# ABSTRACT

Title of Dissertation: **PROBLEMS AND POSSIBILITIES: THE IDENTITIES AND CHALLENGES OF EARLY CAREER SCIENCE TEACHERS**

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Learning to teach is multifaceted and dynamic resulting in a turbulent, fast-changing era of professional life for early career science teachers (ECSTs). Teaching practice is uncertain and tensions are endemic to the profession (Ball, 1993). This dissertation connects to and extends current research of the challenges ECSTs face and how those challenges affect ECSTs' work, identity, and experience. In the first chapter, I introduce my research focus and offer a personal narrative to provide context of my positionality and experiences between myself and my research. In Chapter 2, I offer a systematic review of the literature to provide a contemporary update to Davis and colleagues' (2006) review *Challenges New Science Teachers Face* to answer the question: *What challenges do ECSTs face while navigating their first years of*

*teaching?* Chapter 3 describes the research design, data sources, and general analysis for the longitudinal case study of an ECST, Alexa. The remaining body chapters build upon Chapter 2 and each other in answer to my remaining research questions: *What challenges does Alexa face as an ECST? How does Alexa's teacher role identity develop over time? In what ways do challenges shape Alexa's teacher role identity?* Chapter 4 builds upon the themes drawn from Chapter 2's systematic review to explore the challenges Alexa experiences. Chapter 5 describes how Alexa's identity develops across her early years as an ECST using a Dynamic Systems of Role Identity framework (Kaplan & Garner, 2018). Chapter 6 explores how those challenges impacted Alexa's science teacher identity using a productive friction framework (Hagel & Brown, 2005a). In Chapter 7, I close by summarizing the research, describing its implications, and offering future directions for research and practice.

# PROBLEMS AND POSSIBILITIES:
# THE IDENTITIES AND CHALLENGES OF EARLY CAREER SCIENCE TEACHERS

by

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# Dedication

*For Mom*

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## List of Abbreviations

| | |
|---|---|
| AST | Ambitious Science Teaching |
| BMS | Bumblebee Middle School |
| CCCs | Cross-cutting concepts |
| CCSSO | Council of Chief State School Officers |
| CGT | Constructivist grounded theory |
| CRIOP | Culturally Responsive Instruction Observation Protocol |
| DSMRI | Dynamic Systems Model of Role Identity |
| ECST | Early career science teacher |
| ERIC | Education Resources Information Center |
| FARMs | Free and reduced meals |
| FSU | Florida State University |
| FSUS | Florida State University Schools |
| IDM I | Interdisciplinary Methods I |
| IDM II | Interdisciplinary Methods II |
| InTASC | Interstate Teacher Assessment and Support Consortium |
| MGSM | Middle Grades Science Methods |
| NARST | National Association of Research in Science Teaching |
| NGSS | Next Generation Science Standards |
| NRC | National Research Council |
| NSES | National Science Education Standards |
| NSF | National Science Foundation |
| PCK | Pedagogical content knowledge |
| PDS | Professional development schools |
| PMS | Panda Middle School |

| | |
|---|---|
| PST | Pre-service teacher |
| RSST | Rapid Survey of Student Thinking |
| RTOP | Reformed Teaching Observation Protocol |
| STEM | Science, Technology, Engineering, and Mathematics |
| TAGS | Task analysis guide in science |
| TPACK | Technological pedagogical and content knowledge |
| UMD | University of Maryland |

# Chapter 1: Introduction

Learning to teach is multifaceted and dynamic resulting in a turbulent, fast-changing era of professional life for early career science teachers (ECSTs). As teachers reflect on their preparation, they often describe the student teaching experience as the most critical component and an entry to the *real* work of teaching (Britzman, 2012; Feiman-Nemser & Buchmann, 1985; Horn et al., 2008). Feiman-Nemser and Buchmann (1985) describe difficulties faced at the intersection of teacher preparation and practice and note pre-service teachers (PSTs) can experience a pitfall, or *inappropriate learning*, when preparation and practice do not align. Teaching practice is inherently uncertain, and tensions are endemic to the profession (Ball, 1993). Tensions at the intersection of preparation and practice, or that between university and field, are possibly caused by competing goals on behalf of the PST, mentor, and teacher educators (Valencia et al., 2009).

Not only do PSTs navigate the tension-ridden space between teacher preparation and practice, but also how their identities fit into this space. PSTs do not enter universities as blank slates waiting to be filled with knowledge. PSTs' experiences and beliefs shape how they view teaching and learning (e.g., Lortie, 1977). Their identities coexist and conflict with the teacher preparation program and eventual teaching experiences. When student teachers' identities are not considered as part of the preparatory process and they "inhabit the constrained role of a guest in someone else's classroom, there is little room to develop their own professional identities" (Valencia et al., 2009, p. 319). And just as there are tensions between teacher preparation and practice, PSTs may have tensions with either or both.

Similarly, recent graduates of teacher preparation programs seek to transition from pre-service teacher to in-service teacher. After securing employment, school communities work to enculturate new teachers into the community through mentorship and induction programs. However, often receiving mixed messages between teacher preparation and their new school community, ECSTs frequently default their teaching methods back to the way they experienced schools themselves (Lortie, 1977). In addition to making sense of classroom instruction, ECSTs must quickly adapt to the many requirements of classroom teaching, such as administrative duties, working with families, and socialization into a new school and local community. This plunge into massive responsibility often leads ECSTs to fall into a state of *survival* or "trying to get through the day," rather than a commitment to effective or mastery teaching (H. K. Wong et al., 2005).

Luft (2007) argues "the induction years encompass a vital phase of science teacher development… Beginning teachers are different from pre-service and [experienced] counterparts and deserve some undivided attention" (p. 532). The first years of teaching are under-researched. This is particularly because the population of ECSTs are often overwhelmed and not eager to add on the complexity of participation in a research project (Luft, 2007). Additionally, they vary from their more veteran peers (6+ years' experience) in critical ways—as reported from data collected in the National Survey of Science and Mathematics Education in 2018 (Trygstad, 2020). Novice teachers were more likely to teach in high-poverty schools and schools with troublingly high teacher turnover (p. 2, 8). Novices were also more likely to work in schools that lacked adequate supplies and equipment (p. 8, 64). Additionally, secondary novices were less likely than veterans to hold appropriate credentials for their assigned courseloads (p. 63). Novices felt less prepared to teach science topics (p. 33), use formative assessments (p. 38), differentiate instruction (p. 38), and encourage participation (p. 38); and novices were more likely to hold traditional teaching beliefs when compared to veterans (p. 27).

While not uniform in severity of or reaction to challenges, all ECSTs need to work through the challenges they face to be successful in their early careers.  ECSTs are often left alone to navigate the complex space of their work with different support systems that foreground competing goals and beliefs—left to make decisions about who to listen to and when.

**Significance and Contribution**

Science is a high teacher shortage subject area in Maryland (Maryland Department of Education, n.d.) and all but four U.S. states[1] in the last five years (U.S. Department of Education, n.d.).  Key factors in the science teacher shortage include recruitment (e.g., Luft et al., 2011), retention (e.g., Bozeman et al., 2013), and attrition (e.g., Denton et al., 2021).  Failure in these areas results in negative effects for students, school communities, and the teachers themselves (e.g., Harrell et al., 2019).

A recent report of teacher turnover in the U.S. (Carver-Thomas & Darling-Hammond, 2017) suggests recruiting and keeping science teachers is a continuing problem for schools. Their analysis indicates in a single year 7.2% of math and science teachers left the classroom. They suggest a recent study indicates math and science positions are four times more difficult to fill than an English position (Carver-Thomas & Darling-Hammond, 2017, p. 12).  In short, more teachers are leaving than are being recruited.  This deficit leaves school science positions to be filled by those who are less experienced nor qualified (Carver-Thomas & Darling-Hammond, 2017, p. 12).  In 2017-2018, approximately 44% of teachers had less than 10 years of experience; the modal teacher was in their first year (Ingersoll et al., 2021).  Most math and science leavers exit the profession due to dissatisfaction and related reasons with only 31% of leavers exiting

[1] Alaska, Kansas, Texas, and Utah

due to retirement (Carver-Thomas & Darling-Hammond, 2017, p. 8). The most common areas of dissatisfaction include accountability measures and testing, administrative issues, teaching as a career, and working conditions. Turnover is especially prevalent among beginning teachers. Another report found 18% of new science teachers left after just one year (Ingersoll et al., 2014). Entering the science teaching profession is complex and challenging (Donna & Roehrig, 2024). Unlike other professions where there is a substantial multi-year gradual increase of responsibility (e.g., medicine), teachers may (or may not) undergo a short internship or residency before they are the primary instructor in the classroom with full responsibility. As such, the early years of teaching can be fraught with challenges and tensions.

Additionally, the (not so) recent shift towards the Next Generation Science Standards (NGSS, National Research Council [NRC], 2013) or NGSS-based standards by most states created another layer of difficulty for new science teachers. The *Framework for K-12 Science Education* (Framework, NRC, 2012) and resulting standards conceptualize science learning as a trifold understanding of disciplinary core ideas, science practices, and cross-cutting concepts. The triple focus of the NGSS aimed to move away from prominent conceptualizations of *science learning as a collection of facts* and toward *science learning as a cohesive way of knowing about the material world*. However, historically consistent with other educational reforms, adoption of the ideals of the NGSS has been messy, uneven, and poorly executed. I will describe failures to bring the ideals of the NGSS to fruition at multiple levels.

