CATHY: Yeah (un)... I think it's easier to... if we're  
4 picking, it's easier to measure repulsion because...  
5 BONNIE: Yeah.  
6 CATHY: Like... we can go here... nothing... nothing...  
7 ASHLEY: So maybe how far...  
8 CATHY: It's like... how far this one like retracts back.  
9 DAPHNE: Get it closer...  
10 BONNIE: It can do a variety of things.  
11 ASHLEY: What if you...  
12 DAPHNE: I just want to see if it actually works.  
13 ASHLEY: We have so many ideas!  
14 (15:00)  
15 DAPHNE: Yeah. Well, we have to figure out which  
16 one's...  
17 CATHY: And... do we have to measure the distance between  
18 like, repulsive forces and attractive forces?  
19 ASHLEY: No. I think it's just... force.  
20 CATHY: But might they be different?  
21 ASHLEY: Um...  
22 DAPHNE: I would think that they shouldn't be. But I  
23 always think the wrong thing.  
24 (silence)  
25 (16:00)  
26 (Enter TA)  
27 TA: What are you going to try?  
28 DAPHNE: We're just trying to see... (BONNIE: The spring)  
29 if you change the distance...  
30 BONNIE: Change the distance with the spring (?)  
31 ASHLEY: Here.  
32 DAPHNE: I don't know if this is going to work. Cause  
33 we have to hold one of 'em. This, I guess, is what we're  
34 moving, isn't it? It's not gonna work. The spring  
35 like...  
36 ASHLEY: What if that was held constant and we...  
37 BONNIE: Yeah, what if we...  
38 ASHLEY: ...and we moved this...  
39 DAPHNE: If we moved this one?  
40 BONNIE: Yeah, this one. And then watch.  
41 DAPHNE: So we hold it at it's, like, equilibrium  
42 position (giggles)?  
43 BONNIE: If we can \*find\* an equilibrium position.  
44 DAPHNE: But how are we going to measure that... the  
45 force?  
46 BONNIE: You don't hold this one fixed.  
47 DAPHNE: Yeah.

1 (17:00)  
2 DAPHNE: So it's stretched that far. Wouldn't it stretch  
3 the same, I guess? Something's not right.  
4 BONNIE: \*sigh\*  
5 DAPHNE: It's stretched that much.  
6 CATHY: Cause it's like, once it gets to that point,  
7 every time it's going...  
8 DAPHNE: It's gonna...  
9 BONNIE: Yeah.  
10 CATHY: And they're so thick... they're so thick that to  
11 have it this direction... like...  
12 DAPHNE: Yeah, it might be better to...  
13 CATHY: You can't... you can't like, move it... that  
14 whole length.  
15 BONNIE: Yeah.  
16 DAPHNE: Can we see how far the spring would stretch for  
17 them to come apart? I guess that would just... once the  
18 spring can't stretch anymore then we have to pull it  
19 apart. That wouldn't work.  
20 BONNIE: Yeah, that wouldn't.  
21 DAPHNE: It just seems that it's so much easier to  
22 measure distance than it is to measure force. How do you  
23 measure the force... without... so if we measure how far  
24 it... goes? What if we, like, hold it, until you get it  
25 to the right spot, and then let it go.  
26 (18:00)  
27 CATHY: Or like we would have a, like ruler... down  
28 here...  
29 DAPHNE: Hold that like that, and then let go of that  
30 one, and see how far it goes. And hold it there... like  
31 if we hold it... we hold it one inch... it doesn't go  
32 anywhere. Two inches... (?) go anywhere... three  
33 inches.. it goes...  
34 ASHLEY: Well I guess (?)  
35 DAPHNE: Two inches... one inch... and let it go. Like..  
36 go.  
37 CATHY: Hm... that's weird.  
38 DAPHNE: It just moved! It's not going anywhere. Not  
39 quite half an inch... (?)  
40 BONNIE: Theoretically we could do this \*without\* a  
41 spring.  
42 DAPHNE: Yeah. (?)  
43 (19:00)  
44 (Enter TA)  
45 DAPHNE: ...and it goes back a whole lot more (ASHLEY:  
46 Even more!) What if we do it this way? But that's...  
47 attracting. I was wondering why it was pulling my hands



1 down... like it moves it away at an inch, but at the  
2 other one, it didn't.  
3 CATHY: But it also moves... this back. Like... it's not  
4 like a straight...  
5 DAPHNE: Why does it move the red back more than the  
6 black?  
7 CATHY: I don't know!  
8 BONNIE: Just... it probably could do either...  
9 DAPHNE: It's harder to push it together this way. And  
10 it's a bigger difference so it would be easier to... like  
11 could we take the average of... like where the black is  
12 and where the red is, and then take the average... at the  
13 middle?  
14 BONNIE: Wait, what do you mean?  
15 DAPHNE: Like when it comes off at an angle like that,  
16 take an average of the position so that it's not here or  
17 here, it's there (BONNIE: Oh... right) do you know what  
18 I mean? So it's right between the two.  
19 (20:00)  
20 BONNIE: Yeah, I don't see how else we could...  
21 DAPHNE: Cause it... you could measure it. I mean, it's  
22 a big difference. When you hold it like that it goes...  
23 and then when you hold it like this, it's just not going  
24 very far at all. You know what I mean?  
25 BONNIE: We could do it both ways and sort of see...  
26 or...  
27 DAPHNE: And have that be different trials, maybe?  
28 ASHLEY: What if you did the red end... does that make  
29 the black end go farther?  
30 BONNIE: Is it just the one that's up?  
31 ASHLEY: Yeah, it stretches the outside...  
32 CATHY: I think probably because it's going against...  
33 DAPHNE: So I should hold it away from the ruler. It  
34 might just be because of the way I'm holding my hand.  
35 BONNIE: I think they're the same. I think it's just,  
36 you know.  
37 DAPHNE: What if we held it like... that...  
38 CATHY: It's hard to...!  
39 ASHLEY: Ooh, sorry!  
40 DAPHNE: What if we... (?) the ruler up... it's still  
41 kinda... we'll just take the average of the...  
42 (21:00)  
43 BONNIE: Probably just the red part...  
44 DAPHNE: Get off!  
45 BONNIE: You're not allowed to be together.  
46 ASHLEY: That's not as bad. (DAPHNE: Yeah) And then we  
47 just have a piece of tape for all the... ten places...

1 BONNIE: Yeah, we have two rulers so we could do...  
2 DAPHNE: Yeah, then just measure. Well if we could get a  
3 piece of tape...  
4 CATHY: But then how are we...  
5 DAPHNE: Like should.. would this be our only... only  
6 with these magnets when there's like... like would we be  
7 able to do it with the small magnets and have like...  
8 results that can be compared?  
9 CATHY: We could do it... orient the magnet different  
10 ways.  
11 DAPHNE: This way... this way... this way...  
12 BONNIE: We only get one pair of magnets so...  
13 CATHY: Oh we do? Oh we do.  
14 DAPHNE: This way.  
15 BONNIE: But it should be the same for all... and then  
16 could we measure the attraction also? Or is that... see  
17 how close you can get it before...  
18 DAPHNE: Before what?  
19 (22:00)  
20 CATHY: I think that's really hard because it like...  
21 (BONNIE: Yeah, I know it is) it can only be measuring  
22 one point.  
23 ASHLEY: At what point does it attract each other.  
24 DAPHNE: Cause it will attract the same... well I guess  
25 it won't.  
26 ASHLEY: Once it gets to like two inches.  
27 DAPHNE: Can't really measure, cause it would... so we're  
28 measuring repulsive force.  
29 ASHLEY: So we want to measure repulsion...  
30 BONNIE: We need... spring...  
31 DAPHNE: And we're not allowed to have more than one kind  
32 of magnet?  
33 BONNIE: Well... maybe we can, I don't know.  
34 DAPHNE: If we like put this back, and then...  
35 BONNIE: Yeah, I'm sure we can test another one, we just  
36 can't have more than one set at a time.  
37 DAPHNE: At a time.  
38 BONNIE: Yeah.  
39 DAPHNE: Cause we could get more data. But then the size  
40 of the magnet is different. But the relationship should  
41 still be the same, right? The size of the magnet  
42 shouldn't matter. It's... the relationship of the force  
43 and the distance?  
44 BONNIE: (writing) Measure repulsion not attraction...  
45 DAPHNE: Did that make sense (?)?  
46 CATHY: So like, on those little ones they're set up  
47 exactly the same, like, half of it's positive, half of

1 it's negative.  
2 DAPHNE: I didn't notice. I didn't look at the... if we  
3 use this piece of paper to do it, can we draw a ruler on  
4 here?  
5 (23:00)  
6 BONNIE: Ooh.  
7 ASHLEY: Ah!  
8 DAPHNE: So we don't have to...  
9 ASHLEY: Except for the stupid...  
10 (Enter TA)  
11 TA: (?) Idea?  
12 DAPHNE: Yeah... I think we can start.  
13 CATHY: It's very simple.  
14 DAPHNE: Um, we're going to... hold magnets at different  
15 distances... away from each other, and then let it go and  
16 see how far it pushes it back... and see if holding it  
17 closer makes it push back farther. (TA: Okay) And by how  
18 much.  
19 ASHLEY: And we're measuring repulsion.  
20 DAPHNE: We're measuring repulsion, not attraction.  
21 TA: Okay, how would you measure the force though?  
22 DAPHNE: By the distance...  
23 BONNIE: The distance that it goes?  
24 TA: Is it proportional?  
25 DAPHNE: (dunno noise)  
26 BONNIE: Maybe?  
27 DAPHNE: We'll see! I don't know.  
28 (24:00)  
29 TA: Okay, so, a method like this fine... if you can make  
30 a clear... connection between distance and force. You  
31 have to measure force. If you're just measuring  
32 distance, you need a way to change it to force.  
33 DAPHNE: Oh. Right.  
34 CATHY: We can't only do this...  
35 TA: I'm just saying... with this method you might make a  
36 perfectly persuasive argument about the relationship  
37 between initial distance and how far apart it goes. But  
38 not distance and force, and that's what you have to do.  
39 CATHY: Ok. We have to change this. I don't think we  
40 should even try taking... since we're not measuring one  
41 of the... components... I don't think we should...  
42 DAPHNE: Oh, force?  
43 BONNIE: How do we measure force?  
44 CATHY: Something like... (DAPHNE: Well can't we say  
45 like...) hooking up to the computer with it like... what  
46 did we use the first time?  
47 DAPHNE: What if we use that (motion detector) and change

1 it to a force graph?  
2 (25:00)  
3 CATHY: How do we hook that up though? How is this...  
4 DAPHNE: Like... hold it here... it goes back, like, half  
5 an inch. So that was an inch away. If you... increase  
6 the dis... is that doubling it? Decreasing the distance  
7 by one half... then it goes... dammit... then it goes...  
8 a certain amount... and the factor that it goes, like,  
9 the amount... if we're... changing the distance away by  
10 like you know, if we do two... one... if we're like  
11 cutting the distance in half every time... then it goes  
12 that far. If we put it (?) how much it goes that far and  
13 do a relationship between how... what the...  
14 ASHLEY: Like when we were doing here... times... two...  
15 (26:00)  
16 DAPHNE: If we do... we do one and two way...  
17 BONNIE: Can we time it to find the velocity and  
18 acceleration (?)  
19 DAPHNE: That would be really hard, it's really fast.  
20 (BONNIE: I know) It's too fast. So if we do an inch  
21 away...  
22 CATHY: Wait, how is this telling us force again?  
23 DAPHNE: The relationship between the distances... that  
24 it goes.  
25 CATHY: But how do we know that's a property of force?  
26 DAPHNE: I don't know.  
27 BONNIE: That's what we don't know.  
28 ASHLEY: So right now we know that the reason why these  
29 two are going away is because... (BONNIE: They're  
30 repelled by some force but we can't measure that force.)  
31 because we know that there's force.  
32 CATHY: Then I guess what we're supposed to assume is  
33 that (DAPHNE: We actually have to...) we know whether  
34 there's a force or not.  
35 DAPHNE: And we actually have to measure that a force  
36 exists.  
37 BONNIE: Right... prove that there is a force.  
38 DAPHNE: Point five inches away then it goes two  
39 inches...(?)... it goes... it goes...  
40 (27:00)  
41 DAPHNE: (mumbles)  
42 (silence)  
43 DAPHNE: So... couldn't the force... be... what we  
44 multiply by to get that?  
45 CATHY: That's like assuming that... that's the  
46 relationship. Like you're just assuming... we can  
47 multiply. And we don't have anything to like tell us

1 that that's... like why isn't it like... it's the  
2 metal... that causes it to go this distance... you know  
3 like...  
4 (28:00)  
5 DAPHNE: But we're not changing the... charge... so... it  
6 can't be the metal... because if we're not changing the  
7 charge in the metal then...  
8 CATHY: I just think it could be anything and we're just  
9 assuming... charge... and we haven't proven any...  
10 BONNIE: He told us we have to find a way... to measure  
11 the charge... to measure the charge...  
12 DAPHNE: We can measure the charge!  
13 BONNIE: Not the charge, the force.  
14 DAPHNE: The force.  
15 BONNIE: I don't know how to do that.  
16 DAPHNE: Is that even gonna work? These are pretty low.  
17 (BONNIE: I don't know) I guess maybe if we put it  
18 farther out. We're gonna have to make sure we keep the  
19 (?) distance away...  
20 BONNIE: Someone else is turning on a computer so...  
21 DAPHNE: So what are we measuring? How far it pushes it  
22 back, the closer we hold it?  
23 BONNIE: Yeah, which way are we measuring it though, this  
24 way?  
25 (29:00)  
26 DAPHNE: So if we... but..  
27 BONNIE: I don't know, I'm going to have to see the  
28 graph...  
29 DAPHNE: If we... we hold it a certain distance and that  
30 is gonna pick up how far it goes. (CATHY: If we hang  
31 it...) And then... how far it goes, and how far it goes.  
32 ASHLEY: That brings in gravity.  
33 CATHY: But it would always be con... like, the gravit...  
34 the same gravity would always be there. Can we measure  
35 how much it causes the spring to bounce up? You know  
36 just like we were gonna measure...  
37 ASHLEY: That's still measuring just...  
38 DAPHNE: But it's still so small and... how do you  
39 measure, how do you eyeball that?  
40 CATHY: Well we were going to do that with this.  
41 DAPHNE: But it's easier when it's here because you can  
42 hold it up to a ruler and if you don't move the weight...  
43 CATHY: So couldn't we hold the ruler this way? And  
44 measure this...  
45 DAPHNE: But would it stay? Because are you going to  
46 have to be like 'oh that's what it was.'? Cause that  
47 would be kind of hard.