After nearly a decade, the NGSS have failed to show sweeping reforms starting with issues within the *Framework* and standards themselves. Elby (2019) comments that although the *Framework* claims to put forth three equally principal elements of science learning, the resulting performance expectations continue to give precedence to content knowledge over engaging in science practices. That is, students use practices to better understand canonical science facts, but the *Framework* does not call for the reverse—using bits of science knowledge to meaningfully engage in practices. Additionally, Osborne and colleagues (2018) offer critique of the cross-cutting concepts (CCCs). They describe the origins of the CCCs as murky at best. The authors continue to argue the integrative "application across all domains of science" (NRC, 2012, p. 30) is "only true in the sense that a thermometer is useful in all sciences and, unless the epistemic importance of a crosscutting theme is identified in all disciplines, its salience is likely to be missed" (Osborne et al., 2018, p. 967). They present six styles of reasoning as a more coherent and useful alternative to the CCCs. Lastly, science educators note elements insufficiently woven into the NGSS. For example, McComas and Nouri (2016) describes the afterthought treatment of the nature of science in the NGSS. The authors note during early drafts of the NGSS the missing elements of nature of science were brought forth during public comment. However, instead of integrating the nature of science into the standards themselves, the creators instead added them as a supplementary document in an appendix. The criticisms described here provide a glimpse of the discussion of science education researchers regarding the *Framework* and NGSS.

Teachers are also challenged by issues at the middle levels of adoption, such as state, district, and curricular levels. First, many states are resistant to taking up the NGSS. This leads to mixed messaging between how science teacher educators envision and promote science teaching and what is asked of teachers in the classroom. Additionally, district-level barriers limited how teachers were able to implement the NGSS. For example, Allen and Heredia (2021) identify a variety of external barriers to implementation, such as prioritizing math and reading due to accountability measures, lack of class time, or curriculum adoption. Similarly, school administrators also struggle to best support their teachers' enactment of the NGSS. Principals are increasingly responsible for leading reform, supervision, and evaluation of content area instruction, regardless of their content area expertise (McNeill et al., 2018, 2022). Lastly, curriculum marketed as NGSS-aligned were often hastily released rebrands of former curricula that did not undergo adequate analysis before adoption (e.g., Lowell et al., 2021). These issues compounded with top-level criticisms to create an unclear path for NGSS-aligned classroom instruction.

At the ground level, in classrooms with teachers, the NGSS has failed to inspire the sweeping changes envisioned in the *Framework*. Research indicates science teachers are generally eager for innovations (Anderson et al., 2018; Capps et al., 2016; Crawford, 2007; McFadden, 2019; Veal et al., 2016). However, in the classroom "teachers often believed they were enacting inquiry when they likely were not" and "may struggle to interpret and enact inquiry-related requirements of science education reform" (Capps et al., 2016, p. 934). Miller and colleagues (2018) argue the various challenges of the NGSS play out as "complacent enactment" wherein instruction "could appear to offer ways in which students might be positioned as…epistemic agents [(creators of knowledge)], while actually positioning students as receivers of 'correct' information and practices" (p. 1056). Often teachers want to enact reform-minded instruction but are unsure how to enact reforms considering issues described as a "perpetual beta" (McFadden, 2019). The issues presented above are especially salient for inexperienced ECSTs. Crawford and Capps (2018) describe the sentiment of their pre-service teachers, "My mentor teacher says, we don't have to teach in this way! Our school does not advocate it." (p. 27). It seems Crawford's (2007) statement about the previous standards continues to ring true:

> "It is clear that we are far from attaining our nationally stated goal of a shifting emphasis towards more inquiry-centered K-12 classrooms. It appears that all in the K-12 science teaching community do not embrace these recommendations." (p. 613)

My dissertation connects to and extends current research of the challenges ECSTs face and how those challenges affect ECSTs' work, identity, and experiences. I also recognize entering a new profession is difficult. While this work will bring attention to many areas in which ECSTs need to develop, my aim is not to paint a bleak picture of poor teacher quality; but rather to shed light on areas in which teacher educators, policy makers, and stakeholders can better support these novices more effectively. In this dissertation, I present research to contribute to the following questions:

1. *What challenges do ECSTs face while navigating their first years of teaching?*
2. *What challenges does Alexa[2] face as an ECST?*
3. *How does Alexa's science teacher identity develop over time?*
4. *In what ways do challenges shape Alexa's science teacher identity?*

**Organization of the Dissertation**

In this first chapter, I introduced my topic and research questions and will describe the experiences that drew me to this work. In Chapter 2, I offer a systematic review of the literature to provide a contemporary update to Davis and colleagues' (2006) review *Challenges New Science Teachers Face*. By grounding analysis in the data, rather than teacher's standards documents like other previous reviews discussed below, I hope to shed light on areas not, or not often, addressed by preparation and professional development literature. This is important because common areas of discontent that lead to attrition center around these topics. Overall,

[2] Alexa is the participant studied in this dissertation.

systematic reviews provide science education research with assistance in dissemination, establishing a culture of evidence-enriched practice, finding areas that require future research, and a valuable report of the current state of an area of study (Bennett et al., 2005).

The longitudinal case study in this dissertation aims to add a rich investigation of the challenges and identity development of an ECST, Alexa. In Chapter 3, I describe my research design, data sources, and general analysis. Chapter 4 addresses the challenges Alexa experiences, Chapter 5 describes how her identity develops across her early years as an ECST, and Chapter 6 explores how productive friction shaped Alexa's science teacher identity. These body chapters build on each other, one informing the next. I seek to answer the call for in-depth cases of tension between areas of science teacher identity (e.g., belief and action, Veal et al., 2016). Additionally, the theoretical frameworks used in this study have limited representation in the science education literature. The developers of the Dynamic Systems Model of Role Identity call for longitudinal cases to "characterize the structural and process characteristics of complex dynamic systems that may best capture diverse identity phenomena" (Kaplan & Garner, 2017b, p. 2047). More research is needed to understand how the framework of productive friction (Hagel & Brown, 2005b), originally of the business literature, applies in educational contexts. Therein, I aim to inform understanding of ECSTs' challenges and identity development. This knowledge can be used to better support ECSTs in contexts like teacher preparation, induction, and professional development. Identity work is often overlooked in these programs (Webb, 2015), but a critical aspect of teacher learning. In Chapter 7, I close by summarizing the research, describing its implications, and offering future directions for research and practice.

## Researcher Narrative

I include a personal narrative to provide context of my positionality and experiences between myself and my research. My path to science education research is quite different from most. After earning my undergraduate degree in Social Science Education with a minor in Psychology, I taught for one year in a small, rural, Black & Latinx charter school in the southeast where I was the only White person in the building. While I loved my students and teaching, the school's administration and I were not a good pairing. My former principal described me as "eclectic" and did not mean it kindly. The rules at the school were rigid and strictly enforced for both students and teachers. Students were escorted silently from class to class and could be sent home for seemingly minor infractions, such as missing a belt from their uniform. Teachers had a similarly strict dress code and required all visible tattoos to be covered, which led to my teaching every day with sweatbands on my wrists[3]. The teachers were expected to teach solely from the textbook in a uniform learning progression. For example, the first day reviewed spelling and vocabulary, the next day students did popcorn reading of a chapter, then a day for the review questions at the end of the chapter, and a day for assessment. The teacher was to repeat this pattern with each chapter until the textbook was completed. No deviation.

Both the social contract and teaching norms were jarringly different than what I expected. I am from an exceptionally diverse area. So, I was not expecting to feel so incredibly out of place in a majority-minoritized school; I had gone to one myself. But my schooling experience highly celebrated individuality and my teachers, save for my math teachers, rarely taught from the textbook. Additionally, my university teacher preparation program had focused on activity-based lessons, rather than textbooks as well. Figuring out how to navigate the school's expectations and my experiences was a challenge. On one hand, I very strongly felt it was

[3] Which looks sillier? You be the judge.

wrong to teach my students from a textbook that stated the Civil War was solely about states' rights, but on the other I also was an outsider of the community and wanted to lean into my colleagues' expertise and wherewithal, all of whom were born and raised in the area and reflected the student population's race and cultural norms. These tensions were in addition to the more typical challenges of being a first-year teacher. I felt like there were no good choices for me to make and the position became a major stressor in my life. Therefore, after completing my contract I began searching for a new teaching position.

I found a teaching home at Florida State University Schools (FSUS), a k-12 developmental research school partnered with Florida State University (FSU). FSUS is purposefully diverse. Charter admissions aim to match demographics of the surrounding area and the school has about 50% minoritized enrollment. As I was dual-certified Social Science 6-12 and General Science 5-9, I was offered a position teaching sixth grade science. I first taught Earth and Space science, then we made a course offering change and I switched to a comprehensive course that covered life, earth, and physical science.

Although I was fully credentialed, I considered myself, and many still would, an out-of-field science teacher because I had little collegiate coursework in the sciences or science pedagogies. As such, I sought out support to help me transition to science teaching. At FSUS, teachers were encouraged to try research-based methods and strategies. I was funded to attend professional development held by researchers, including the National Association of Research in Science Teaching (NARST) annual conference, and summer workshops facilitated by FSU's Office of Science, Technology, Engineering, and Mathematics (STEM) Teaching Activities and Florida Center for Research in STEM. I was also connected with many of the authors of Argument-Driven Inquiry, who were my colleagues and included my new teaching mentor, Kristin Wilson. Teachers were also encouraged to make connections with FSU researchers and teacher educators. Drs. Sherry Southerland, Lama Jaber, Ellen Granger, and Todd Bevis were all instrumental in my early development as a science teacher. I also regularly invited a guest instructor, Carlos Villa, from the National High Magnetic Field Laboratory. Additionally, I leaned into my fellow early career teacher, Amanda Mills, who regularly lent an ear as I puzzled through my understanding of science teaching and learning. In short, I heavily relied on people both near and in extended research-based community networks to make sense of my new role.

During this time, I completed my master's degree at FSU in Curriculum and Instruction with a focus on Science Education. As FSUS and the FSU College of Education have strong connections, there was a great deal of overlap between my social worlds of work and higher education. There was harmony in the vision of good science teaching between the two groups. Each valued what has been termed reformed or ambitious science instruction that focused on deep conceptual understanding over memorization of many factoids. However, I felt tension between the vision described above and the teacher evaluation system used at FSUS. The teacher evaluation protocol was developed to *fit* all content areas and had a specific vision for good teaching. When observed by administrators, I crafted lessons to fit the teacher evaluation system's vision of good teaching. For example, for one observation I engaged students in a physical science lesson focused on graphing various rates of speed. I had students go outside to the sidewalk, where I had marked distances at equal intervals, and they timed each other skipping, running, and walking the sidewalk segment. Afterwards, they averaged and graphed their data. This lesson received nearly perfect marks and earned me the rating of "highly effective teacher"—a rare feat at FSUS. This would have been excellent—if I felt like it was a good lesson. But I felt like a bad teacher that day. I checked all the boxes on the teacher evaluations systems model of good instruction, but very few of how I had come to understand *good science teaching*. My lesson had many great generalist aspects, such as group work, going outside, and multiple representations. However, it was lacking in engaging students in the practices of science, such as developing their own methods of data collection and analysis. The strict time limit to *show my stuff* and *reduce risk* of unexpected student behaviors, ideas, and outcomes forced me into a pre-packaged lesson where student sensemaking was minimal. *Just follow the directions kids and you too will do a science!*

During my master's, I became interested in the intersection of research, teacher preparation, and K-12 schools. This interest was heavily influenced by my experience at FSUS. I felt unprepared in science teaching and was able to seek out support through researchers, teacher educators, and research-based strategies and materials to better navigate my practice. But also, the strong tensions I felt between how I knew *good science teaching* and how I was evaluated as a teacher. My journey to this point led to my pursuit of a doctoral degree at the University of Maryland (UMD).

I have had many opportunities to collaborate with teacher candidates at UMD. I served as both a teaching assistant and instructor for courses focusing on science and middle grades teaching and learning. Additionally, I supervised teaching candidates during their internships; I regularly observed, met with them to discuss, and assessed teacher candidates' progress. Later in my program, I took on the position of Professional Development Schools (PDS) Coordinator. In this role, I continued as an instructor and supervisor, but also collaborated closely with mentors and PDS coordinators of other content areas. At UMD, I got a behind the scenes view of teacher preparation and facilitated many of the logistical aspects of the secondary science and mathematics candidates' student teaching internships. I also served as a research assistant for two projects. The first was a support role in facilitating professional development for two teachers around improving writing instruction in science. The second was a longitudinal study for which I conducted interviews, observations and collected artifacts with and from early career teachers.

Through my work as a teacher educator, I came to realize my experience as a classroom teacher was unique. In addition to my non-traditional route to science teaching, FSUS is an uncommon school model. Founded in 1857, FSUS was originally housed on FSU's campus across the street from the College of Education. Although the school's campus was relocated to an outlying neighborhood in 2001, FSUS maintains strong connections with FSU. Additionally, although FSUS is technically within the borders of the Leon County School District, the school is a district unto itself, identified by the state as FSU Lab School District[4]. Therein, although FSUS is in a district like most schools, the school and the district are, for all intents and purposes, one in the same. At FSUS there was little restriction in how I taught my course. And although I had colleagues to lean on for support, as the only teacher of my course. During my time at FSUS I taught on an island–developing a curriculum and assessments on my own from scratch with only a list of standards as a guide. While there are other isolated schools in the United States, they are few in number and it is rare that they would be in a city rather than a rural community. Additionally, the connections between FSUS and FSU were open and flowed in both directions. FSU researchers could reach out to FSUS administrators and teachers to propose research partnerships. As FSU employees, FSUS teachers had access to academic resources, such as the library and tuition remission for coursework. Conversely[5], UMD's

[4] The district housed one other school while I was employed–a k-8 school in Pembroke Pines, 470 miles away. Classroom level employees had little to no interaction between the two schools. In this work, I am omitting the on-paper connection because in person there was no liaising between the two.
[5] I am not arguing one model is better than the other. Each has its benefits and drawbacks.

partnerships with k-12 schools are mediated by the bureaucracy of large school districts. The districts we work with often provide curriculum and course materials. There are also typically multiple instructors of non-elective courses so teachers can co-plan and pool resources. Most nearby teachers do not work closely with UMD faculty and those that do have limited connections. Research must first be approved at the district level and is sometimes blocked even when a classroom teacher is on board. Districts geographically further from universities often have even less access to the benefits than partnering schools. The experiences of teachers at schools partnered with UMD are more typical than those at FSUS, but still unique from the average school. In seeing into many different schools as a teacher, researcher, and teacher educator, I became more curious about how experiences and membership in various social worlds affects early career teachers' practice.

# Chapter 2: Challenges of Early Career Science Teachers - A systematic review

**Research Question #1: What challenges do ECSTs face while navigating their first years of teaching?**

Davis, Petish, and Smithey (2006) offer a systematic examination of new science teachers' challenges in answer to the call for understanding ECSTs' experiences in face of mounting nationwide science teacher retention issues. The authors drew literature from seven prominent education journals and the Education Resources Information Center (ERIC) database to review 112 unique empirical papers. To analyze the papers, the authors identified 5 primary themes of science teaching from the Interstate Teacher Assessment and Support Consortium (InTASC) core teaching standards (InTASC, 1992, 2002) and National Science Education Standards (NSES, NRC, 1996): (a) understanding the content and disciplines of science, (b) understanding learners, (c) understanding instruction, (d) understanding learning environments, and (e) understanding professionalism. Bianchini (2012), Luft and colleagues (2015), and Navy with colleagues (2022) provide similar reviews described in the following paragraphs.

Bianchini (2012) conducted a narrative review of the views, experiences, and classroom practices of beginning science teachers in studies published between 1998 and 2010. She limits her review to those teaching full- or part-time in internships or alternative certification programs, as well as in-service teachers in their first through third year of teaching. She first describes research connecting teacher education to later classroom practice. Next, she identifies strengths and weaknesses of induction programs while making global comparisons. The third key category Bianchini identifies is the effects of school context and individual agency. She finishes her review with directions for future research. She recommends more longitudinal studies and studies of mis/connections across preparation, induction, and practice. She also calls for research to develop and use more robust conceptions of teacher learning. Bianchini also notes most studies have one or a few traditionally prepared participants tracked for a brief time. She recommends increasing diversity in these three areas. Additionally, she finds the literature lacks understanding of the impacts of beginning science teachers on their students.

Luft and her colleagues (2015) conducted a comprehensive review of studies that investigated newly hired teachers of science in their first through fifth years of teaching that were published between 1982 and 2012. The authors organized findings into seven broad categories, (a) content, (b) learners and learning, (c) professional practice and learning environments, (d) equity, (e) assessment, and (f) professionalism, drawn from American, English, Australian, Canadian, and New Zealander teaching professional standards. As a result of the review, the authors describe the importance of well-designed induction programs and the need for alignment between preparation and induction programs. They also conclude each section with specific research questions to drive future research.

Navy and colleagues (2022) conducted a systematic review of studies published between 2011 and 2020 of the learning opportunities of newly hired teachers of science, those in their first five years in service. The authors criticize the literature's focus on the "turbulence of the early years of teaching" and argue it thus "overlooks the opportunities to learn that should be cultivated and curated" (Navy, Luft, et al., 2022, p. 245). The authors identified three dimensions of opportunities to learn: (a) preparation programs, (b) professional learning programs, and (c) in context, such as national policies, schools, or colleagues. Navy and colleagues (2022) put forth three overarching conclusions. First, opportunities to learn are multidimensional and multifaceted. Second, opportunities to learn cut across classrooms and communities. Lastly, learning opportunities should acknowledge new science teachers to think of themselves as individuals with a variety of experiences. They concluded their review with future research questions and a call for the science teacher education community to support the professional development of newly hired teachers of science.

In this chapter, I draw on Davis and colleagues' (2006) methods to create an updated review (Zawacki-Richter et al., 2020) with contemporary literature. Specifically, I ask, *What challenges do ECSTs face while navigating their first years of teaching?* Understanding ECSTs' challenging experiences may inform our work to better prepare and support ECSTs.

**Methods**

To locate appropriate contemporary literature, I conducted a hand search of articles published between 2013 and 2023 in the 7 prominent educational research and science educational research journals used in Davis and colleagues' (2006) review: (a) *American Educational Research Journal*; (b) *Journal of Research in Science Teaching*; (c) *Journal of Science Teacher Education*; (d) *Journal of the Learning Sciences*; (e) *Science Education*; (f) *Journal of Teacher Education*; and (g) *Teaching and Teacher Education*. 2013 was selected to coincide with the release of the NGSS (NRC, 2013). Additionally, I completed an ERIC database search, using relevant search terms[6], which resulted in 5,669 possible articles, with likely overlap. Preliminary review of selected articles found via the ERIC database suggested 2 additional journals would be relevant to this review and so I also hand searched (i) *Research in Science Education* and (j) *School Science and Mathematics*.