1 BONNIE: Where's our mouse?  
2 ASHLEY: Cause gravity would pull it back down.  
3 DAPHNE: ...pulls it right up.  
4 (30:00)  
5 CATHY: I know but if that's... I know but if that's the  
6 only... like what we have here is not measuring force in  
7 any way.  
8 ASHLEY: Well what if it was like this?  
9 BONNIE: Where's our mouse?  
10 ASHLEY: Like this will detect that it's coming closer  
11 to... right?  
12 (Enter TA)  
13 TA: I don't know if it will see that. I mean what...  
14 you're trying to measure separation again, aren't you?  
15 ASHLEY: Mhmm.  
16 BONNIE: The force between them.  
17 TA: How are you going to do that?  
18 BONNIE: There's an option... force graph?  
19 TA: Uh there's... okay... and how does it get the force  
20 graph?  
21 CATHY: From the distance graph.  
22 BONNIE: The velocity... er no...  
23 TA: It gives you the force graph cause there's a force  
24 probe connected to it.  
25 DAPHNE: Oh... so we're measuring the force? Right?  
26 With the force probe! (laughs)  
27 (31:00)  
28 TA: Um... that's not the force probe.  
29 BONNIE: Where's the force probe?  
30 TA: That's it. No, on top of the box. That.  
31 BONNIE: Force probe... model F P 2.  
32 CATHY: What does that look like?  
33 BONNIE: I'm guessing you have to untangle this.  
34 CATHY: How does that work?  
35 BONNIE: (?) (fiddles with force probe)  
36 DAPHNE: What do you... put with it? What do you attach  
37 to it? One end... one of the magnets?  
38 ASHLEY: Or a spring.  
39 DAPHNE: But we already... but it seems that you can't  
40 measure repulsion with that.  
41 (32:00)  
42 DAPHNE: And we already know that... that's not going to  
43 work.  
44 BONNIE: Yeah.  
45 DAPHNE: You're supposed to attach (?) to that?  
46 CATHY: The probe isn't...  
47 DAPHNE: How does that work?

1 TA: Don't do that!  
2 CATHY: We would attach something down here.  
3 TA: Let me see this to make sure it's actually hooked up  
4 appropriately. So attach things to the hook. This  
5 magnet... I mean, it's a magnetic force probe. But we  
6 found... yeah... we found that it can work though with  
7 magnets here... and here and here.  
8 (33:00)  
9 DAPHNE: So what, you attach the magnets to each other?  
10 Attach a magnet to that?  
11 TA: Or if you want to get the magnets far away, you  
12 could string one of them up. Like use a string or  
13 something. And attach a magnet here. And then bring  
14 this magnet around... and see... and see the effect.  
15 ASHLEY: But then would you have to just measure  
16 attraction?  
17 TA: You can measure repulsion too.  
18 ASHLEY: But like... say this is attached to this, right?  
19 If I go like this... it's gonna move backwards. Does  
20 this register backwards?  
21 TA: It won't necessarily... okay...  
22 ASHLEY: Do you see what I mean?  
23 TA: Yeah, I see what you mean but...  
24 ASHLEY: Or does it only pull this way and...  
25 TA: So let's say you strung this up... okay, and the  
26 string is supporting this, and without this magnet, this  
27 just feels the weight of this. Right? If you do  
28 attraction, and this thing wants to get pulled down and  
29 the reading will increase. If you do repulsion, this'll  
30 be pushed up a bit and you'll get...  
31 (34:00)  
32 ASHLEY: It'll record something?  
33 TA: Yeah. Oh, absolutely. As long as you zero it with  
34 whatever... whatever weight hanging from it that you  
35 want. Then it'll appear as positive or negative.  
36 BONNIE: We have to attach it with a string or something?  
37 TA: You can do whatever you want. (BONNIE: Okay) I  
38 mean... some other groups are trying this already, so you  
39 can check that out.)  
40 DAPHNE: But didn't we already figure out that there's  
41 only one... point at which they're going to attract, and  
42 everything else after that it's not really... I mean, if  
43 we measure attraction, we're only measuring one thing.  
44 Unless we hold it apart... and then let it go.  
45 CATHY: Well he just said that it could measure  
46 repulsion.  
47 ASHLEY: Yeah, so we can still measure repulsion.

1 DAPHNE: Is it just going to be more negative... the more  
2 it repels?  
3 ASHLEY: Mmhmm.  
4 CATHY: Yeah.  
5 ASHLEY: Do you want to open the... longer thing?  
6 (35:00)  
7 (unintelligible talk about screen)  
8 ASHLEY: We wouldn't want a spring here... because  
9 that'll move... (DAPHNE: A string) (CATHY: I think we  
10 just want string) that'll be tension on...  
11 (Exit 1)  
12 DAPHNE: So how are we going to...(?)  
13 CATHY: And should we just attach this to the side of the  
14 table?  
15 BONNIE: Okay, but how... why would we attach it to  
16 this... because we...  
17 CATHY: Well this has to... I mean, we can't be holding  
18 this cause this is gonna be (?) has to be like  
19 stationary.  
20 BONNIE: But where are we gonna (?) hold the magnets  
21 underneath it?  
22 DAPHNE: Can we tape a ruler to the table or something?  
23 (?) to know exactly... tape a meterstick to the table so  
24 we know exactly... how far we're holding it?  
25 (36:00)  
26 CATHY: Mmhmm.  
27 (Re-enter 1)  
28 DAPHNE: Are we going to tape it? Because I would think  
29 that tying a string to a place they're going to repel  
30 would be... destructive. Should we tape the string to  
31 the top here?  
32 ASHLEY: Yeah... did he take our...  
33 BONNIE: I've got the tape.  
34 (talk about constructing tape and string)  
35 CATHY: Maybe... maybe we should just tie it cause... we  
36 just don't know how far it's gonna like... come back up.  
37 (37:00)  
38 ASHLEY: Doesn't it feel weird?  
39 CATHY: Mmhmm.  
40 BONNIE: The thing is, I am left-handed...(?)  
41 DAPHNE: So how do you want to tape it on like one...  
42 like this...?  
43 ASHLEY: Yeah... that's what I... cause that would keep  
44 it level.  
45 DAPHNE: Keep it level?  
46 (talk about taping, inconsequential)  
47 (38:00)



1 DAPHNE: What if we do two strings, and we hold it on its  
2 side? Do one on this side and one on the other side?  
3 Cause... this is gonn.. this isn't gonna hold it like  
4 this.. it's gonna... so if we do...  
5 CATHY: What if you looped it around... like...  
6 DAPHNE: But didn't... didn't we say that putting it on  
7 the side it was supposed to be repelling would kind of be  
8 disruptive?  
9 (39:00)  
10 DAPHNE: The only way to hold it like this would be to  
11 put a st... string on this side. And then another string  
12 on the opposite side and hold it to... otherwise it's not  
13 going to hold it. It'll hold it like that if we do that  
14 if we make the string the exact same length.  
15 ASHLEY: Or you can put... are you going to put another  
16 one on the...  
17 DAPHNE: Other side.  
18 ASHLEY: Yeah.  
19 DAPHNE: Try and tape it... get off!  
20 (40:00)  
21 CATHY: So we have to figure out how to secure this to  
22 the side.  
23 ASHLEY: Okay.. so we're going to change distance here  
24 and find the force here. Yes. Okay.  
25 DAPHNE: Get off.  
26 (41:00)  
27 CATHY: Why did he say at the beginning that we had a  
28 force reader?  
29 ASHLEY: And as we do them, I guess we should save...?  
30 DAPHNE: Yes.  
31 (Enter TA)  
32 (TA helps group do something with the monitor)  
33 (42:00)  
34 CATHY: Okay, we can tape this up to the side so we  
35 can... would it work just having this rest on the side?  
36 (43:00)  
37 (TA adjusts program)  
38 (44:00)  
39 TA: So there you go, huh?  
40 CATHY: So do we decide (?) or is force in Newtons?  
41 TA: It's not Newtons. It's not calibrated. But as long  
42 as you, as long as you zero it with everything that you  
43 want on there, um...  
44 BONNIE: It'll give you a force.  
45 TA: Then what you do with the magnet will be force  
46 relative to that, so...  
47 (Exit TA)

1 ASHLEY: Um, can we change the axis, because I'm  
2 pulling... PULLING to get those little things. So we  
3 need like... (CATHY: Oh you mean, oh I see) two and  
4 minus two.  
5 (45:00)  
6 ASHLEY: Try and click on the axis.  
7 (chatter about scaling graph)  
8 CATHY: And we don't care at all about time.  
9 BONNIE: No. Because it should happen quickly and it...  
10 CATHY: So we will... pick a distance... record the  
11 distance... measure the force... and just keep... going  
12 up in (?)  
13 BONNIE: Do we have a meterstick? Need to get one.  
14 (46:00)  
15 ASHLEY: Let me try that here...  
16 ASHLEY: I guess we can still decide whether...  
17 attractive or repulsive would be better. So we could  
18 just switch that one. Can you push start for a second?  
19 CATHY: Yeah.  
20 (starts program)  
21 CATHY: So if it's minus you are... what are you doing to  
22 it?  
23 ASHLEY: Oh sorry, go ahead. Start it again and I'll  
24 show you what I'm doing. Pushing up... pulling down...  
25 pushing up... pulling down...  
26 (47:00)  
27 CATHY: Okay.  
28 BONNIE: Ehh... there we go.  
29 DAPHNE: So pulling down makes a negative force?  
30 ASHLEY: Makes it go up.  
31 BONNIE: Wait, pulling down makes it go up?  
32 CATHY: Wait, do it again, do it again.  
33 DAPHNE: So pulling down makes a negative force.  
34 BONNIE: That makes sense. Negative goes down.  
35 CATHY: We probably want to write that... in something  
36 that we would do... one of these...  
37 (2 writes in journal)  
38 (48:00)  
39 CATHY: I really think... I really didn't think we had a  
40 way to measure force based on like what he said. Okay, I  
41 think we'll be ready. So what... kind of increments  
42 should we go in?  
43 ASHLEY: Hold on a second...  
44 CATHY: Is it not lined straight?  
45 BONNIE: No, it's like twisting around.  
46 ASHLEY: As I put the magnet towards it.  
47 (problem with hanging magnet)

1 ASHLEY: Actually, can you start it?  
2 CATHY: Oh sure.  
3 BONNIE: Just a little practice run here, hold on.  
4 (49:00)  
5 ASHLEY: Let me try it again.  
6 CATHY: Okay.  
7 DAPHNE: Which are you moving?  
8 BONNIE: Here, make it touch...  
9 (fiddling with magnet)  
10 ASHLEY: Try making it one and negative one. I would  
11 love a way to (?)  
12 CATHY: Do you want to be writing down everything?  
13 BONNIE: Yeah, I do.  
14 CATHY: And I can go over there...  
15 (50:00)  
16 ASHLEY: It's not pulling down... as this comes closer it  
17 twists around...  
18 CATHY: Do we have too much string?  
19  
20  
21  
  
22  
  
23

Group Three

1  
2  
3 (0:00)  
4 (1:00)  
5 ALLISON: All right. I was thinking... could we... have  
6 something in the middle, like... a paperclip or  
7 something, for instance? And measure, like the further...  
8 what?  
9 (2:00)  
10 CHUCK: I thought we were just doing two magnets.  
11 ALLISON: We are doing two magnets but with the... like,  
12 with the distance it's going... to... what was I saying?  
13 I don't know, like, I feel like... you can feel the  
14 force... oh, no, I'm wrong. Never mind. (Exit)  
15 BRANDON: I have an idea. We can put some kind of weight  
16 on the top of (?) and make 'em go in slow motion. It's  
17 harder, but then you'd have to know what the force of  
18 friction was.  
19 CHUCK: No friction! (laughs)  
20 (3:00)  
21 BRANDON: Yeah. Why do you think that (?)  
22 ALLISON: To see if...  
23 CHUCK: Wasn't force mass times velocity?  
24 BRANDON: Mass times acceleration.  
25 ALLISON: We can see when at.. like at what height it...  
26 flipped over.  
27 BRANDON: That's good.  
28 ALLISON: Like here, feel it. Where exactly... does it  
29 go over. And then for here... oops, sorry. For here,  
30 like, where... it comes out.  
31 BRANDON: There's  $K X$  squared. You just brought  $K X$   
32 squared to the table. Thanks.  
33 DJANGO: Hooray, but we don't know the spring constant!  
34 (4:00)  
35 BRANDON: We don't need to.  
36 ALLISON: Is there any way to attach them to 'em?  
37 DJANGO: Tape.  
38 BRANDON: What's the idea?  
39 DJANGO: I don't really know.  
40 BRANDON: You just got the stuff. This is tough.  
41 DJANGO: I know.  
42 ALLISON: I think...  
43 CHUCK: We're trying to answer the question, "how does  
44 the force between two magnets.  
45 DJANGO: How about, this is attached to one side, and  
46 this is attached to another, and that magnet pulls it...  
47 till... there's not enough force... the spring...