[6] science AND (early or new or preservice or beginning or novice or intern or "student teacher") AND (teacher or educator) AND (secondary or middle or high or "junior high" or sixth or seventh or eighth or ninth or tenth or eleventh or twelfth)
Published between 2013 and 2023 inclusive
Published in a peer-reviewed journal

### *Selection Criteria and Review Process*

I systematically reviewed the possible articles by eliminating articles that did not meet selection criteria by first screening titles, then abstracts, followed by methods, and a final reading of the full paper. Articles from the ERIC database listed titles and abstracts simultaneously and were reviewed together. I cataloged records of inclusion/exclusion reasoning in my systematic review database. For inclusion, articles needed to be: (a) a good-quality peer-reviewed, empirical research article (b) focused on science education (c) of ECSTs (d) in a secondary setting (e) within the United States. Under condition (a), peer-reviewed, empirical research article, I excluded systematic literature reviews, meta-analyses, historical analyses, and theoretical works. Systematic literature reviews and meta-analyses, while empirical, draw their data and findings from other research articles. Additionally, in the case of historical reviews, the data are likely far outside the time bounds of this review. Theoretical works were excluded because they lacked participant data and cannot meet other inclusion criteria. The second condition (b) limited articles to science settings. This condition eliminated many articles that had mixed (e.g., math and science) or general (content unlisted) content areas. Furthermore, although engineering and computer science are related to the sciences and often housed together, they were excluded from this review because they each have their own norms and content. Inclusion of engineering and computer science content areas would increase the number of variables and would confound the findings of this review. This work defined (c) ECSTs as teaching candidates, or PSTs, in preparation for joining the profession to in-service teachers in their first 5 years of teaching. Articles with mixed participants (e.g., early career & veteran (6+ years)) were excluded. Additionally, articles that had ECSTs, but primary data collection and/or analyses focused on another group (e.g., students, parents, or administrators), were also excluded. Participants needed to be working in or in preparation for a secondary school (condition d) position. This work defines secondary as grades 6-12. I excluded articles that looked at elementary, higher education, mixed, or informal sites. Lastly, I excluded articles that did not draw data from the United States (condition e), including articles that compared the United States to another nation.

This review differs in selection criteria from the Davis and colleagues (2006) piece in a few key areas. First, Davis and colleagues included *mixed* works (e.g., science and math, early career and experienced), whereas I limited the bounds to not include mixed studies. I opted to not include mixed studies because in many cases it is not possible to disentangle the data and findings of ECSTs and other participants. Second, the authors included studies of elementary ECSTs. I decided to exclude elementary ECSTs to better match the complementary case study of this dissertation. Additionally, the preparation and work of a secondary content-area teacher is quite different than an elementary generalist. Similarly, while the authors included literature from outside the United States, I limited my review to United States participants to better match the complementary case study in this dissertation. As context varies greatly on the global scale, by bounding this review to one country, I limit the opportunity to confound variables by making inferences and connections about contexts with which I am not familiar. I documented each round of exclusion with color coded highlights and a code denoting reason for exclusion in my systematic literature review database. Articles in the final rounds also include a page number or description of where another can find the evidence for exclusion.

Appendix A holds a summary table (Alexander, 2020) of papers included in this review which describes the number of participants, pre-service or years in-service of participants, and grade level band, as well as the primary and related themes discussed below. To confirm suitable research quality, articles were analyzed with Luft and colleagues' (2015) rubric to review research articles (Figure 1) for inclusion in a systematic review. The rubric draws on guidelines set forth by fellow researchers and the American Educational Research Association. Articles scoring a zero in design or results were eliminated, and remaining articles needed a score of 2 or above for inclusion in this review. Articles that did not meet inclusion thresholds were re-scored by a secondary reviewer. Articles meeting the threshold upon second review were reconsidered and reviewers discussed the papers until consensus scores were met. The selection and final confirmation protocol resulted in the 128 papers used in this review (Figure 2).

**Figure 1**

*Rubric to review research* (Luft et al., 2015)

| Criteria | Score = 1.0 | Score = 0.5 | Score = 0.0 | Comment |
|---|---|---|---|---|
| Research question or research focus | Clearly stated question or focus and relates to theory and/or literature. | Loosely stated and somewhat connects to theory and/or literature. | Absent or poorly grounded in literature and/or theory. | Early studies may not have a clear connection to theory. |
| Design and procedures | Detailed information about an appropriate design, and appropriate data collection and analysis process based on the question. | Adequate information is presented, but more information could be provided about the design, data collection or data analysis, or a better design, data collection and analysis process could be used. | Limited or no information provided regarding the design, data collection and analysis. | Limitations in this area may be a result of the page limits of the journals, and the expectations within the field. |
| Results and discussion | Claims are well-supported by the analysis. | Claims made, but may lack thorough substantiation, or important claims are not made. | Claims step beyond the data, are unsupported, or are not made. | |
| Contribution to the field | Well-reasoned and justified commentary about the contribution to the field. Clear contribution to the field. Not overstated. | Reasonable contribution to the field, but may lack clear justification, reasoning or significance. | Limited or no clear contribution to the field specified. | Contributions are often situated within social and political contexts, which change over time. |

**Figure 2**

*Graphic Depiction of Article Selection and Review Process*

| Total Article Pool | *American Educational Research Journal* n = 518 | *Journal of the Learning Sciences* n = 214 | *Journal of Research in Science Teaching* n = 681 | *Journal of Science Teacher Education* n = 531 | *Journal of Teacher Education* n = 455 |
|---|---|---|---|---|---|
| # Excluded: Titles | n = 462 | n = 180 | n = 578 | n = 329 | n = 240 |
| # Excluded: Abstracts | n = 33 | n = 26 | n = 48 | n = 68 | n = 106 |
| # Excluded: Initial Skim | n = 21 | n = 6 | n = 42 | n = 89 | n = 103 |
| # Screened for inclusion | n = 2 | n = 2 | n = 13 | n = 45 | n = 6 |
| Total articles included in literature review: 128 | | | | | |
| # Screened for inclusion | n = 12 | n = 14 | n = 11 | n = 6 | n = 41 |
| # Excluded: Initial Skim | n = 12 | n = 41 | n = 70 | n = 523 | n = 161 |
| # Excluded: Abstracts | n = 34 | n = 39 | n = 52 | n = 536 | n = 5,467 |
| # Excluded: Titles | n = 356 | n = 460 | n = 747 | n = 1,354 | |
| Total Article Pool | *School Science and Mathematics* n = 414 | *Science Education* n = 554 | *Research in Science Education* n = 880 | *Teaching and Teacher Education* n = 2,419 | *ERIC Database Search* n = 5,669 |

*Note.* Because the number of assessed journals required 10 columns, they are listed in the topmost and bottommost rows so there was enough space for print to be legible. Readers should read columns towards the centermost row of the table.

I read each selected paper and created a summary of key findings in my systematic review database (Onwuegbuzie & Frels, 2016). To synthesize the findings, I conducted a constant comparative analysis by identifying the primary challenge authors focused on, then creating overarching themes of the challenges. I identified five overarching themes across the included articles: Theme 1 – *Instruction and Learning Environments*; Theme 2 – *Equitable and Justice-Oriented Teaching*; Theme 3 – *Joining the Science Teacher Community*; Theme 4 –

*Developing as a Professional*; and Theme 5 – *Science Content and Disciplinary Practices*. Table 1 summarizes the number of articles identified in each theme and representation of size of study, grades taught, and career stage.

**Table 1**

*Representation of articles by theme and study characteristics*

| Study characteristics | Theme 1 | Theme 2 | Theme 3 | Theme 4 | Theme 5 | Total number of articles |
|---|---|---|---|---|---|---|
| Number of articles | 50 (39.1) | 29 (22.7) | 21 (16.4) | 15 (11.7) | 13 (10.2) | 128 |
| Mean *n* participants | 13.7 | 9.3 | 18.7 | 21.2 | 28.6 | 15.9 |
| Median *n* participants | 7 | 6 | 4 | 15 | 10 | 7 |
| Grades taught | | | | | | |
| Middle school (6-8) | 1 (2) | 1 (3.4) | 1 (4.8) | 0 (0) | 1 (7.7) | 4 (3.1) |
| High school (9-12) | 10 (20) | 4 (13.8) | 7 (33.3) | 2 (13.3) | 2 (15.4) | 25 (19.5) |
| Secondary (6-12) | 39 (78) | 24 (82.8) | 13 (61.9) | 12 (86.7) | 10 (77) | 99 (77.3) |
| Career stage | | | | | | |
| Preservice | 33 (66) | 16 (55.2) | 10 (47.6) | 11 (73.3) | 10 (77) | 80 (62.5) |
| In-service | 10 (20) | 8 (27.6) | 9 (42.9) | 4 (26.7) | 3 (23) | 34 (26.6) |
| Both | 7 (14) | 5 (17.2) | 2 (9.5) | 0 (0) | 0 (0) | 14 (10.9) |

*Note.* Percentages are listed within parentheses.

I subsequently identified challenges other than the primary challenge that were experienced by participants and cataloged them in my database. Because each challenge is deeply enmeshed in each ECST's experience, there was often overlap across the themes. For example, a researcher focused on social justice teaching (Theme 2) may write of a participant describing their struggle with a strict, authoritarian school culture (Theme 1). Although only the primary challenge identified by researchers was used to place articles into primary themes, an article expressing multiple challenges will be discussed in multiple themes when relevant. Readers will notice papers they feel might belong in a different section; maintaining consideration of the interrelated connections across the themes will assist readers to better benefit from this review. Unlike similar reviews, which started with a framework typically drawn from teacher preparation standards, I argue leaving codes open to emergent themes can reveal key elements of ECSTs' experiences and ground findings in the data, rather than existing constructs (Alexander, 2020).

Studies of PSTs, typically in their final or only year of study, widely outnumber studies of new in-service teachers across the possible five years. Although understanding how teacher educators train and support future science teachers during the pre-service years is important, we would be remiss to fail to monitor the results of our efforts in those teachers' first years in the classroom. As described in the introduction, in-service teachers in their first years of teaching are different than pre-service and more veteran peers and deserve the attention of researchers. Further breakdown of how selected articles represent teacher experience (Figure 9, Appendix A) shows studies of first year teachers heavily outweigh studies of second through fifth year teachers combined and the studies rarely depict teachers in years four and five. Beginning teachers continue to have high rates of attrition with nearly 45% of new teachers leaving the profession in the first five years (Ingersoll et al., 2018, p. 20) and should be a focus of research efforts.

Few studies identified participants with alternative or missing certifications. The National Survey of Science and Mathematics Education found 15% of middle school and 26% percent of high school studies were alternatively certified and 10% and 17% had no teaching credentials respectively (Trygstad, 2020, p. 19). This is not an insignificant portion of the overall ECST population and should have an adequate focus of research efforts.

Because of the high inclusion of articles on pre-service teachers, many researchers identified participants as *secondary* as they could take a position in either middle school or high school later. But many of the studies with mixed participants across grades while in-service taught were primarily high school teachers with one or a few middle school teachers (e.g., Stroupe, 2016). There was a surprising lack of studies with middle school teacher participants.

**Theme 1 – Challenges Related to Instruction and Learning Environments**

The first theme, *instruction and learning environments*, centers around the ways "teachers understand and integrate assessment, planning, and instructional strategies in coordinated and engaging ways" (Council of Chief State School Officers [CCSSO], 2013, p. 9). This theme also reflects the physical and social context of the classrooms and schools where instruction takes place. Although the NGSS claim they "do not dictate the manner or methods by which the standards are taught" (NRC, 2013, p. xiv), the NGSS website[7] now offers tools to measure the alignment of lessons and assessments with the intentions of the NGSS. For example, the Educators Evaluating Quality Instructional Products (EquIP) Rubric for Science evaluates instructional materials across nineteen criteria, such as integrating the three dimensions and scientific accuracy, to measure alignment with the NGSS and quality of materials (NextGenScience, 2021). The studies reviewed in this theme respond to the challenge: *How do ECSTs understand and engage in planning, enacting, and assessing effective science instruction*[8]*?*

Theme 1 is the largest theme in terms of number of papers (50, see Table 1). The characteristics of the papers (e.g., number of participants, grades taught, career stage) are roughly the same as the overall trends across all included papers (Table 1). Theme 1 is most connected with Themes 2 and 3 (*Equitable and Justice-Oriented Teaching, Joining the Science Teacher Community);* both drawing from and spreading to the themes ( Appendix A, Table 13). The

[7] https://nextgenscience.org/evaluating-ngss-design/evaluating-ngss-design
[8] I thought about adding a question about "what is effective science instruction?" But the only answer I can draw from the papers would only answer the question "How do science education researchers define effective science instruction?" Which felt away from the topic "Challenges ECSTs face"

subsections of this theme include: (a) *pedagogical content knowledge (PCK)*, (b) *reformed and inquiry teaching*, (c) *attending and responding to student thinking*, (d) *assessment*, (e) *classroom environments*, (f) *technology integration*, (g) *reading and writing in science*, and (h) *larger school structures*. Readers will notice the possibility for subsections to overlap. For example, *reformed and inquiry teaching* could be housed within *PCK*. However, in cases like this I opted to keep papers in tighter groups to reduce conflation. As such, all papers in the *PCK* section use the construct by name in analysis and all papers in *reformed and inquiry teaching* focus on that specific element of PCK.

***Pedagogical Content Knowledge***

Pedagogical content knowledge (PCK) is how knowledge of content and pedagogy are integrated by teachers during instruction and can develop over time (Abell, 2008). The articles in this section include papers that generally focus on PCK, however the subsequent sections (e.g., Instructional Strategies, Reformed and Inquiry Teaching) also contain elements of PCK. ECSTs rapidly develop PCK (P. Brown et al., 2013; Luft et al., 2022; Thompson et al., 2013). For example, Thompson, Windschitl, and Braaten (2013) conducted a longitudinal, multi-case study of how ECSTs develop ideas of good teaching and the tools they use to do so. The researchers found three patterns of development: (a) readily integrating ambitious[9] practices, (b) finding space to use one ambitious practice, and (c) reappropriating ambitious language to re-label unambitious tools or practices. They argue ECSTs' PCK development depends on how they negotiate membership in multiple communities (e.g., university, school). If PSTs deeply take up ambitious practices they can resist or reform traditional teaching pressure and ambitious

[9] Note: Across this review, researchers refer to *ambitious* science teaching. They are often referring to the work of the Ambitious Science Teaching program developed at the University of Washington (ambitiousscienceteaching.org).

tools and routines (e.g., modeling-based inquiry) can help ECSTs bridge their ideal and enacted teaching practice.

ECSTs' PCK is shaped through teachers' membership in communities and through their own sense of "what is going on here" – their *epistemological framing* (Elby & Hammer, 2010). Chakrin and Campbell (2022) conducted a qualitative study to explore ten PSTs' epistemological framing of teaching and found three frames: (a) delivering knowledge, (b) guiding knowledge, and (c) making space for collaborative and iterative knowledge construction. Similarly to Thompson and colleagues' work, Chakrin and Campbell's (2022) participants took up ambitious practices in numerous ways with epistemological framing perhaps explaining part of the root of the differences. Norville and Park (2021) investigated how cooperating teachers affected PSTs' PCK. The authors found cooperating teachers did not significantly impact PSTs' PCK and of the few impacts changes were most common in planning and reflection, not implementation. However, PSTs' efforts to navigate power dynamics between themselves and cooperating teachers or other community members negatively impacted the development of PCK. Therein, Norville and Park (2021) recommend PSTs are given more autonomy in student teaching to try out ideas and call to support PSTs as they navigate power dynamics with cooperating teachers without overstepping boundaries. Together these papers explore ways ECSTs' PCK is developed, expanded, and limited in the early years of practice.

Some researchers explored how PCK developed in niche aspects of science content. Sickel and Friedrichsen (2018) explored how early career biology teachers expanded understanding of teaching with natural selection simulations through Magnusson's (1999) three lens PCK model: (a) expanding knowledge in a singular knowledge domain, (b) integrating knowledge across knowledge bases, and (c) knowledge strongly addressing central facets of natural selection. They found PSTs' individual knowledge bases developed at unequal, varied rates, such as Noah who expanded knowledge of assessment faster than other knowledge bases or Meredith whose knowledge was relatively static. The authors suggest knowledge bases specifically addressed through coursework (e.g., assessment, evolution) became more robust overall. They also found participants with constructivist orientations expanded and integrated knowledge bases more than their didactic-oriented peers. Another paper focused on how PSTs developed PCK of History of Science across a semester (Rutt & Mumba, 2019). Rutt and Mumba (2019) found PSTs expanded their knowledge base of History of Science and developed positive views of integrating the History of Science into instruction (e.g., demonstrating scientists' humanity); however, participants felt inclusion would be difficult due to a variety of constraints (e.g., class time, resources).

***Reformed and Inquiry Teaching***

This review begins in the publication year of the NGSS when drafters called for conceptual shifts in science classrooms. The authors aimed for science instruction to "reflect the interconnected nature of science as it is practiced and experienced in the real world" and "focus on deeper understanding and application of content" (NRC, 2013, p. xix). In this work, I refer to reformed and inquiry teaching broadly to include papers focused on pedagogies aligned with the goals of the NGSS.

Teacher educators aim to design coursework and provide experiences to support PSTs' understanding and future implementation of reformed and inquiry teaching. Binns and Popp (2013) used interview and survey methods to investigate how PSTs conceptualized inquiry and found participants had mixed definitions and understandings of inquiry. Hutner and colleagues (2021) found that while many PSTs adopted the goals emphasized in their preparation program, the goals of PSTs remained in flux and were often in conflict with other pedagogical goals (e.g., using inquiry vs. preventing misconceptions). Jaber (2021) describes the case of a PST, Keith, who experienced a similar pedagogical conflict and across a semester eased his hesitation of leading students toward incorrect answers to shift towards a view of responsive teaching that made space for students' sensemaking. Keith's epistemic empathy— "the capacity for tuning into and valuing someone's intellectual and emotional experience within an epistemic activity"—aided his realization that feelings of uncertainty are a part of science learning for both himself and his future students (Jaber, 2021, p. 439).