1 BRANDON: You don't want...  
2 DJANGO: Where's the other magnet?  
3 CHUCK: "How does the magnetic FORCE between 'em depend  
4 on the distance?"  
5 DJANGO: (?)  
6 ALLISON: We could do... I don't think that we should use  
7 the springs.  
8 CHUCK: Springs don't make sense right now.  
9 (5:00)  
10 CHUCK: "How does the magnetic force BETWEEN two magnets  
11 depend on the distance BETWEEN them?"  
12 ALLISON: Basically, we have to prove  $F$  equals  $K Q$  one  $Q$   
13 two over  $R$  squared.  
14 CHUCK: What?  
15 ALLISON:  $F$  equals  $K Q$  one  $Q$  two over  $R$  squared.  
16 BRANDON: Yeah. Except with magnets instead of charges.  
17 ALLISON: With magnets instead of charges. So...  
18 BRANDON: I mean, we can figure out a max distance.  
19 Yeah, there's gonna be a max distance where...  
20 DJANGO: Don't we have to figure out force though?  
21 BRANDON: Right, before that...  
22 CHUCK:  $F$  equals  $K Q$  one  $Q$  two over  $R$  squared...  
23 BRANDON: No, that's the wrong side. There's gonna be a  
24 max distance... that it'll allow itself to be, before  
25 attracting all the way.  
26 CHUCK: That brings back friction....  
27 ALLISON: I don't think it matters.  
28 (6:00)  
29 CHUCK: It just scared you!  
30 BRANDON: I know!  
31 ALLISON: Cuz' we're not measuring the force. We're  
32 seeing how the force is affected.  
33 DJANGO: That's gravity.  
34 BRANDON: Who could think of all those equations? This  
35 is the spring constant!  
36 ALLISON: I don't think it matters with these, cuz' we're  
37 not trying to find the exact force, we're just trying to  
38 find how force... how force and... distance relate.  
39 We're not looking, we're not... we're not saying like...  
40 BRANDON: There you go.  
41 ALLISON: I think that... what we need to do is... mark a  
42 spot where one magnet is gonna start out at. And bring  
43 the other one closer...  
44 BRANDON: What if you tape one to the thing...  
45 DJANGO: We need something that...  
46 BRANDON: Can't move.  
47 DJANGO: No friction.

1 BRANDON: Space?! You want... space?  
2 CHUCK: Let's ice the table over!  
3 DJANGO: We should go to space...  
4 (7:00)  
5 ALLISON: We could... hang something... in the air.  
6 There's like... air friction, but that's not... if we  
7 hang them.  
8 DJANGO: Yeah, like a... thing where they... like a  
9 pendulum kind of thing?  
10 CHUCK: Yeah.  
11 DJANGO: We need string! (leaves)  
12 ALLISON: If we have like...  
13 BRANDON: I don't understand this pendulum idea.  
14 ALLISON: I'm trying to explain it to you now. It's so  
15 you have... two things like hanging, and then you bring  
16 them like... they're on a string, so there's no...  
17 BRANDON: Oh, so M G will be the same on them.  
18 ALLISON: What?  
19 BRANDON: If they weigh the same, M G will be the same if  
20 they're both on the string... bring the strings closer  
21 together.  
22 ALLISON: To weigh them?  
23 CHUCK: Do we have anything to hang them to weigh them  
24 from though?  
25 BRANDON: Bring the strings closer together.  
26 ALLISON: To weigh them?  
27 CHUCK: I mean, to hang them from.  
28 BRANDON: We could make something.  
29 ALLISON: Well, we'll make a little contraption.  
30 BRANDON: We could make something using a box...  
31 cardboard box.  
32 ALLISON: So like...  
33 CHUCK: We could use the microphone!  
34 ALLISON: Just pull up (?) Sorry.  
35 (8:00)  
36 CHUCK: No it's (?) probably short out the mic or  
37 something. I know it's a bad idea. I'm just curious  
38 what would happen if you put a magnet near a microphone.  
39 I'm not going to do it, I'm just curious what happens if  
40 you put a magnet near a microphone. A microphone.  
41 BRANDON: Do each thing hanging down...  
42 ALLISON: I feel like... okay... oh, I like... okay,  
43 ready, look at this for a second. See like, I'm pushing  
44 these two magnets apart, right? If we can get the  
45 distance of where... it repels it too, then that's like  
46 our starting...  
47 BRANDON: That's more supposed to be (?)

1 ALLISON: No, still from hanging from those.  
2 BRANDON: How can you get the distance from hanging,  
3 it's... especially if it's hanging off the side, it's  
4 gonna go up like this... you're gonna have to measure the  
5 height...  
6 (9:00)  
7 CHUCK: I say we do... the most you could do is lower it,  
8 using one of the things to keep it steady.  
9 BRANDON: No, this idea that you had was great.  
10 Actually, this was a really great idea. Because you can  
11 tape one of these, well, for the repulsion, you can still  
12 tape one to there and (ALLISON: Just figure out how far)  
13 you can get... this value. (laughs)  
14 CHUCK: Should we tape 'em down to see (?)  
15 BRANDON: That's like a dipole.  
16 ALLISON: I feel like if we do all parts of it on like...  
17 BRANDON: No, I mean, remember that homework he asked  
18 about dipole?  
19 DJANGO: Oh yeah, so they have to do that.  
20 ALLISON: I feel like there's a force of friction.  
21 CHUCK: Keep the one away from it!  
22 (10:00)  
23 ALLISON: Wait, I did it... hold on, I did it before and  
24 it didn't mess up. Let's see 'em.  
25 BRANDON: This one doesn't have rubber on it.  
26 CHUCK: There's another problem. Find another magnet  
27 without rubber.  
28 ALLISON: No, you hold the one rubber one.  
29 DJANGO: Yeah, you hold the rubber one, and you let the  
30 other one move.  
31 ALLISON: See, and then you get this... yeah, as long as  
32 the friction is... you can neglect it.  
33 CHUCK: Hold on, question, question, question,  
34 question... When the velocity... I have a question, when  
35 the velocity, for example, if you have it around here...  
36 it's only that initial force...  
37 ALLISON: (gasps and applauds) I know what to do!  
38 CHUCK: What?  
39 ALLISON: All right. We measure. We take it like...  
40 this is like... all right, ready? Here's like our  
41 farthest point. You move it a little bit closer.  
42 CHUCK: Where's our ruler?  
43 ALLISON: What? And then, like, there, no.... it's not  
44 working... like see how it...  
45 CHUCK: You mean a centimeter at a time?  
46 ALLISON: (?)  
47 (11:00)

1 DJANGO: We need it on wheels.  
2 BRANDON: We need something that...  
3 CHUCK: That's just too complex... we should do it in  
4 the, hey guys, we should do it in the pipes!  
5 BRANDON: Jesus Christ.  
6 DJANGO: Think about those little skateboards that you  
7 used to play with. (crosstalk)  
8 BRANDON: You know what? That's a better idea than the  
9 one we have right now, because with that you can do  
10 different distances.  
11 DJANGO: Hot Wheels? (laughter)  
12 BRANDON: Well I guess can too, but... we need to do, we  
13 need to make up a table with like distance... one  
14 millimeter, two millimeter, three millimeter, four  
15 millimeter.  
16 CHUCK: Uh, centimeters.  
17 ALLISON: Millimeters.  
18 BRANDON: Millimeters.  
19 CHUCK: You want to do one millimeter at a time?  
20 BRANDON: Yeah.  
21 CHUCK: Ouch.  
22 BRANDON: So like one millimeter and you're, we're like,  
23 okay, this is zero millimeters... like that far...  
24 ALLISON: If we had a piece of paper that we can...  
25 BRANDON: And if we do them upright, that will reduce  
26 friction, so that's a good... so that's like...  
27 (12:00)  
28 CHUCK: Why would it reduce friction?  
29 BRANDON: Because there's less surface area touching the  
30 table.  
31 CHUCK: There's still... there's still surface area... on  
32 the walls of the thingie. If anything, this would be  
33 less friction, because if you're pushing against it like  
34 this...  
35 BRANDON: No, but this one's wider, so that doesn't get  
36 any on the walls. Since that one's wider, it saves it.  
37 DJANGO: Everyone's writing theirs.  
38 CHUCK: Yeah, that's what I was thinking, we should  
39 write.  
40 ALLISON: What?  
41 DJANGO: We could balance it off (?)  
42 BRANDON: Because they have to weigh... equal...  
43 CHUCK: We could fly it off the balance!  
44 DJANGO: We need some Hot Wheels.  
45 ALLISON: We do need some Hot Wheels. All right. I  
46 think... this is what I think. Oh, they're not here...  
47 CHUCK: I'm listening.



1 (13:00)  
2 ALLISON: All right. I think if we have something...  
3 very specific, you know, distances, like one millimeter,  
4 like, every mark is a millimeter. We'll just mark the  
5 thing.  
6 CHUCK: Okay.  
7 ALLISON: So every time it moves we'll mark the distance.  
8 And from that distance, we can get... that's our R.  
9 CHUCK: Okay.  
10 ALLISON: That's the R where they repul... repel... or  
11 that's the R where they started to attract.  
12 CHUCK: The problem I'm personally having is that, when  
13 you do bring the two magnets together... the closer they  
14 are the stronger the force is, the faster the velocity  
15 should be...  
16 ALLISON: Oh, so we need the velocity to prove that the  
17 force... changes.  
18 CHUCK: Well... what ends up happening is that you have  
19 the... you have... the... you have the... when it's  
20 closer, it's gonna push away harder, so it's gonna travel  
21 farther. You have like a tight... when the force is  
22 barely touching it, it's barely gonna push it away...  
23 does that make sense?  
24 (14:00)  
25 ALLISON: Right, okay, so that will... that proves it  
26 though. That's the, how does the magnetic force between  
27 the two magnets depend on the distance. The force... the  
28 further it goes... the stronger the force. So, the closer  
29 it is, the further it's going to go.  
30 CHUCK: Okay.  
31 ALLISON: So, as long as we figure out a way to get... to  
32 prove that. Like that's what we're trying... we're gonna  
33 measure...  
34 CHUCK: The attraction...  
35 ALLISON: All right. For... all right, this...  
36 BRANDON: (?) as long as we put thought into (?)  
37 ALLISON: Well this is, okay, ready? We're trying to  
38 measure...  
39 (crosstalk)  
40 ALLISON: All right, we're trying to measure.. the... how  
41 force is affected by the distance. So, say you have them  
42 together. The closer they are together, the further the  
43 one is going to go away, which means the more force, you  
44 know, is on it.  
45 BRANDON: Well that's we're testing, but yeah, that's our  
46 hypothesis.  
47 (15:00)

1 ALLISON: Right, so then there... so we have to get like  
2 the distance between each, right? Between like how far  
3 it goes (BRANDON: Yeah) so... there's more force. Right.  
4 But then... how do we do (BRANDON: Together one?) Yeah.  
5 BRANDON: The same idea. Except... (CHUCK: You can't  
6 have the friction) you measure it... you just begin by  
7 measuring it... there's no... I mean, there's no  
8 perfect... you would just have to set this at... like,  
9 let's say this is zero... it's obviously (?)... and this  
10 is, you'd have to start it at one. And our answer would  
11 have to be... just discrete. It'd have to be yes or no.  
12 Cause we can't... we don't know the rate...  
13 DJANGO: Shouldn't it be ideally be the same on both?  
14 BRANDON: Yeah. And a good support for that is this...  
15 the reason I believe it's the same for both is this (puts  
16 magnets together, lets them fly apart.)  
17 (16:00)  
18 ALLISON: So we only have to do the one way and say that  
19 it represents the other way because...  
20 CHUCK: No, you should do both.  
21 ALLISON: Right. Well, we'll do both.  
22 CHUCK: We should do... guys, for this one, let's do  
23 multiple experiments.  
24 DJANGO: Doing both? But they (?) the same.  
25 (crosstalk)  
26 ALLISON: So we need a way...  
27 CHUCK: So we need a sheet of paper to do this on. Don't  
28 (?), do it on a piece of paper. Mark off distances...  
29 BRANDON: Well let's write our hypothesis. You can write  
30 that. Might as well (?)  
31 CHUCK: Do big bold lines! Are you sure you want to do  
32 this on a track?  
33 ALLISON: (?) a blank... like a clear sheet...  
34 CHUCK: A what?  
35 ALLISON: Like a blank, um, I guess we could do it like  
36 this.  
37 (17:00)  
38 BRANDON: Oh, we're doing it on a piece of paper? Make  
39 it attract? (ALLISON: That way we have...) That's a  
40 great idea, yeah.  
41 ALLISON: That way we can, we'll mark every...  
42 millimeter. We won't put a number, we'll just mark it.  
43 DJANGO: How about this?  
44 ALLISON: D'ya think? (holds one magnet up, knocks it  
45 over with another one.)  
46 BRANDON: Niiice.  
47 ALLISON: The distance?