Teacher educators report areas PSTs continue to struggle with while implementing reformed and inquiry teaching in field placements. PSTs found challenges within and external to reformed and inquiry instruction. For example, PSTs struggled to support students within authentic science inquiry to communicate science ideas with larger communities and refine investigative procedures (French & Burrows, 2018). Additionally, PSTs found external barriers to reformed and inquiry instruction, like Cian and colleagues' (2017) participants who found inquiry-based practices time consuming and difficult to implement while managing classroom behaviors. Some participants also expressed inquiry only works well with certain students (Cian et al., 2017, p. 196). But accounts of who those "certain students" were seem conflicted as one PST suggested inquiry is for Honors students because low-tracked students could not handle inquiry, while another found herself unable to lead Honors level students in inquiry as they preferred to wait to hear the answers in lecture.

In their first years of teaching, ECSTs continued to grapple with implementing reformed and inquiry instruction. A study of first year teachers found the new teachers favored teacher-centered approaches and directed-inquiry (teacher provides question and procedure) and/or verification lab (students verify known concepts through provided procedures) investigations (Ozel & Luft, 2013). Another study of two first year teachers found although the ECSTs envisioned reformed pedagogy they were unable to enact reformed teaching due to constraints in the school context (Strom et al., 2018). Similarly, a study of ECSTs in their first five years found the teachers became significantly less reform-oriented over time (Luft et al., 2022). Stroupe and colleagues (2022) investigated how second year graduates of an ambitious program maintained ambitious practices in their school context. The authors found some teachers were able to shift school-based contextual discourses, such as convincing colleagues to use phenomena as the driving feature of a unit, while others felt limited by the school culture and resources. Across contexts, ECSTs continued to value, seek support for, implement, and modify instructional practices to be more ambitious. In a comparison of ECSTs in general vs. science-specific induction programs, Navy and colleagues (2021) investigated first and second year ECSTs' reformed instruction. They found teachers in the science-specific induction program were significantly more likely to enact reformed instruction in their second year of teaching. Throughout these studies, authors recommend continued support of ECSTs' reformed and inquiry-based instruction and navigation of school contexts beginning during preparation (Stroupe et al., 2022) which extends into formal induction support (Navy et al., 2021).

A collection of studies focused on PSTs' task selection (H. Kang, 2017; Ozcelik & McDonald, 2013; Tekkumru-Kisa et al., 2022; Whittington & Tekkumru-Kisa, 2020). For example, Kang's (2017) cross-case analysis of eight PSTs revealed two categorizations of task design: content-focused and disciplinary practice-focused. PSTs with a content focus generally concentrated on either content or processes in low-demand tasks. PSTs with a focus on disciplinary practices engaged students in sensemaking consistently or shifted from low- to high-demand tasks. Similarly, Aminger and colleagues' (2021) study explored how PSTs incorporated mathematics and computational thinking into science instruction at varying levels of cognitive demand. Through a longitudinal case of a beginning biology teacher, Sickel and Friedrichsen (2015) explored how a participant navigated constraints to design and adjust 5E (Bybee et al., 2006) instruction. Additionally, at times ECSTs realized their intent to enact reformed tasks fell short and possibly constrained student thinking (Braaten et al., 2022) or did not make sense to students (Navy, Jurkiewicz, et al., 2022). Tekkumru-Kisa and colleagues (2022) offered an exploration of how PSTs planned for and implemented a cognitively demanding science task. Using the Task Analysis Guide in Science (TAGS, Tekkumru-Kisa et al., 2015), authors found PSTs used five categorizations of students' ideas:

> "As evidence of content coverage, as obstacles to understanding, as tools to prime student thinking, interest, and activity, as elements of a positive classroom environment, and as the raw material of learning" (Tekkumru-Kisa et al., 2022, p. 4).

The authors found PSTs who viewed students' ideas as resources for learning promoted higher cognitive demand and made better use of pedagogical tools, such as practices for facilitating productive discourse.

***Attending and Responding to Student Thinking***

Contemporary reforms call for teachers to use students' ideas as resources for learning in the classroom (Davis & Palincsar, 2023; Larkin, 2012; Penuel & Reiser, 2018). Works in this section focus on how ECSTs notice, attend to, respond to, and reflect upon student thinking so the ideas may be used to develop a more sophisticated understanding. Wang and Oliver (2023) focused on how PSTs noticed events in the classroom and found PSTs mostly concentrated on the mentor teacher rather than students. PSTs concentrated on events that were novel, connected to prior experiences, were consistent with expectations, and/or they saw themselves reacting in a different way (Wang & Oliver, 2023). Additional papers explored how PSTs noticed, interpreted, and reflected on students' assessment responses (H. Kang & Anderson, 2015) and classroom video recordings (Barnhart & van Es, 2015). As teachers can only respond to students' ideas if they first notice them (Levin et al., 2009), together these papers suggest PSTs' attention and subsequent response and reflection should be addressed in practical experiences.

Several studies explored ways ECSTs attend and respond to student thinking in the moment during sensemaking discussions (Bang & Luft, 2014; Cian & Cook, 2020; Izci & Siegel, 2019; Kloser et al., 2019; Larkin, 2017; Meier et al., 2020; Napier et al., 2020; Pecore et al., 2023; Rutt & Mumba, 2022; Stroupe, 2014). Although some articles in this area suggested ECSTs struggled to facilitate sensemaking conversations in classrooms, the ways ECSTs attend and respond to students' ideas were varied and nuanced (Cian & Cook, 2020; Kloser et al., 2019; Pecore et al., 2023; Stroupe, 2014). For example, Stroupe's (2014) multi-case study of five beginning teachers explored how ECSTs shaped discussion norms so students could act as epistemic agents, who mold the knowledge, sensemaking, and practices of their science classroom community. Two participants' *breadcrumb epistemology*—using targeted questions to lead students to *truth* bit by bit—framed how they facilitated class discourse in ways that positioned students as passive receivers of canonical science knowledge; as they feared veering from the breadcrumb questions would cause students to get lost (Stroupe, 2014, p. 504). Conversely, three other participants aimed to create knowledge *with* students. They were unconcerned when students' scientific understandings advanced in a non-linear fashion and often chose not to research the complete explanation of puzzling phenomena so they might build knowledge with students. Additionally, Kloser and colleagues' (2019) multi-site case study of science methods courses offered how rehearsals and organizational tools supported PSTs' learning to facilitate sensemaking discussions.

Attending and responding to students' ideas requires ECSTs to encounter uncertainty in their classrooms wherein students "express unease about their own understanding and then articulate gaps or inconsistencies" advancing their thinking around scientific topics (Watkins et al., 2018, p. 569). Stroupe and Gotwals (2018) described how preparation in ambitious teaching practices prepared PSTs to manage uncertainty through practice making pedagogical judgements about students' emergent ideas and experiencing instructional strategies from a students' perspective. A design-based, multi-case study explored how two third-year middle school teachers managed uncertainty during classroom argumentation (Chen et al., 2019). The two teachers, Kay and Dean, were selected for their low-moderate and high-moderate Reformed Teaching Observation Protocol (RTOP, Piburn & Sawada, 2000) scores, respectively. The authors found Kay did not attempt to maintain students' uncertainty, but rather "emphasized that 'data can prove'" and "treated students as receivers of isolated ideas" (Chen et al., 2019, p. 1253). Conversely, Dean could effectively maintain and reduce uncertainty. Chen and colleagues' (2019) analysis found Kay and Dean shared some practices, such as using physical materials to model phenomena, but also differed in meaningful ways. For example, while Kay encouraged students to compare claims without effort to modify as needed afterwards, Dean asked students to consider arguments from multiple perspectives and use reasoning to reshape and strengthen arguments. Additionally, Dean's practice included many opportunities for social negotiation—when "students collaborated to mitigate uncertainty by establishing an acceptable consensus within a community"—whereas Kay had limited use (Chen et al., 2019, p. 1237). Additional studies suggest managing uncertainty is challenging for ECSTs because it drives epistemic tension (Braaten et al., 2022), such as uncertainty about evidence, and/or anxiety due to personal uncertainty about managing students' uncertainty (Chakrin & Campbell, 2022; Jaber, 2021). Jaber's (2021) case study describes how a teaching candidate was able to alleviate anxiety about students' uncertainty through his experiences in a responsive teaching course.

***Assessment***

Assessment is a vital element of teaching practice. It is also a complex process that requires effort from teachers before, during, and after instruction. The papers in this area focused on ECSTs as they developed expertise in and implement assessment. Gotwals and Birmingham (2016) investigated how seven PSTs in a yearlong methods course advanced their understanding of formative assessment. The authors found PSTs shifted from lower to high cognitive demand questioning and *Initiate, Respond, Evaluate* (Cazden, 2001) talk patterns towards a reflective toss pattern when leading discussions with students during their internships (Gotwals & Birmingham, 2016). PSTs did not move towards a nuanced understanding of students' thinking, but rather maintained a dichotomous notion that students' answers were correct or incorrect. This influenced the ways PSTs asked questions, their goals for asking questions, how they responded to students in the moment, and how they interpreted students' responses (Gotwals & Birmingham, 2016, p. 382). Talanquer and colleagues (2013) explored how 43 PSTs evaluated evidence of students' thinking during an inquiry unit. They found PSTs attended to both Task-General (e.g., learning objectives) and Task-Specific (e.g., performing an investigation) elements of students' work. However, attention was often limited to acknowledging inclusion of expected ideas without evaluation of unanticipated student thinking and general science process skills (Talanquer et al., 2013, p. 202). Izci and Siegel (2019) offer a case study of an alternatively certified first year chemistry teacher as they tracked her efforts to use assessment data to adjust instruction. They found that although she held constructivist views and valued the formative function of assessment, she instead enacted a transmission-oriented approach and did not select appropriate assessments for her aims (Izci & Siegel, 2019, p. 10).