1 CHUCK: That's a matter of different surface areas.  
2 Cause watch...  
3 BRANDON: But that's constant!  
4 CHUCK: No no no no no no no, it's gonna be able to go  
5 closer because of the surface area difference.  
6 BRANDON: Oh yeah?  
7 CHUCK: Whereas, if you have it like this, hold on  
8 (BRANDON: I have an idea...) But look, already here...  
9 (?) the entire thing...  
10 BRANDON: No, no, that's a great idea. I got it... it's  
11 great, you just do it on this...  
12 CHUCK: It's close.  
13 ALLISON: Can we mark that?  
14 (18:00)  
15 BRANDON: No, that's not what I mean. Hold on. No, this  
16 is there. Okay? You can put a ruler right here... this  
17 is constant... friction... how close does this have to go  
18 to that before it knocks over.  
19 CHUCK: Different surface area.  
20 BRANDON: But it's the same for your tra... as long as  
21 (DJANGO: This is the same.) in your experiment you're  
22 recording the same... what do you mean?  
23 CHUCK: The amount of surface area of this area right  
24 here is different from that surface area.  
25 BRANDON: Well then we'll find something flatter.  
26 DJANGO: Yeah, but then we can't do attract...  
27 BRANDON: Stop being specific, think of ideas.  
28 DJANGO: We can't do attraction that way.  
29 ALLISON: Yeah... I think that...  
30 BRANDON: Well you can kind of do attraction this way  
31 too, it's just...  
32 ALLISON: I think that we need this, because we need to  
33 prove the distance in order to say the stronger... the  
34 closer together, the stronger the force.  
35 BRANDON: The problem is (?) we're gonna come up with a  
36 max value, and everything within it is gonna be  
37 encompassed.  
38 CHUCK: That's why we're doing... that's why we're doing  
39 the track.  
40 DJANGO: What if we went this way...  
41 BRANDON: See if you can make it (?)  
42 DJANGO: Then they have the same surface area.  
43 (19:00)  
44 CHUCK: Huh?  
45 DJANGO: Then they would have the same surface area.  
46 CHUCK: The same surface area.  
47 BRANDON: My point is, no matter how you measure this,

1 once you (?) the max distance... what is... what is...  
2 what are you gonna.. are you gonna time how fast this  
3 thing goes?  
4 CHUCK: No, no.  
5 BRANDON: Once you figure out a mass distance... max  
6 distance... everything within that distance is  
7 encompassed, and you just write "yes".  
8 ALLISON: No, that's why you need this, because you need  
9 to say how far it travels. Like, it travels further...  
10 BRANDON: In an amount of time.  
11 ALLISON: No, I don't... that doesn't matter. It just  
12 travels further the closer together... no....  
13 DJANGO: But that's...  
14 BRANDON: But you're gonna get a... oh the repel one!  
15 ALLISON: The repel.  
16 CHUCK: Why don't we just do repel.  
17 BRANDON: Yeah, the repel... yeah.  
18 ALLISON: We need the track.  
19 CHUCK: For the repel... need the track.  
20 DJANGO: I don't know how to compare to the... to the  
21 attract...  
22 CHUCK: The attraction... we basically see just how  
23 fast...  
24 BRANDON: The max value...  
25 CHUCK: What happens with the attraction is the closer it  
26 is the faster (?) closer to the (?)  
27 (20:00)  
28 DJANGO: Right, but look. We have to find... force on  
29 distance... depends on distance.  
30 ALLISON: So this is distance.  
31 DJANGO: By this... jumpin' out there, it's not gonna  
32 have any more. It's, it's gonna get to a point where  
33 it's not even gonna... beat off each other, and it's  
34 gonna still keep going.  
35 CHUCK: Yeah, that's what we were talking about.  
36 BRANDON: I think that'll work for repel. But, but I  
37 don't know about... I know it won't work for the attract.  
38 It can't. Are you saying there's a max distance for  
39 repel, too?  
40 ALLISON: There's a max distance, which is when they're  
41 right next to each other. When you get them a millimeter  
42 apart...  
43 BRANDON: That's true, cause you're going the opposite...  
44 that's the opposite as the attracting force. See with  
45 the opposite... with the repel, you start, that's the  
46 max... it's gonna go.  
47 ALLISON: Well we can just... all right...

1 DJANGO: It's supposed to go that way.  
2 ALLISON: Here's how we do attract. We start at the very  
3 end. We start at, you know, as far apart as possible.  
4 No, no, no, no... listen... with  
5 (21:00)  
6 repel, we're putting.. we're starting them together...  
7 with attract... you start them far apart. You're like,  
8 okay, nothing happens, move it a little closer  
9 together... nothing happens, nothing happens, nothing  
10 happens... so you're proving that with distance nothing  
11 happens but when you get closer, something does happen,  
12 and once something happens, then it all happens (BRANDON:  
13 That's true, you're right, you're right, you start...)  
14 but we just have to show that we like, when we start  
15 back, nothing happens, so, as distance moves closer... as  
16 the distance moves closer the force... increased.  
17 BRANDON: Rather than actually drawing this map right  
18 now, just draw... we should draw a big overview of it,  
19 and we should draw what, what, we should already... we  
20 should draw what we're measuring... what our graph's  
21 going to look like.  
22 CHUCK: Remember (?)  
23 ALLISON: What do you mean, what our graph is gonna...  
24 (BRANDON: Yeah, like) here.  
25 BRANDON: Yeah, different paper. Cause you're already...  
26 you already did a lot of work.  
27 ALLISON: I'm just going to continue, cause we're going  
28 to need this eventually, right?  
29 BRANDON: So we're gonna have a track, right? We're  
30 gonna have a track like this. I mean, some of you guys  
31 gotta help me to make sure I'm not...  
32 (22:00)  
33 CHUCK: We're gonna have a track.  
34 BRANDON: There's a track, right?  
35 CHUCK: We're gonna have a, we'll have it on a scale.  
36 BRANDON: Ah, should I call.. what do you guys want to  
37 call distance? D, R, or S?  
38 ALLISON: D.  
39 BRANDON: Okay. Um. Distance is going... is there going  
40 to be one taped down...  
41 ALLISON: Yeah. We're gonna hold... cause the rubber one  
42 isn't gonna move. Cause we want one to move and not the  
43 other. So we'll hold the one. We can hold it at a  
44 certain point. We'll like mark a point. Yeah.  
45 BRANDON: Okay. Uh... how are we going to set it in  
46 place, just hold it?  
47 ALLISON: Somebody can hold it there.

1 (23:00)  
2 DJANGO: Should I like, bring some sort of wheels for  
3 that though?  
4 CHUCK: (laughs) No wheels!  
5 ALLISON: I really want... I think that wheels would...  
6 CHUCK: It's great, but it's not gonna work.  
7 BRANDON: We need a long track, though. Long and... we  
8 have to bring a level, to make sure it's level.  
9 DJANGO: There's a level over there.  
10 ALLISON: What about one of those... um... like ah....  
11 air... like ah...  
12 DJANGO: Then it would just go on forever.  
13 ALLISON: Oh, that's true.  
14 CHUCK: Keep going.  
15 BRANDON: As long as you keep the same track for  
16 everything. That's fine.  
17 ALLISON: Yeah, we're using the same thing. We are...  
18 doing...  
19 BRANDON: Distance?  
20 ALLISON: Distance. Distance and...  
21 DJANGO: I think we should come up with several ways to  
22 study this.  
23 BRANDON: Yeah, I like that.  
24 CHUCK: Tim?  
25 BRANDON: For this experiment right now...  
26 CHUCK: Wheels of some sort? Hot Wheels or something?  
27 (24:00)  
28 TA: Let me call my supplier.... It'll be here in six to  
29 eight weeks.  
30 BRANDON: ...we're using distance... which is... which is  
31 substituted in as force.  
32 ALLISON: Right.  
33 CHUCK: Right at the end of the semester.  
34 DJANGO: Let's go to Toys R Us or something.  
35 TA: Do you have a way of measuring force yet?  
36 CHUCK: Yes!  
37 ALLISON: Yes.  
38 DJANGO: Yeah.  
39 ALLISON: We're...  
40 TA: Okay, what's your plan?  
41 CHUCK: We set up a track like so. With millimeters. We  
42 have one stationary magnet.  
43 TA: Uh huh.  
44 BRANDON: This is all repulsion, by the way.  
45 TA: You're doing repulsion.  
46 ALLISON: Mmhmm.  
47 TA: Got it.

1 BRANDON: Um, we take another... magnet...  
2 ALLISON: Hold it.  
3 BRANDON: ...hold it at various distances away from this  
4 one (TA: Yes) and let it go (TA: Okay)  
5 ALLISON: We measure the distance that it goes.  
6 BRANDON: The distance that it goes is going to be big D,  
7 which is our... acting as our force.  
8 ALLISON: It's like, the closer together, the larger the  
9 force.  
10 BRANDON: That's our hypothesis.  
11 TA: Okay, okay, so... so if there's more force, right,  
12 you expect it go farther.  
13 ALLISON: Further.  
14 (25:00)  
15 TA: Okay. So, my question for you is, what is the  
16 relationship between force and that distance. Is it  
17 linear, or do you not know, or what is it?  
18 ALLISON: It should be linear.  
19 TA: Huh?  
20 ALLISON: Should it be linear?  
21 BRANDON: It seems, it...  
22 ALLISON: Cause each... like as you get...  
23 CHUCK: It's R squared.  
24 BRANDON: It would seem that, just from our hypothesis...  
25 TA: What's R squared? What's R squared?  
26 ALLISON: Linear, right? No?  
27 CHUCK:  $F$  equals  $k \frac{Q_1 Q_2}{R^2}$ .  
28 TA: Why are you using that equation?  
29 BRANDON: This is magnetic.  
30 CHUCK: (?)  
31 TA: Well, I mean, this is about motion anyway, right?  
32 Isn't it also true, like, let's say I move this to two  
33 centimeters, and it goes away, right? Let's say I move  
34 it to one, it'll move away farther, you'd think, right?  
35 ALLISON: Yeah.  
36 TA: On the way, it will go past two. It's still... I  
37 mean, while it's being pushed away, it's constantly  
38 receiving a force, and that force is changing.  
39 BRANDON: Yeah, it's receiving a force for a longer  
40 period of time at the one than it is...  
41 (26:00)  
42 TA: It's pretty tough to measure that force. I mean,  
43 how are you going to measure what the force is at the  
44 start? As it's pushing away, that distance is changing.  
45 BRANDON: We need distance over time.  
46 (Exit TA)  
47 ALLISON: So we should...

1 BRANDON: Stopwatch.  
2 CHUCK: Wait a second... mass... times... gravity!!!  
3 BRANDON: I see what he's saying. He's sayin' let's  
4 say... this is one, this is two, this is three...  
5 ALLISON: When it gets to two, it's still feelin' the  
6 force.  
7 BRANDON: It's not the same force. If you do a rate, if  
8 you do a rate...  
9 CHUCK: I'm just havin' fun.  
10 BRANDON: Distance versus... what do you think about  
11 doing a rate thing?  
12 CHUCK: We'll need the tracks.  
13 BRANDON: How much time does it take to get to there,  
14 from there, from one, from two, from three...  
15 ALLISON: You guys, this isn't going to work.  
16 CHUCK: That's why we need the track.  
17 (27:00)  
18 BRANDON: Cause what he was saying was, if you do it from  
19 zero, you're still getting that... let's say you do it  
20 from one. Do it from zero, it goes this far, right?  
21 Well, you're still feeling the force from one, from two,  
22 and from three... wouldn't that make it exponential?  
23 CHUCK: Parabolic.  
24 ALLISON: It's stick to ah... it's sticking to the paper.  
25 CHUCK: Parabolic's exponential.  
26 BRANDON: Yeah, you're right. It makes parabolic. It  
27 doesn't matter, we've got to set something up.  
28 ALLISON: It's not working cause it's... cause there's  
29 too much friction...  
30 CHUCK: It's a relationship between friction and uh lack  
31 of...  
32 ALLISON: Well, we can use these... within the track...  
33 BRANDON: We're running out of time.  
34 (28:00)  
35 BRANDON: Okay, we got fifteen minutes before we should  
36 probably start taking data.  
37 CHUCK: Well we should still be thinking about how to  
38 design the experiment.  
39 BRANDON: All right, there's gonna be a session where we  
40 get feedback.  
41 DJANGO: I'm gonna work on experiment two.  
42 BRANDON: What's experiment... two?  
43 (Exit 4)  
44 ALLISON: There's like so much friction that it's not...  
45 going away... like... would it slide better on that?  
46 That's slippery, isn't it?  
47 DJANGO: I'll get some Hot Wheels.