In 2013, Lyon published two articles on supporting PSTs' development of equitable assessment practices, particularly around language needs. In a study of eleven PSTs, he found candidates readily shifted towards a formative view of assessment but had difficulty planning an equitable science assessment. Although they described knowledge of language issues in assessments, they did not apply the knowledge to their assessment plans (Lyon, 2013b, p. 461). In a case study, Lyon explored how one PST developed a focus on incorporating discourse into science assessment. The candidate was solely focused on students' understanding of core science ideas and failed to interpret their use of language in science (Lyon, 2013a, p. 294).

Together these articles suggest ECSTs can describe effective assessment practices in theory but struggle to use them effectively in practice. Additionally, ECSTs' experiences with high-stakes, standardized testing was not the primary focus of any included article. However, the associated challenges were referenced across the literature selected for this review. High-stakes testing contributed to a variety of ECSTs' challenges, including: (a) rigid, tightly paced curricula (Borgerding et al., 2015; Izci & Siegel, 2019; Strom & Martin, 2022), (b) administrative pressure (Stroupe, 2016), (c) conflict with pedagogical goals (Hutner et al., 2021), and (d) use of limited classroom time (Roychoudhury & Rice, 2013).

***Classroom Environments***

Several studies looked at how ECSTs set up science learning environments. Articles focused on the physical environment, resources, classroom scientific culture, classroom management, and uncommon environments, such as the practice of "floating" or developing a digital environment during the COVID-19 pandemic. This section covers research focused on teacher-developed environments; wider aspects of the environment (e.g., school culture, administration) are explored in the section on *Larger School Structures*.

Stroupe (2017) investigated how three first-year teachers designed and used their classroom as spaces of science. He found ECSTs had differing definitions of science, and those understandings shaped how they designed and used classrooms as places of science; thus, each classroom nurtured a unique form of science. However regardless of the differences, Stroupe (2017) found each ECST supported science as a community endeavor. For example, Karen viewed science as a messy, empirical, experimental way to explain the world. In her work, she moved students outside the bounds of the classroom to experience science in their communities. Karen allowed students to freely use equipment to design investigations to test their hypotheses and provided large poster paper for students to publicly display their evolving ideas. She physically organized the classroom for students to sit in groups rather than alone. These features supported Karen's students to engage in the "messy" work of science. Each ECST arranged their classroom, so students were in groups and permitted them to move between groups. They also aimed to foster a classroom culture where students were not afraid to be wrong and could think out loud so students could use ideas as resources to advance science understanding over time. Stroupe (2017) argues science educators should pay special attention to how ECSTs design environments to enact ambitious instruction.

Very few articles focused on classroom management as the primary focus of study. However, in many articles the participants identified classroom management as a tension in their practice (Bang & Luft, 2014; Binns & Popp, 2013; Braaten & Sheth, 2017; H. Kang & Zinger, 2019; Marco-Bujosa et al., 2020; Navy, Jurkiewicz, et al., 2022; Rutt & Mumba, 2023; Strom, 2015; Strom et al., 2018; Strom & Martin, 2022; Varelas et al., 2023; Wray & Richmond, 2018). For example, Binns and Popp (2013) endeavored to explore how PSTs made sense of inquiry-based instruction, but participants were overwhelmingly focused on developing classroom management skills. Raven and Jurkiewicz (2014) investigated how 21 PSTs conceptualized bullying in science classrooms. They found the participants are not adequately prepared to deal with bullying in science classrooms and had different notions of what comprises bullying. Participants conceptualized bullying to be heightened during instruction on controversial topics. Challenges around classroom management were not limited to misbehavior or inherently negative. For example, the participants in Kang's (2017) study struggled to motivate their students to participate in science tasks. Overall, ECSTs often struggled to manage student behaviors in science classrooms.

ECSTs need resources to conduct their work. Navy and colleagues' (2020) paper explored which human, material, and social resources participants had available and how participants accessed the resources or not. The participants most often referenced social resources from within (e.g., content area colleagues, mentor teachers) and outside (e.g., university professors, professional development) schools. Participants described how material resources (e.g., textbooks, lab equipment) were often too few and/or inadequate. In this study, participants mentioned commonly using their knowledge of students as a human resource. In a similar study, Stroupe (2016) conducted a multi-case study of five first-year teachers' available and utilized resources. He found participants used resources in ways aligned with their epistemic stance; more ambitious-aligned participants capitalized on resources from their teacher preparation program, while transmission-focused teachers valued resources from the school context and departmental norms. One participant, Rebecca, worked to alleviate resource-based tensions by combining an ambitious practice, using puzzling phenomenon, and a school-preferred resource, the textbook, in a unit on osmosis (Stroupe, 2016, p. 69). Across the papers in this review, ECSTs lamented scarce and inadequate resources (Cian et al., 2017; Dubois & Luft, 2014; Izci & Siegel, 2019; Marco-Bujosa et al., 2020; Moseley et al., 2014; Rodriguez, 2015a; Strom et al., 2018; Strom & Martin, 2015, 2022; Stroupe et al., 2022; Varelas et al., 2023). However, at times resources were available but participants could not access them (Mark et al., 2020) or did not seek them out (Saka et al., 2013).

Two papers explored ECSTs' experiences in atypical classroom environments. First, Dubois and colleagues (2014) followed three first-year "floating" teachers who travelled from room to room throughout the day, without a classroom of their own. The authors found "floating" limited the ability for new teachers to implement standards-based instruction. The participants experienced many challenges specific to floating, such as needing to keep all teacher and student materials on a rolling cart and being scheduled in non-science classrooms without lab spaces. The teachers described feeling like outsiders in their assigned classrooms wherein they could not change the classroom arrangement nor use available resources, such as writing on the whiteboard (Dubois & Luft, 2014, p. 15). Second, Weinburgh (2022) directed a single case study of John who completed student teaching during the initial COVID-19 pandemic lockdown (March 2020 onward) and his first year began virtually and ended hybrid. John described trying to navigate learning to teach biology and learning to teach remotely at the same time. From this experience, Weinburgh (2022) drew four themes: (a) other ways became the norm, (b) no wisdom from elders, (c) I built it, but they did not come, and (d) what happened to hall, bus, club, or cafeteria duty (p. 240). First, John found without a physical classroom the management and instructional strategies he learned in college were irrelevant to working with his muted students. Additionally, John lacked support from more experienced colleagues as they all had the same limited experience with virtual and hybrid instruction and were equally stressed and pressed for time. Third, John recounted poor student attendance and participation during the pandemic. He felt dispirited when he spent hours designing materials for lessons, but students did not participate, attend, or submit assignments. Lastly, John felt incredibly isolated from his students and colleagues. He even yearned for additional assigned duties, such as lunch monitor, he was missing because they would have afforded him time to chat with students and colleagues. Overall, John's experience was isolating and challenging, but he *survived* and described looking forward to the new *new normal* (Weinburgh, 2022, p. 240).

### *Technology Integration*

As technology integration becomes increasingly ingrained in contemporary classrooms, the articles in this section explore which and how technologies are used in science classrooms. Classroom technology advances quickly and has changed heavily across the decade this review spans. In 2013, Bell and colleagues examined ways PSTs used technology during student teaching. They found PSTs used PowerPoint™ to embed multimedia, such as videos, pictures, and simulations, into presentations to improve student engagement and visualization via a computer projector system (Bell et al., 2013). More recently, Kilty and Burrows (2021) conducted a similar study and found PSTs thought technologies useful in a science classroom included "general school supplies, science-specific instruments (e.g., microscopes), and pedagogical technologies (e.g., whiteboards)" (Kilty & Burrows, 2021, p. 585). PSTs felt social media had low usefulness. Specific technologies PSTs described include Kahoot©, smartphones, safety equipment, data collection instruments (e.g., sling psychrometer), and scientific calculators. Kilty and Burrows (2021) found the PSTs excelled in using technology to make scientific views accessible and addressing science with appropriate pedagogy but were weak in supporting students' understanding of the relationship between technology and science. Maeng (2017) explored how technology functioned to support an ECST's differentiated instruction and found technology aided formative assessment collection and analysis to attend to students' varied needs.

Studies in this area also focus on how ECSTs develop and implement *technological pedagogical content knowledge* (TPACK, Koehler & Mishra, 2005) in science classrooms. Coursework and fieldwork supported PSTs' developing TPACK by providing opportunities to observe and implement combined technology, pedagogy, and content into practice, such as interactive whiteboards, presentation technologies, online content, collaborative tools, and content-specific tools (Habowski & Mouza, 2014). Maeng and colleagues (2013) explored how PSTs developed TPACK during technology-enhanced inquiry instruction. The authors found PSTs selectively used technology when they felt it was appropriate, such as "an engaging 'hook' to a lesson, to facilitate data collection, to facilitate data analysis and to facilitate communication and discussion of results" (Maeng et al., 2013, p. 853). PSTs felt their use of technology was limited and referenced external barriers (e.g., curriculum) to implementation.