1 BRANDON: We need to stop and think about... what does  
2 time do if we bring it into this equation.  
3 CHUCK: Get a... get a nice long strip of that.  
4 ALLISON: I don't think it would work. There'd be like  
5 bumps.  
6 (29:00)  
7 DJANGO: It's.. it's kind of... it's one of those things  
8 that's kind of smooth and stick sometimes.  
9 ALLISON: It's like (?)  
10 BRANDON: At least we could convert it into a velocity,  
11 which is a... vector.  
12 ALLISON: Velocity. And then velocity... make sure  
13 you... make sure that there's no... no wrinkles allowed.  
14 CHUCK: I know, I know. There you go... nice...  
15 smooth... (applies tape to table) They're hanging it.  
16 BRANDON: That's what I was thinking of.  
17 (30:00)  
18 BRANDON: I need one of those...  
19 CHUCK: What?  
20 ALLISON: Wait.  
21 BRANDON: These? (L-shaped wood thing)  
22 ALLISON: It does work on this thing better.  
23 CHUCK: It does? It works better?  
24 ALLISON: Mmhmm.  
25 CHUCK: Uh huh. But wouldn't you make those lines a  
26 little bigger?  
27 BRANDON: It need to go this way.  
28 ALLISON: I know. (?)  
29 CHUCK: What?  
30 ALLISON: We'll do this experiment and then... I don't  
31 know if we can actually measure time.  
32 CHUCK: Time isn't necessary here. This is a matter of  
33 (?) acceleration and deceleration.  
34 BRANDON: Okay, let's think about... this height... we  
35 shouldn't think about design. We can design it however  
36 we want. We should start, we should do theory. Like  
37 what's your theory here.  
38 (31:00)  
39 CHUCK: No, we need to design the experiment!  
40 BRANDON: This IS the design. I mean, it really is.  
41 Once you have this, you can make anything. There's not  
42 any limitations.  
43 DJANGO: So like, my theory is.  
44 BRANDON: You got this magnet hanging from... a lever  
45 (1 & 3 crosstalk)  
46 BRANDON: Like that?  
47 DJANGO: This one's better for distance. Different

1 distances.  
2 DJANGO: Do we have to use both batteries like that?  
3 (32:00)  
4 BRANDON: Use what?  
5 DJANGO: Like both batteries against each other?  
6 ALLISON: Magnets?  
7 DJANGO: Could it like, pick up some... (BRANDON:  
8 Something) paperclips?  
9 BRANDON: Yeah. That's a very good idea.  
10 ALLISON: But we're trying to... the force between the  
11 two magnets, depending...  
12 DJANGO: No it's...  
13 BRANDON: (?)  
14 CHUCK: Watch this. It launches.  
15 ALLISON: All right. Where...  
16 (33:00)  
17 BRANDON: Are you making this so that the string  
18 difference... something needs to be different. Something  
19 needs to move. Something needs to be our measuring  
20 device. Like... like how much it stretches, or how much  
21 (?) right here.  
22 CHUCK: Guys, if we need a blade, I have one. Guys... a  
23 blade?  
24 ALLISON: All right, yeah, um...  
25 BRANDON: That's great.  
26 ALLISON: This's really hard. Are they all going to be  
27 like... there's no way to do this... type of thing?  
28 CHUCK: Great Caesar's ghost!  
29 (34:00)  
30 CHUCK: We can tape this down or we can like... something  
31 so that we don't have to hold it like that... where's  
32 the other one? He has the other magnet.  
33 BRANDON: So what are you measuring?  
34 DJANGO: I don't know.  
35 CHUCK: He's just having fun.  
36 DJANGO: I'm thinking.  
37 CHUCK: Guys we have our table, we have our little uh  
38 slider ready...  
39 BRANDON: What if... get something... it can't... I guess  
40 it can't be metallic. But it has to weigh... as much as  
41 this puppy here. (ALLISON: So (?) like this is our  
42 starting point.) You put an even weight on the other  
43 string...  
44 CHUCK: Do... do units of five on that thing... like  
45 every five make it longer since we know...  
46 BRANDON: Start at a...  
47 ALLISON: Wait, one... one, two, three, four...

1 CHUCK: First one's zero.  
2 (35:00)  
3 ALLISON: Zero, one, two, three, four, five...  
4 DJANGO: You're missin' it.  
5 BRANDON: I know, I'm trying. I was thinking that would  
6 be weighed into it, but like if you had a weight on this  
7 side, and you bring that closer to this... it's how much  
8 it pulls the weight... up.  
9 DJANGO: Wouldn't it go until it hits this, then?  
10 BRANDON: (laughs) Maybe. I don't know... hold on... but  
11 I do like it. Yeah, it's someth... (DJANGO: We need two  
12 pulleys) we need something that measures, do you know  
13 what I'm sayin'? No, no, no. You want this other  
14 rope... attached to the weight. But you can't have it...  
15 you can't have the other weight metal, cause you don't  
16 want it to attract this.  
17 DJANGO: We'd have to get them to repel, and see how much  
18 it repels it there.  
19 BRANDON: No, because... if the other side of the pulley  
20 was on it, it would be.. and you had the same weight,  
21 it'd be like equalized right there... so let's say my  
22 finger's the other weight I'm talking about. It's  
23 hanging onto this.  
24 (36:00)  
25 BRANDON: And that's equal. That's at an equal distance,  
26 right? Now you take a meter stick upright... now that's  
27 gonna pull my thing up... a certain distance... it's  
28 gonna pull this weight up that distance.  
29 DJANGO: Right.  
30 BRANDON: But then it goes back to that same problem he  
31 was talking about with the time. Because no matter what,  
32 this zero is gonna pass the same measurement you made for  
33 one, which is gonna pass the same measurement you made  
34 for two, pass the same measurement you made for three...  
35 or... you could always subtract this guy... no, you  
36 can't. Well, think about a different kind of force.  
37 Like height. As you get higher, the tension... the force  
38 gets... the force doesn't...  
39 CHUCK: Guys... I say we should try this one.  
40 ALLISON: We could time it.  
41 CHUCK: Time what? The repulsion? Or the attraction?  
42 (37:00)  
43 BRANDON: So what is this... but we're gonna time it...  
44 ALLISON: Can I see the... can I just see the...  
45 CHUCK: Why don't you measure the time of repulsion?  
46 ALLISON: Because... of what...  
47 CHUCK: You don't have to.

1 DJANGO: Until it stops... is that what you're talking  
2 about?  
3 ALLISON: Yeah.  
4 CHUCK: You don't need that cause...  
5 ALLISON: No, because... from here... oh... no, I don't  
6 think the time... because it's less... it's not going as  
7 far... (CHUCK: Exactly) so it's not gonna be as long.  
8 CHUCK: You have to measure distance on this.  
9 ALLISON: But he said... okay, what Tim was saying  
10 though, is that, as it passes, like, one millimeter, it's  
11 gonna get the force from like each close...  
12 BRANDON: ...from two, and it's gonna get the force from  
13 when you start at three. If you start at zero...  
14 CHUCK: That's why it shoots the farthest.  
15 BRANDON: ...it moves out here, yeah, because you keep  
16 getting that force. (?)  
17 DJANGO: There's an equation for that, isn't... you can  
18 just do exponential, right?  
19 (38:00)  
20 BRANDON: Yeah, that's what I'm saying, it's  
21 mathematical. It's a mathematical relationship. Is it  
22 exponential, is it? When you keep, when add this and you  
23 add that and you add that you keep adding that distance  
24 as you go. You keep adding that next one.  
25 DJANGO: I wish I was smart.  
26 ALLISON: Isn't it like...  
27 BRANDON: Me too! Like... the zero... is the max  
28 repulsion because... all these added up. And then you  
29 have your four repulsion, which is gonna be equal...  
30 which is gonna be... three is gonna equal... uh, some  
31 number minus the four repulsion. Two is gonna equal...  
32 some number minus the three plus four repulsion. One is  
33 gonna equal some number plus... you know what I mean?  
34 That number is... is the force... that's happening.  
35 DJANGO: So there's a constant.  
36 (39:00)  
37 BRANDON: Maybe.  
38 DJANGO: But we got to find every single millimeter in  
39 between too.  
40 BRANDON: Yeah, that's true. If that's really a  
41 constant.  
42 ALLISON: Gimme a piece of paper, please.  
43 BRANDON: What do you need?  
44 ALLISON: Can I have a piece of paper out of there?  
45 BRANDON: I don't have much paper left.  
46 ALLISON: It's my notebook!  
47 BRANDON: Okay... that's a good idea, actually. We gotta

1 use the spring constant. It's complicated. We just need  
2 to figure out these mathematics. Once we figure out the  
3 mathematics, we'll be fine.  
4 (Enter TA)  
5 (40:00)  
6 DJANGO: We're not sure if that's like an exponential  
7 growth or decline or if there's a constant involved.  
8 TA: Do you know, do you know... right.  
9 BRANDON: There's gotta be a max... that we're gonna be  
10 able to...  
11 TA: Do you know how far it'll go, distance-wise? You  
12 will have to know how the force depends on distance.  
13 Because, whatever the force is, that affects what the  
14 acceleration is.  
15 BRANDON: That's what our question is.  
16 TA: That's what the question is, so... you're trying to  
17 measure force, and to do it by moving it distance, in  
18 that kind of way, is circular.  
19 ALLISON: But... but we're saying that the distance is...  
20 the...  
21 BRANDON: We need to use... other forces...  
22 ALLISON: We're trying to say like, that the distance...  
23 is the... like the further it goes... the more force.  
24 Like that's... you can assume that.  
25 (41:00)  
26 TA: Um... yes. There's more... I mean, right. The  
27 farther it goes, the more force is must've had on it to  
28 start with, but, you need to relate that distance you  
29 measured to the force you're actually interested in.  
30 Okay.  
31 ALLISON: No.  
32 TA: You're trying to measure force. The thing you're  
33 physically measuring is distance. You need a bridge to  
34 get from that distance to force, somehow. You get to  
35 (?), it might not be linear. It might take twice as, or  
36 four times the distance.  
37 (Exit TA)  
38 ALLISON: I don't understand.  
39 BRANDON: A bridge to get from... the force... the  
40 distance...  
41 ALLISON: So do you think... well, the timing won't work.  
42 BRANDON: That's why (?)  
43 CHUCK: I think we got a stopwatch (?)  
44 BRANDON: It's definitely a hanging deal.. (laugh)  
45 CHUCK: Meters per second squared.  
46 (42:00)  
47 ALLISON: Yeah, but how do you...

1 BRANDON: Gravity's... see, here's M G H, if it's  
2 hanging. Um... it's just a... um... it's just uh...  
3 (inactivity)  
4 BRANDON: These are pulleys. And this was that weight.  
5 ALLISON: Distance is...  
6 BRANDON: This was the same weight...  
7 DJANGO: So if we get the opposite with the same  
8 (BRANDON: same) here, and push... and put it at certain  
9 point, and then flip it up and see how... that's the same  
10 thing, man.  
11 BRANDON: Same idea.  
12 DJANGO: Yeah.  
13 BRANDON: Because you measure distance. We can, we can  
14 figure out um.. how much weight it will lift up...  
15 different weights...  
16 DJANGO: Yeah...  
17 (43:00)  
18 ALLISON: To be... put something onto one of the  
19 weights... like one weight is holding it, and this is  
20 holding something else...  
21 BRANDON: It takes force to lift something! It'd be M G  
22 H then, if we lift it, and M would be...  
23 ALLISON: \*gasp\* We put paperclips on them! And the more  
24 paperclips, the heavier it's gonna be... so we just  
25 see...  
26 BRANDON: Same height...  
27 ALLISON: At the same...  
28 BRANDON: Same... we can't do paperclips, we'd need a lot  
29 of them... for that...  
30 ALLISON: Well we do like little...  
31 BRANDON: We need two pulleys... we need two pulleys.  
32 ALLISON: So weight is a force, so it's showing the  
33 force... but what... where does distance come into play?  
34 Do we measure the distance?  
35 BRANDON: And another pulley!  
36 (TA calls for students to hold discussion)  
37 ALLISON: I like this idea.  
38 BRANDON: I don't know... I guess...  
39 ALLISON: I feel like that's what they're doing...  
40 BRANDON: This idea... I like this idea...  
41 ALLISON: All right. Screw that. I'm the... it's  
42 like...  
43 BRANDON: What kind of relating...  
44 ALLISON: Force... we're relating two forces.  
45 BRANDON: How much force does it take to lift it...  
46 ALLISON: How does that relate to distance?  
47 (45:00)

1 BRANDON: Weight. How it relates to weight.  
2 ALLISON: Yes, but we have to depend on the distance  
3 between them...  
4 (TA instructions)  
5 BRANDON: We have to take data today?!  
6 (TA instructions)  
7 (46:00)  
8 BRANDON: Okay, well first we thought maybe we could  
9 design a track and measure distance. But then, when you  
10 do that, you end up, kind of, going in circles with the  
11 force that you're trying to get. Cause you're trying to  
12 say that distance is the force. So then we started  
13 thinking maybe we should use, um, something uh hanging  
14 off of like two pulleys, and, use weight, sort of, like M  
15 G H... different weights... and how that relates to the  
16 attraction between magnets. We're on that wavelength  
17 right now.  
18 (Group 3 presents)  
19 (47:00)  
20 (Group 1 presents)  
21 (48:00)  
22 (49:00)  
23 (Group 4 presents)  
24 (50:00)  
25 (Group 5 presents)  
26 (51:00)  
27 (52:00)  
28 BRANDON: Yeah, I was just thinking that, like, we're  
29 sort of measuring a force like M G going up, based on a  
30 certain distance that magnets are away from each other,  
31 but the thing that's changing there is mass, and then the  
32 distance that you space them. So I was just gonna run  
33 this by everybody, cause I don't always catch things. If  
34 you do trials with different distances the magnets are  
35 from each other, based on... and you do different masses  
36 for each of those.  
37 V: How are you attaching your... the mass to the  
38 magnets? How are you.. are you actually attaching...  
39 (53:00)  
40 BRANDON: No, it's on a pulley system, so the mass is  
41 actually on the other side. (V: Oh, okay) And then the  
42 magnets are gonna be set a certain distance, and what  
43 you're measuring is the attractive force.  
44 V: Any idea how much the change in...  
45 BRANDON: Yeah, in some ways it might not even lift. But  
46 we do five trials and we would do.. uh, you would do  
47 different... that's how... those five trials would

1 represent different distances those magnets were. And as  
2 the one pulled closer to the stationary one's down  
3 here... as the one pulled closer to the stationary, it  
4 would lift the weights.  
5 V: So do you think that (?) so the magnets come together  
6 and they don't move at all? I mean, or...  
7 BRANDON: No, you're going to have different.. different  
8 weights to be able to tell how... the M G is what you're  
9 measuring the force over there... to tell you...  
10 DJANGO: I don't know whether or not what you're saying  
11 is...  
12 ALLISON: Yeah, I'm like, oh, I don't know what you're  
13 saying.  
14 BRANDON: That's why I ran it by the group.  
15 TA: Tyler had a question... cause, they claim they ran  
16 into problems because they're doing something where  
17 you're attracting magnets, right?  
18 (54:00)  
19 V: (something about what 2 just said)  
20 TA: Okay, so, how is what you are doing different than..  
21 you're not actually attracting them and letting them snap  
22 together are you? I mean, how is what you are doing  
23 different? Are you starting with them sort of...  
24 BRANDON: Well there's a resistance already with this  
25 weight. Sometimes it might just attract together. What  
26 we're doing is... okay, here, I guess we need a visual on  
27 this.  
28 V: Would you be like, would you be putting weights on it  
29 to see like...  
30 TA: Maybe I just don't understand what you said.  
31 BRANDON: Okay, that's usually the case. Um... not you  
32 personally, but anyway... you have one stationary magnet  
33 that's like taped. That's down here. The other one is  
34 on a pulley system with different weights that have to be  
35 set and established, cause we don't, I don't know how  
36 much these things way. So, then there's different  
37 trials. And those trials are based on different  
38 distances away from that magnet. You're gonna have to  
39 find a set weight though, for it to be sort of equal so  
40 you can position it where you want it.  
41 (55:00)  
42 TA: When you take a data point, though, nothing is  
43 moving? Is that true?  
44 BRANDON: When you take a data point, your trial's at...  
45 you're only measuring the amount of weight, so, you're  
46 measuring just a force. At different distances though,  
47 you have five different trials. So you can plot it



1 several different ways. You could plot it as force  
2 against distance, or you could just plot mass versus  
3 distance.  
4 TA: I can't picture this.  
5 DJANGO: I think we'll have to do it. Cause I can't  
6 picture it.  
7 ALLISON: I can't picture it.  
8 V: (question)  
9 BRANDON: The distance is already set. The weight is the  
10 variable.  
11 V: You just vary the weight?  
12 BRANDON: Yeah.  
13 (58:00)  
14 TA: So if you want to keep communicating about this, I  
15 would suggest that you build it, and then, you just check  
16 out what it is they're doing, and see if it works better.  
17 I don't know.  
18 BRANDON: And if it doesn't, yeah, I mean, I don't know.  
19  
20  
21  
22  
23  
24

Group Four

1  
2  
3 0:00)  
4 BETH: (reading from lab report grading) "Very good also,  
5 except that the term 'all slopes' in your rule is not  
6 very clear. All slopes... to be...  
7 AMELIA: "Between any two points or between consecutive  
8 points only." (?) Well, we were looking...  
9 DIANE: \*laughs\* Did you see this guy? Which action  
10 figure is that, anybody know? My lack of...  
11 CARL: Magneto maybe? I don't know.  
12 TA: Of course it's Magneto!  
13 DIANE: Is it?  
14 AMELIA: I love that movie.  
15 DIANE: That makes sense...  
16 CARL: It just looks different in the movie.  
17 (TA gives instructions on lab handout.)  
18 (1:00)  
19 (2:00)  
20 (TA asks class to brainstorm ideas. "What do you have to  
21 measure?" "How would you measure distance?"  
22 (3:00)  
23 (TA asks "How would you measure force?")  
24 CARL: (whispers) Computer program.  
25 BETH: How far it moves from its initial position? I  
26 don't know. Cause if, like, you pulled the two  
27 centimeters and you moved it in right away, you know that  
28 the force is stronger. But maybe if you move it out like  
29 six centimeters it'll move in a centimeter (?) move in  
30 the whole way?  
31 TA: Okay, something that you could compare forces and  
32 know which ones are stronger and weaker.  
33 BETH: But I don't know how to measure the magnitude.  
34 (4:00)  
35 TA: But we need an actual magnitude.  
36 (Another group suggests timing it. This group responds  
37 skeptically. "It moves really fast." Another group  
38 suggests charges, TA points out that magnets are not  
39 charges.)  
40 AMELIA: Do you actually want 'em in a force, or can we  
41 use something that's representative... of it.  
42 TA: Not only do we want, but we absolutely MUST have a  
43 FORCE.  
44 AMELIA: Oh. Aight.  
45 (5:00)  
46 (Class talk)  
47 TA: Have you ever seen a detector that measures force?

1 I'm asking, have you?  
2 DIANE: The tension? When we're doing like a spring,  
3 like the oscillation, wasn't it like a force density  
4 thing?  
5 TA: You mean when we did that thing with the springs and  
6 we had that little force probe that measured the force?  
7 DIANE: Yeah.  
8 TA: That? Oh yeah, if you look at that little box you  
9 have, you'll see one of those. I wasn't saying that you  
10 were wrong, I just wanted you to remember that yes you  
11 had used this thing before. Now, so you have this, and  
12 you can use it, and you know the program is on here to do  
13 the, you know, it's the Old Motion Detector program that  
14 you used last time. There's also a motion detector in  
15 there you could use, if you want. There are other ways  
16 to measure force as well, and there's other...  
17 (6:00)  
18 TA: You can use anything in the room that you want...  
19 so... how would you like to do that? So you have... to  
20 think about precisely how you're gonna set this up to  
21 measure force and how you're going to get this distance  
22 between the magnets. Now, here's the other issue.  
23 What... what sort of data do you need? Good answer!  
24 You're gonna have to find the relationship between force  
25 and the distance... apparently there was enough force  
26 there (?) distance.  
27 (7:00)  
28 (Class talk "Is one data point enough" No.)  
29 DIANE: Because one is not... well you know the  
30 relationship between force and that one distance but...  
31 that doesn't tell you how it varies.  
32 TA: Okay.  
33 (Class talk. Think about how to get different  
34 distances.)  
35 (8:00)  
36 AMELIA: All right guys, what are we gonna do first?  
37 I'll be data. I haven't done data in...  
38 BETH: I can be the journalist. I haven't done that  
39 in...  
40 AMELIA: Have done eval... no... okay, I know what we  
41 should do for this...  
42 (9:00)  
43 BETH: How did (?) last time?  
44 CARL: I was journal. Katie was checker.  
45 BETH: And the week before journal you were what?  
46 CARL: Checker.  
47 BETH: Checker, yeah, so we are going in the right order.

1 AMELIA: I'm going to be evaluator next.  
2 CARL: So I'll be data?  
3 BETH: After check... I haven't done journal yet.  
4 AMELIA: Journal is...  
5 BETH: Then I'll do journal again last. We do the first  
6 thing... aw, you're lucky.  
7 AMELIA: I just don't want to be evaluator. I can't do  
8 that, with the...  
9 CARL: Yeah, we'll see what we get this week.  
10 AMELIA: I don't want them to be like 'this group,  
11 there's something fishy... conspiracy...'.  
12 BETH: I don't understand how we're going to use this  
13 thing.  
14 AMELIA: Oh I know. Well, I don't...  
15 CARL: We need a spring... then we need to hook it up.  
16 (10:00)  
17 AMELIA: Hey, you're a guy. You should know how to do  
18 this.  
19 (Exit 3)  
20 (Re-enter 4)  
21 DIANE: These are more powerful and like you could  
22 probably see a better effect, except that it's... like  
23 hard to...  
24 BETH: Can I play?  
25 CARL: Should I go to...  
26 AMELIA: What we need to do... here guys, this is what we  
27 need to do. Come here, guys. I know how we should do  
28 this.  
29 DIANE: What are you thinking?  
30 AMELIA: Now the best thing is... the relationship  
31 between force and distance we'll have to do um...  
32 BETH: Jeez, this is so fun!  
33 DIANE: How are we gonna... how we gonna measure it with  
34 this?  
35 AMELIA: Well yeah but... we'll have to do different  
36 distances, and then what we have to do is we do it like  
37 ten trials per each distance and we...  
38 DIANE: With what... how are you gonna set it up though?  
39 AMELIA: I don't know. I figured Ryan's a guy, he should  
40 know how to do it. But my point is that once we like...  
41 BETH: Should we attach... something to the magnet...  
42 like, put them on...  
43 DIANE: Do you want the less strong one? If that'd be  
44 easier to work with. Like this we could see a bigger  
45 effect.  
46 (11:00)  
47 BETH: Yeah, it's so weird to like... (?)

1 (crosstalk)  
2 AMELIA: So are we gonna have to like... put tape on  
3 these, like, closer to the spring?  
4 CARL: I don't know. We gotta figure out how we're gonna  
5 measure force or whatever.  
6 DIANE: I think we're gonna have to like, we'll have to  
7 keep, like, if you keep this, like, here, and then you  
8 have this attached somehow to up here, and then, yeah,  
9 well, what feels it? It's this thing pulling down?  
10 BETH: Yeah. So I guess, if we hook the spring onto (?)  
11 that's the spring.  
12 AMELIA: Right. So if it pulls... oh we need a loose  
13 spring, cause that's not gonna...  
14 (Exit 2 and 4)  
15 (12:00)  
16 (setting up equipment)  
17 (13:00)  
18 (14:00)  
19 (15:00)  
20 (Enter TA)  
21 TA: Why are you doing that? What are you gonna do?  
22 AMELIA: Tie a magnet (?)  
23 (conversation is going on off-camera)  
24 DIANE: Oh and for this we're going to have to... we're  
25 gonna have to use the motion detector, right? Cause  
26 it'll pull it down a certain length and then we'll have  
27 to translate that thing into a force.  
28 AMELIA: Well the thing is, we like... we like... you...  
29 a couple inches...  
30 (16:00)  
31 (phantom voice)  
32 CARL: See, when we change the spring the (?) If we  
33 just... if we just... if we just changed the length of  
34 the fishing line... that might work. Like if we hook it  
35 over top of the force probe... put this... you make sure  
36 this stays on the ground... that'll give you something.  
37 BETH: Tape that to the ground and then change the length  
38 of...  
39 DIANE: All right let's try... let's see if that's better  
40 for what...  
41 BETH: So we can make a loop?  
42 DIANE: How are we gonna keep that on there? You could  
43 tape it on there.  
44 BETH: Yeah, gimme a piece of tape.  
45 CARL: Wait, are we gonna (?)  
46 BETH: Well I think we should wait until the hook (?) and  
47 then we can run a piece of fishing line through it. Then

1 let the (?) change the length, like pull it up higher.  
2 (17:00)  
3 CARL: Or we can just (?) really long piece? If we tape  
4 a long piece of line, then we don't have to... cause (?)  
5 tape, do you know what I mean?  
6 BETH: So just cut the... get a little piece and just cut  
7 it?  
8 CARL: Or just like pull it up a couple of inches (?)  
9 BETH: Okay.  
10 (Exit 2)  
11 DIANE: Which program is this?  
12 CARL: For the motion detector.  
13 DIANE: Hm, the only one (?) Uh oh. That's like cause  
14 this is not... is this... is this anywhere... is it  
15 plugged in or anything?  
16 CARL: You need to find which way they attract and which  
17 way... they attract that way...  
18 (18:00)  
19 BETH: (?)  
20 DIANE: If you just slipped a little string inside, would  
21 it just stay there? Oh no, we have to secure it anyway,  
22 I think it'd be... well you know like the force  
23 between... two... we just hold it between it?  
24 AMELIA: How about we hang the...  
25 BETH: Wait... what do you mean, between these two?  
26 DIANE: Yeah.  
27 BETH: It's glued together.  
28 DIANE: Oh.  
29 AMELIA: Wait... are you saying to put like... hold that  
30 one by the string and let that one just be attracted to  
31 that?  
32 DIANE: Yeah we have to keep one like... planted on the  
33 ground.  
34 CARL: No we have to... we have to let this one plant on  
35 the ground because there's... it's gotta feel force.  
36 AMELIA: And why couldn't it go up that way? Why can't  
37 they attract that...  
38 CARL: Because then that wouldn't measure the force  
39 because... this is what measures force.  
40 DIANE: Oh that's true... and we would only be...  
41 AMELIA: Yeah, it's that they are repelling... (?) this  
42 is gonna measure like something...  
43 DIANE: Yeah we'd only be going one di... we'd only be  
44 going the attraction force then, yeah. That's what...  
45 CARL: (?)  
46 DIANE: Yeah that would be very difficult to know the  
47 compression.

1 (19:00)  
2 AMELIA: So are just going to do different distances and  
3 then measure them and do like... do to see if it's like  
4 an inverse or direct relationship type thing?  
5 DIANE: Sure... yeah.  
6 BETH: You can wrap it the way you were... and then I'll  
7 wrap the tape around it...  
8 AMELIA: (?)  
9 BETH: So that the bottom is still exposed.  
10 DIANE: But this is not working. The box is connected,  
11 the box is powered, the box is turned on. No, this is  
12 not on, probably, right? What does this (?) on the  
13 bottom?  
14 Oh like a CD port.  
15 BETH: So when you wrap it around (something technical  
16 about fastening magnets)  
17 (20:00)  
18 (Enter TA)  
19 TA: All right what's up here. What's the plan?  
20 BETH: All right. We think we're going to put this on  
21 the ground and tape it down so it can't move. And then,  
22 put this so that it's attracted to this, and then, tie it  
23 on here and change the length of like...  
24 TA: Oh right, so you change how far apart they are.  
25 BETH: Yeah.  
26 TA: ...force for each of those different distances.  
27 BETH: Yes.  
28 TA: Okay.  
29 BETH: Yeah.  
30 DIANE: So we don't... we don't need... we can just  
31 measure the force use... okay... so we don't need the box  
32 here?  
33 TA: You need the box. The little box in the back? Yes.  
34 But you don't need \*that\*.  
35 DIANE: Yeah, that's...  
36 TA: So... okay...  
37 DIANE: Go on with that.  
38 TA: No no no, that was wrong.  
39 DIANE: Oh.  
40 TA: The box I was referring to was that little box back  
41 in the corner that you plug this thing into.  
42 DIANE: This plugs into...?  
43 TA: So you want to exit the program. This force probe  
44 is plugged into a box.  
45 (21:00)  
46 (something)  
47 TA: That box goes into the computer. You are using that

1 box. But you are not using the motion detector.  
2 DIANE: The motion detector. How do I get out of here?  
3 TA: That wasn't a question (?) Start it up again.  
4 DIANE: It is this one though.  
5 TA: Pick "Com 1"  
6 BETH: So should we measure like lengths, like make (?)  
7 lines.  
8 CARL: Make what lines?  
9 AMELIA: Well I mean this one is being still.  
10 (crosstalk)  
11 TA: (something about program) Make sure the little box  
12 is plugged into the computer, oh, make sure the box is  
13 ON. Is the little box turned on? There's a power switch  
14 somewhere.  
15 AMELIA: No. Yeah, I guess.  
16 (22:00)  
17 DIANE: So how did you guys end up doing that?  
18 BETH: We're trying to figure that out.  
19 AMELIA: Will it still be attracting when... I can't wait  
20 for the third X-Men.  
21 DIANE: You're just trying to keep it on there?  
22 (talk about hanging the equipment)  
23 (23:00)  
24 (24:00)  
25 (This part is hard to hear. They discuss the mechanics  
26 of how to build the equipment.)  
27 DIANE: All right. So let's start... let's see like what  
28 we can see based on, yeah, with what distance and what's  
29 possible to measure.  
30 (?)  
31 (25:00)  
32 DIANE: Down to the floor.  
33 AMELIA: Let's put some tape like on the bottom.  
34 CARL: (?)  
35 (More inaudible talk about setup.)  
36  
37



## Appendix B: SCL-2 Materials

# Everything You've Ever Wanted To Know About Lab... But Were Afraid To Ask

## Mission Statement

*You are going to learn three basic things this semester:*

4. **How to recognize *relationships*.** All the complicated stuff that goes on in a physics lab can be boiled down to a simple premise: if you change one thing, another thing changes too. First we identify *what* changes. Then we try and decide *in what way* it changes. This is what we call *functional dependence*. That's all physics equations are, really, a precise statement about how changing one thing will affect another thing. In this lab, we will explore many different kinds of physical phenomena and try to figure out *what affects what* and *how*.
5. **How to make a persuasive case for your data.** In physics, answers don't just pop up out of the ground, ready to be printed in a textbook. Data from an experiment doesn't make much sense at a first glance. First you must be able to understand what data *means*. Then you need to be able to *present* this data to others in such a way that it will persuade them that the *conclusions* you've drawn from this data are correct. In order to do these things, you must have a good understanding of the limitations of your observations, or *how precise your data is* and *how well you can trust it*. For this, we will try to develop quantitative estimates of how accurate our results are.
6. **How to make a computer do the hard stuff.** We will be using the *Microsoft® Excel©* spreadsheet to tabulate data, crunch numbers, and construct graphical representations of our data. Not that we can't do these things by hand, it's just that a computer can do it a lot faster, relieving us of a lot of busy-work and allowing us to do a lot more with our data. If you plan on going into research, it is essential to know how to use a computer spreadsheet.

## The Experiments

*This semester we will be doing five experiments, each of which will span two weeks. The first week is devoted to **data collecting**, while the second week is devoting to **data analysis**. This is what you'll be doing:*

### Week One

- *Brainstorming and Planning:* You will not be given step-by-step instructions on how to do the experiment. You will receive a short description of what you'll be investigating, and it will be up to you to design your *own* experiment. There are many ways to do this, so be creative and work with the physics that you know.

- *Data Collecting:* You will be given ample time to collect as much data as will be useful for you.
- *Presentation and Discussion:* Here you have an opportunity to show the rest of the class your method, and to see what other groups did.

### **Week Two**

- *Analyzing Data:* Using Excel<sup>®</sup>, you will be taking a close look at your data in order to decide what it means and how you can *prove* to others what it means.
- *Presentation and Discussion:* Different groups will frequently have contradictory results. This is your chance to present your case, observe other groups' cases, engage in healthy debate, and possibly reconsider your conclusions.
- *Class Consensus:* In some cases, each lab section will be trying to come to a single consensus conclusion.

## **Materials**

Please bring with you to class each week:

- Loose-leaf paper for writing your lab reports. These will be collected by the TA and each group member will be given a copy. You may want to keep a folder or notebook for these labs, as they will be a useful reference for future labs and lab quizzes. (Papers torn out of a bound NB will not be accepted.)
- A calculator.
- Anything at all that you think will be useful. Our lab room has a huge supply of odds and ends for you to use in designing your experiment, however, feel free to bring in anything from outside that you feel may help your group out.

## **Grading**

The lab grade makes up part of your total course grade. This grade will be based on:

- Lab reports
- Participation in the planning, experiment, presentation, and class discussion
- Lab practicals

## **Lab Reports**

At the end of the two-week experiment, you will hand in a complete lab report. This report will include:

- *The Journal:* A discussion of what you did, how you designed your experiment, and what results you got, written so that an absent student could understand what you did.

- *Data and Interpretation:* Your data, in a form that would be easy for an absent student to understand. Here is also where you discuss what your data means, what conclusions you've drawn from it, and a persuasive *case* proving that your conclusion is valid.
- *Evaluation:* After you've had a chance to see what data and conclusions other groups have gotten, it's important to go back and reconsider what you've done. Here is where you discuss how you could improve upon your experiment, in light of what you learned during lab and during the class presentations.

In writing your lab report, it is important to consider the following things:

- Design and thoughtfulness. Did you do a careful and thoughtful job in creating your experiment, and was this thought reflected in the journal?
- Clarity and completeness. Were you able to clearly explain your experiment so that someone could reproduce it?
- Persuasiveness. What conclusions did you draw from your data, and were you able to back up these conclusions with this data, in a convincing way?
- Evaluation. After observing the experiments of other groups, were you able to critique your own lab, make constructive changes, or if this is the case, explain why your experiment was better than those of your classmates?

*Your grade will not depend on whether or not your conclusions agree with some accepted standard.*

## **Roles**

You will be working in groups of *four*. The division of labor will be as follows:

1. *The Journalist:* This person is responsible for taking notes of everything that happens during the experiment, and writing up the "Journal" section of the lab report.
2. *The Data Interpreter:* This person deals with tabulating and displaying the data, operating the computer, and writing up the "Data and Interpretation" section of the lab report.
3. *The Critic:* This person is responsible for taking notes during the class presentations and discussions, and for writing the "Evaluation" section of the lab report.
4. *The Checker:* This person is responsible for checking all sections of the lab report before it is turned in, and reading the comments made by the grader on past lab reports, and suggesting ways to improve.

You must rotate roles every week, so that each person gets a chance to do every task at least twice. While the lab report is a group grade, it is necessary that you show that you are pulling your own weight in the group work.

## **Participation**

A portion of your grade will depend on your participation in the class activities. This includes taking an active role in presenting to the class and participating in the class discussions. Your TA will be observing your activity throughout the semester.

## **Lab Practicals**

There will be two lab practicals this semester. As opposed to other lab activities, you will do this on your own and receive an individualized grade.

## **Attendance**

The labs are an integral part of this physics course, so missing a lab will affect your comprehension of the course material and impair your progress through both the lab and the lecture part of this course. There are no makeup labs. If you miss or have missed a lab, contact your TA immediately. If have a VALID WRITTEN EXCUSE, you will be allowed to do a makeup activity that will take at least two hours. If you do not have a written excuse, you will get a zero for that lab.

## ***Lab 0:***

### **How To Use Excel<sup>©</sup> To Illustrate Data**

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*The purpose of this activity is to:*

- *Guide you through an example of what this semester's lab activities will be like.*
- *Show you some of the features of Microsoft<sup>®</sup> Excel<sup>©</sup> that you will need to know about for future labs.*

*This lab will not be turned in for a grade, however, it is a good reference for future labs and a good review for lab practicals, so keep it handy.*

## **WALKING TO SCHOOL**

*Microsoft<sup>®</sup> Excel<sup>©</sup> is a spreadsheet program that can be used to tabulate, analyze, and illustrate information in a variety of different ways. You will use this program in every lab this semester to help understand your experiments and to communicate your results with others. Keep in mind that Microsoft<sup>®</sup> Excel<sup>©</sup> is available on almost every public computer in the university, in case you want to work with it outside of lab.*

**Suppose you are asked the following question:**

How long does it take you to walk to school?

**For the next ten days, you time how long it takes for you to walk from your apartment to school. You get the following times: 21 min, 25 min, 22 min, 22 min, 19 min, 26 min, 23 min, 24 min, 19 min, and 21 min.**

**In the next sections, you will learn how to illustrate your data using the Excel<sup>©</sup> spreadsheet so that it conveys the right amount of information.**

Creating a Data Set

- A. Double click the Excel icon. This will open the program**
  
- B. In cell A1, label the “A” column “Days”. In cell B1, label the “B” column “Times”.**

**Under the “Days” column, you want to list the ten trials you took. Sometimes, when the number of trials is large, it can be a pain to have to fill in every number by hand. There is shortcut around this. In A2, type “1”. In A3, type “2”. Now select these two cells. Notice a small square on the lower right corner of the selected cells. This is the fill handle.**

- C. Click the fill handle and drag it all the way down to 10, or however far you want. Excel<sup>©</sup> will automatically fill in the rest.**
- D. Under the “Times” column, enter your data, the times recorded to get to school. Now you have a simple data set to work with.**

### Graphing Data

**At the top of the screen is a blue, yellow, and red icon, the Chart Wizard icon. Click this and a menu will pop up. Here are fourteen different ways in which your data can be graphically illustrated. You’ll find during this semester that different kinds of data are best shown with different kinds of illustrations. Select XY (Scatter) and hit Next.**

- A. Here Excel<sup>©</sup> asks you which data set you want to graph. Using the mouse, highlight the two columns of information you want to use. It will give you a preview of how this chart is going to look. This illustration is a basic point plot graph with the days on the x-axis and the times on the y-axis. Hit Next.**
  
- B. Excel<sup>©</sup> now asks you to select what data you want to graph. Highlight the two columns (without the titles) and hit Next.**
  
- C. A graph needs to be detailed enough so that one can understand it without an explanation, yet concise enough to be understood at a glance. That’s why you must always give your chart a title and label your axes. Title your chart “Time it Takes to Walk to School”. Label your x-axis “Days” and your y-axis “Time”. Hit Next.**

- D. Now Excel<sup>®</sup> will give you the option to either place this chart next to your data, or on a separate sheet. For this chart, select As new sheet, and hit Finish. You now have a chart that displays your data!**

### Certainty Bars

Very few things you can measure in the real world can be determined “exactly”. Therefore, when referring to a scientific figure, it is important to specify how “certain” any figure is. For example, there is a big difference between saying that something costs “five dollars and six cents”, and saying that something costs “around five dollars”. Any time you take a measurement, it is important to determine how certain you know that calculation and to include that certainty with the calculation itself.

**Let’s say that after you finish timing your walks to school, you notice that there are discrepancies between the different timing devices you used. Some days you used a wristwatch. Some days you looked at the clock in your apartment before you left, and checked the clock at school when you arrived. And some days you asked a friend for the time.**

**After comparing these different clocks, you determine that there is at most a 3 minute discrepancy between different devices. Since you’re just doing this experiment for fun, it is not important to be more precise, but it is still necessary to determine how well you know your result. You’re going to place a 3 minute error bar on each data point, so that you can see that any given point could be either 3 minutes too high or low.**

- A. On your chart, double-click one of the data points. Select Y Error Bars. Choose Display Both. Select Fixed Value and type in “3”. Hit Okay. Now each of your data points has a certainty assigned to its time value. Keep in mind that you can also assign a certainty to the x-axis parameter, if necessary.**

**There are many ways one can determine the precision of a measurement.**

**Some lab devices actually state a “tolerance level”, or, how close it can determine that it is measuring. Things like reaction time can be measured by you. And other things, like the reading on a scale, one can make a rough estimate of how well one can read the needle.**

**But however you do it, it is absolutely important that you assign a level of certainty to any calculation.**



★ Check with your TA before proceeding.

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## BURNING OUT LIGHT BULBS

*Now that you know the basics of compiling and plotting data, you will now perform an actual experiment and produce illustrated data for a grade.*

How much voltage does it take to burn out a light bulb?

*Normally it will be up to you and your group to design your own experiment to accomplish this task. Today you'll be guided through it.*

Collecting and Analyzing Data

- A. You have been given an electrical power source. This box can supply a current of electricity to an electrical circuit. Notice the voltage dial. You can change the amount of electricity this box produces by raising or lowering the voltage.**
  
- B. You have been given six Christmas lights. Notice that there are two wires leading out of the bulb. Using an alligator clip and a cable, connect one of these wires to the red plug on the power source marked with a “+”. Connect the other wire to the black plug marked with a “-”.**
  
- C. Find out how much voltage is required to burn a bulb out! Do this with all six bulbs. Keep track of your data on a new spreadsheet and create an appropriate graph of your data.**
  
- D. How well were you able to determine the maximum voltage of each bulb? Create the appropriate error bars on your graph.**

## The Test

What's the highest voltage at which *most* of a collection of bulbs will stay lit without burning out?

**Your group will be asked by the TA to submit a value answering this question. At the end of the class, the TA will light a bulb up until it burns out. The group that submits the highest voltage *without* going over the burning-out voltage will receive extra credit.**

★ Class Discussion

---

## To Hand In

**Make sure your groups' names are on your two spreadsheets. Save your data to your group diskette for a grade.**

## Optional

*You'll be using Microsoft® Excel© all throughout this course, so you'll need to get used to it. If you have time at the end of lab, or in your spare time, try experimenting with different charts. There are many different ways you can display your data. Remember that neatness counts and creativity is rewarded.*

# Excel© Hints

## Graphing Equations

Let's say you want to make a graph of a function. In the "A" column, fill in a list of x-values you want to use as your range (1 through 10, for example). Next, click on the cell B1. In here, fill in the function you want to use, preceded by an equal sign,

for example: “=3\*x” to make a linear plot with a slope of 3, or “=x^2” for a parabolic function. In B1, the y-value corresponding to A1 will automatically appear. Drag the fill handle down to fill in the rest. Finally, plot the data.

Remember, you can work with several sets of data at once, as well as refer to different sets when tabulating a new set. For example, if you have data in columns A, B, and C, you can make a sum of this data in the D column by filling in cell D1 with “=A1+B1+C1”.

### Multiple Plots

When plotting your data, you can select several different columns and plot them simultaneously on the same graph. This is useful for comparing data. **Highlight** several columns of data and hit the **plot** icon. It will automatically use the first column as your x-values and each other column as a y-plot.

### Error Bars

There are a few different ways you can put error bars on your data. On the graph, double click one of the data points and a menu will pop up. Under **X Error Bars** or **Y Error Bars**, you can select the **Error Amount**.

- Selecting **Fixed Value** will put the same size error bar on all your data points.
- Selecting **Percentage** will create error bars whose size is proportional to the value of the data point.
- You can also enter in manually the error bars for each data point by selecting **Custom** and specifying both a column that contains “upper limit” values and a column that contains “lower limit” values for the error bars.

Which method you use depends on how you determined the uncertainty in your measurement. You must be able to justify *why* you chose particular error bars.

### Other Tools

Click on the “Σ” at the top of the screen. Here is a list of useful tools that can be used with data sets:

- To **Sum** data, first highlight a cell you want the sum to appear in, then select **Sum** under the Σ icon. Next, highlight the data you want to sum and hit enter. The sum will appear in the cell.
- To **Average** data, first highlight a cell you want the average to appear in, then select **Average** under the Σ icon. Next, highlight the data you want to average and hit enter. The average will appear in the cell.

# Lab 1: Damped Oscillations, Part One

---

You have been asked to design a metronome for a famous pianist, and you have decided to use a spring with a small mass attached, which will bounce up and down with the beat. Now, this metronome will only be useful if the *period* (or the time it takes for one full cycle) of an oscillation stays the same over a long enough time interval (at least for a three minute tune). When you let the spring oscillate for a long period of time, you observe that the amplitude gradually gets smaller. What about the period?

**Question:** *Does the period of a spring stay the same over time?*

This week you will focus on **data-collecting**. Next week, we will do a lot more with your data and try to answer some more questions about your metronome, so use your time wisely and take as much data as time allows.

### Timetable

<b>I. Introduction:</b>	<b>10 min</b>	<b>Whole class</b>
<b>II. Brainstorming and Planning:</b>	<b>10 min</b>	<b>Groups of 4</b>
<b>III. Carrying out the Experiment:</b>	<b>40 min</b>	<b>Groups of 4</b>
<b>IV. Class Discussion:</b>	<b>30 min</b>	<b>Whole Class</b>
<b>V. Evaluate and Reconsider:</b>	<b>15 min</b>	<b>Groups of 4</b>

## Lab 2: Damped Oscillations, Part Two

---

This week is a continuation of last week's activity.

You have been asked to design a metronome for a famous pianist, and you have decided to use a spring with a small mass attached, which will bounce up and down with the beat. Now, this metronome will only be useful if the *period* (or the time it takes for one full cycle) of an oscillation stays the same over a long enough time interval (at least for a three minute tune). When you let the spring oscillate for a long period of time, you observe that the amplitude gradually gets smaller. What about the period?

**Question:** *What happens to the period of a spring over time?*

This week you will focus on **data analysis**. Last week you took data to decide whether or not the period stayed the same. Today you're going to *prove* whether it does or doesn't. Your goal is to develop a strong, quantitative argument proving that either (a) the period stays the same, or (b) the period changes over time.

### Timetable

<b>I. Introduction:</b>	<b>10 min</b>	<b>Whole class</b>
<b>II. Brainstorming and Planning Meeting:</b>	<b>10 min</b>	<b>Groups of 4</b>
<b>III. Carrying out the Experiment</b>	<b>40 min</b>	<b>Groups of 4</b>
<b>IV. Class Discussion</b>	<b>30 min</b>	<b>Whole Class</b>
<b>V. Evaluate and Reconsider:</b>	<b>15 min</b>	<b>Groups of 4</b>

You will be turning in the following things in your lab report for a grade.

(From last week)

1. Journal
2. Evaluation

(From this week)

3. Data interpretation
4. Evaluation

## Lab 3: Ohmic Materials, Part One

---

There are some materials that conduct electricity so that the *current* that flows through it is *linearly proportional* to the applied *voltage*. Such a material is called “Ohmic”. If you know that a material is Ohmic, you can tell what the current is just by knowing how much voltage you are applying. Predictability is important for certain electrical hardware.

**Questions:** *Is an electrical resistor Ohmic?*  
*Is a light bulb Ohmic?*

This week you will focus on **data-collecting**. Make sure to collect enough to data so that next week you can *prove* whether or not these materials are Ohmic.

**Before you begin, present a plan of how you’re going to carry out this experiment and how much data you’re going to take, i.e. how many trials and data points you will collect.**

### Timetable

I. Pre-lab Discussion	10 min	Whole class
II. Planning the Experiment	20min	Groups of 4
III. Data Collecting	40 min	Groups of 4
IV. Class Discussion	25in	Whole Class
V. Writing the Report	15 min	Groups of 4

## Lab 4: Ohmic Materials, Part Two

---

This week is a continuation of last week's activity.

There are some materials that conduct electricity so that the *current* that flows through it is *linearly proportional* to the applied *voltage*. Such a material is called "Ohmic". If you know that a material is Ohmic, you can tell what the current is just by knowing how much voltage you are applying. Predictability is important for certain electrical hardware

**Question:** Propose a "rule" that determines whether data is linear or not.

According to this rule, are either of your materials Ohmic?

For the class discussion, be prepared to state clearly what your standard for linearity is, and prove whether or not the resistor and the light bulb are Ohmic.

### Timetable

I. Introduction:	10 min	Whole class
II. Brainstorming and Planning Meeting:	10 min	Groups of 4
III. Carrying out the Experiment	40 min	Groups of 4
IV. Class Discussion	30 min	Whole Class
V. Evaluate and Reconsider:	15 min	Groups of 4

## **Lab 5: Magnetic Force, Part One**

---

When you hold two magnets close to one another, they feel either an attractive or a repulsive force between them, depending on their orientation. It appears that the magnitude of this force depends on the distance between the two magnets. But how?

Question: How does the force between two magnets change if you change the distance between them?
--

### **Timetable**

<b>I. Pre-Lab Discussion</b>	<b>10 min</b>	<b>Whole class</b>
<b>II. Planning the Experiment</b>	<b>20 min</b>	<b>Groups of 4</b>
<b>III. Data Collecting</b>	<b>20 min</b>	<b>Groups of 4</b>
<b>IV. Class Discussion</b>	<b>20 min</b>	<b>Whole Class</b>
<b>V. More Data Collecting, Lab Report</b>	<b>40 min</b>	<b>Groups of 4</b>



## Lab 6: Magnetic Force, Part Two

---

When you hold two magnets close to one another, they feel either an attractive or a repulsive force between them, depending on their orientation. It appears that the magnitude of this force depends on the distance between the two magnets. But how?

Question: Describe *quantitatively* the relationship between magnetic force and distance between the magnets. Use whatever tools and techniques you'd like, as long as they can be explained to the rest of the class during the presentation.

### Timetable

Planning the Analysis	10 minutes	Groups of 4
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- *How are you going to illustrate your data?*
- *How are you accounting for uncertainty in the measurements?*
- *What seems to be the behavior or features of this relationship?*
- *How can you quantify this relationship so that it can be communicated to others?*

<b>Data Analysis</b>	<b>50 minutes</b>	<b>Groups of 4</b>
<b>Class Discussion</b>	<b>40 minutes</b>	<b>Whole Class</b>
<b>Writing the Report</b>	<b>10 minutes</b>	<b>Groups of 4</b>

## ***Lab 7: Light Refraction, Part One***

---

**When light moves from one medium into another, it appears to change direction. We call this change of direction “refraction”. We would like to explore the refraction of light through water.**

Questions:

What determines how much light refracts when it enters water? How can you describe the refraction quantitatively?
--

### **Timetable**

<b>I. Pre-Lab Discussion</b>	<b>5 min</b>	<b>Whole class</b>
<b>II. Planning the Experiment</b>	<b>30 min</b>	<b>Groups of 4</b>
<b>III. Class Discussion</b>	<b>20 min</b>	<b>Whole Class</b>
<b>IV. Data Collecting</b>	<b>40 min</b>	<b>Groups of 4</b>
<b>V. Writing the Lab Report</b>	<b>15 min</b>	<b>Groups of 4</b>

## **Lab 8: Light Refraction, Part Two**

---

**When light moves from one medium into another, it appears to change direction. We call this change of direction “refraction”. We would like to explore the refraction of light through water.**

Questions:

What determines how much light refracts when it enters water? What is the quantitative relationship between this factor and the refraction?
--

### **Timetable**

<b>I. Pre-Lab Discussion</b>	<b>5 min</b>	<b>Whole class</b>
<b>II. Analysis:</b>	<b>50 min</b>	<b>Groups of 4</b>
<b>III. Group Presentations:</b>	<b>30 min</b>	<b>Whole Class</b>
<b>IV. Class Discussion:</b>	<b>10 min</b>	<b>Whole Class</b>
<b>V. Evaluate and Reconsider:</b>	<b>15 min</b>	<b>Groups of 4</b>

## Lab 9: Double-Slit Interference, Part One

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When a beam of light passes through two thin slits, something funny happens. The light creates a pattern on the other side that looks like this:



This is what we call an “interference pattern”. This week you will be investigating this phenomenon.

Questions:

1. What things might affect the spacing between the bright spots? After you’ve brainstormed some ideas, call your TA over to help you narrow it down to *two* factors for you to investigate experimentally.
2. What is the relationship between the spacing of the bright spots and the two factors? Design an experiment that will explore these relationships.

### Timetable

<b>I. Brainstorming:</b>	<b>15 min</b>	<b>Whole class</b>
<b>II. Taking Data:</b>	<b>30 min</b>	<b>Groups of 4</b>
<b>III. Class Discussion:</b>	<b>10 min</b>	<b>Whole Class</b>
<b>IV. Taking Data-:</b>	<b>30 min</b>	<b>Groups of 4</b>
<b>V. Writing the Lab Report:</b>	<b>25 min</b>	<b>Groups of 4</b>

## Lab 10: Double-Slit Interference, Part Two

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When a beam of light passes through two thin slits, something funny happens. The light creates a pattern on the other side that looks like this:



This is what we call an “interference pattern”. This week you will be investigating this phenomenon.

Questions:

3. You have chosen two factors to explore for a possible relationship to the spacing of the bright spots. How well can you describe these relationships?
4. After observing what other groups in the class have done, can you pool together all the information and build a more accurate model of what things affect the spot spacing?

### Timetable

<b>I. Data Analysis:</b>	<b>60 min</b>	<b>Groups of 4</b>
<b>II. Group Presentations:</b>	<b>25 min</b>	<b>Whole Class</b>
<b>III. Class Discussion:</b>	<b>10 min</b>	<b>Whole Class</b>
<b>IV. Writing the Lab Report:</b>	<b>15 min</b>	<b>Groups of 4</b>



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