***Reading and Writing in Science***

Several studies looked at how PSTs learned to support their future students' reading and writing in science content areas (Cook & Dinkins, 2015; Mawyer & Johnson, 2019; Meier et al., 2020; Pytash, 2013). Mawyer and Johnson (2019) found before coursework in content area reading, PSTs were not prepared to use science texts in meaningful ways with students. However, PSTs were able to use general and genre-specific reading strategies themselves while reading scientific texts. Cook and Dinkins (2015) investigated how PSTs drew on popular fiction to promote disciplinary literacy during a course. Throughout the course PSTs were able to connect non-fiction ideas to fictional texts and offered a variety of instructional strategies (e.g., jigsaw, KWL chart) in their unit plans. PSTs continued to struggle to offer differentiated reading material and planning strategic writing instruction. Meier and colleagues (2020) investigated how PSTs understood pedagogy around academic language, particularly while working with emergent bilinguals. They found focused instruction on academic language supported PSTs' understanding, but required sustained, self-reflective effort by both PSTs and course instructors. In sum, PSTs often enter education programs with little knowledge of teaching reading and writing in the sciences but can learn with targeted support.

### ***Larger School Structures***

In this work, I use *larger school structures* to refer to elements of schools that affect teachers and classrooms that are outside the ECSTs' locus of control. Few articles included in this review addressed larger school structures as a primary focus of investigation. However, many participants identified elements of larger school structures as a driving tension of their experiences. The most prominent tensions were driven by policies related to (a) accountability, (b) administrators, (c) and scheduling.

Accountability measures operate with the aim to ensure children receive high-quality education by holding schools accountable for students' knowledge, skills, and behaviors (Brill et al., 2018). Systems of accountability vary widely across the United States as federal, state, and local actors can implement policies that trickle down to classrooms. Common forms of accountability in the United States include standardized assessments, teacher and school evaluation, and learning standards (Brill et al., 2018). The already high stakes of providing students high-quality education are raised further when funding is tied to accountability metrics—furthering the pressure to perform well. However, throughout this review ECSTs described ways elements rooted in accountability limited their agency to offer, in their view, high-quality instruction.

Most commonly, teachers described an inability to alter rigid curricula required by school systems or administrators. At times, teachers found the rigid curricula limited their ability to engage students in disciplinary learning, as the curriculum focused on rote knowledge retention (Binns & Popp, 2013; Norville & Park, 2021; Strom & Martin, 2022; Stroupe, 2016; Windschitl, Lohwasser, Tasker, et al., 2021). Teachers also struggled to provide remediation, cover content in depth, or add disciplinary elements when they were driven to stay on a tight lesson schedule (H. Kang & Zinger, 2019; Marco-Bujosa, 2023; Marco-Bujosa et al., 2023; Rutt & Mumba, 2019; Strom, 2015; Strom et al., 2018; Strom & Martin, 2022; Stroupe, 2016; Weinburgh, 2022; Windschitl, Lohwasser, & Tasker, 2021). For example, Stroupe (2016) describes two PSTs who "felt constrained by their school's curriculum and expected pace of instruction," which pressured them to "[funnel] student thinking to 'correct answers'" as they "juggled the balance of 'reteaching,' keeping pace of the curriculum," and making space for students' thinking (p. 63). Students are treated as uniform learners when teachers cannot adjust rigid curricula to provide culturally responsive lessons. For instance, Strom (2015) describes an ECST, Mauro, who taught courses in Environmental Science, which had a standardized test and tight curriculum guide, as well as Earth Science, an untested subject with flexible curriculum. Strom (2015) writes, "because Earth Science did not have a standardized test associated with it Mauro felt he had room to tailor his teaching to his students' needs and interests," while in Environmental Science he was "more likely to rigidly adhere to [the curriculum] rather than modify [it] according to the students' needs, as he felt heavier pressure to 'cover' material for the tests" (p.

8). Teachers also address how they were forced to use inadequate materials at times, such as Sandy who was frustrated by a required school-level assessment with poorly worded questions that were at times not even covered in the associated required lessons (Norville & Park, 2021, p. 455). Often the purpose given for the strict adherence to selected curriculum referred to the importance of excelling on standardized, high-stakes tests.

Accountability drives efforts to measure teachers' effectiveness and performance. Teacher evaluation systems are one of the ways schools attempt to quantify teachers' work. Wallace (2019) shares an ethnographic case study of a Louisianian ECST's, Ms. Ister, experience with a standardized teacher evaluation protocol. Ms. Ister felt very constrained by the practice. She expressed the measure forced her to erase student individuality and limited culturally responsive teaching because if she failed to play the game (i.e., follow rubrics exactly) her job would be at risk. In addition to teaching science, Ms. Ister described teaching her students how to be observed. Ms. Ister summarized:

> "My rating as a teacher, like my job and where I stand is based off of that, heck yeah I am going to prep [students] because I don't want to lose my job or be rated as an ineffective teacher because of whatever it may be. It's hard. They try to standardize students" (Wallace, 2019, p. 976).

Wallace argues the teacher evaluation system became self-defeating, constraining the evolution of the teaching practices it set out to improve.

ECSTs also describe ways in which school administrators served as adversaries to overcome, rather than allies supporting their vision of science teaching. Administrator's policies caused tensions for ECSTs (Bang & Luft, 2014; Braaten, 2019; Kier & Chen, 2019; Marco-Bujosa, 2023; Mark et al., 2020; Moseley et al., 2014; Saka et al., 2013). For example, Braaten

(2019) describes how participants' school administrators used observation checklists to monitor if teachers used a required *Focus Lesson* instructional routine. If a teacher did not meet elements of the checklist, the report indicated goals were not met and the data was shared weekly at faculty meetings. Some ECSTs struggled due to mid-year administrative turnover (Doney, 2013; Strom et al., 2018; Strom & Martin, 2022) or unavailability of administrators (H. Kang & Zinger, 2019). Lack of a consistent administrator often caused ECSTs confusion around expectations and difficulty garnering support. Saka and colleagues' (2013) paper described the case study of a first-year teacher, Nathan, who experienced salient tensions with school administrators. The administrators were preoccupied with improving accountability metrics around mathematics and reading, which led to school policies requiring math practice problems at the start of each lesson in every subject. He also experienced a marked lack of investment in resources for the science department, support of behavior management for students, and overall physical presence of administrators around the school. Mid-year Nathan spoke up to express his opinions on some school policies at a faculty meeting, but administrators did not value his ideas. Nathan shared, "…we went to this meeting, and I poured my heart out to my administrator and I was told not to come back next year" (Saka et al., 2013, p. 1234). Nathan's administrators drove him from the school community and across state lines to a new school the following year. Excellent administrators were not highlighted across the selected literature in this review, however that is not to say they do not exist. Likely, when administrators did not cause tensions for ECSTs they were left out of the discussion of ECSTs' experiences. Regardless, school administrators play a strong role in shaping the work of ECSTs and their development.

Many ECSTs described how the school's scheduling caused tensions in their work from lack of time, additional assigned duties, and large class sizes. First, ECSTs felt they lacked time to adequately plan for the instruction they envision (Bang & Luft, 2014; Binns & Popp, 2013; Cian et al., 2017; Doney, 2013; Gallo-Fox & Scantlebury, 2015; Izci & Siegel, 2019; Maeng, 2017; Napier et al., 2020; Navy et al., 2020; Ortega et al., 2013; Rodriguez, 2015a; Rutt & Mumba, 2019; Sickel & Friedrichsen, 2015; Strom, 2015). ECSTs also struggled fit all the amount of content and/or engage students in disciplinary practices into provided instructional time (Binns & Popp, 2013; Borgerding et al., 2015; Chakrin & Campbell, 2022; Cian et al., 2017; Cian & Cook, 2020; Dubois & Luft, 2014; Kloser et al., 2019; Marco-Bujosa et al., 2023; Roychoudhury & Rice, 2013; Rutt & Mumba, 2019, 2023; Sickel & Friedrichsen, 2015). Second, some ECSTs were overwhelmed by additional duties (Bang & Luft, 2014; Doney, 2013; Napier et al., 2020; Ortega et al., 2013; Rodriguez, 2015a; Saka et al., 2013; Strom, 2015; Strom & Martin, 2015). Lastly, a handful of ECSTs struggled to lead large classes of students (J. Brown et al., 2018; Rodriguez, 2015a; Strom, 2015)

### *Summary and Commentary for Theme 1*

ECSTs need to understand and engage in planning, enacting, and assessing effective science instruction. Overall, this review indicates ECSTs' rapidly develop in this area across their first years of teaching, however development is not linear, varies across ECSTs (even within small groups, such as graduates of a specific program), and is affected by contextual factors, such as community membership and epistemological framing. Studies indicate ECSTs have a mixed understanding of inquiry, reformed, and/or constructivist teaching practice. Courses were successful in realigning ECSTs' beliefs and instructional practices in reformed ways; however, ECSTs struggled to implement reformed instruction in the classroom, often due to limitations of context (e.g., strict curricula or administrator demands). Many, but not all, ECSTs lapsed into traditional-oriented routines during their first years, even when they expressed reform-oriented beliefs. Reformed approaches might be supported by science-specific induction programs and ways ECSTs are able to shift contextual discourses. ECSTs struggled to facilitate sensemaking conversations in classrooms and maintained a dichotomous notion that students' answers were correct or incorrect. The ECSTs shown to excel in this area were often supported through coursework that specifically targeted practices related to leading sensemaking discussions. This review suggests ECSTs can describe effective assessment practices in theory but struggle to use them effectively in practice. ECSTs entered programs with little knowledge of teaching reading and writing in science but improved with targeted support.

Contexts heavily shaped ECSTs classroom environments. ECSTs design their classrooms as places of science in several ways. Classroom management was widely addressed as a personal struggle by participants, but it was not an area of focus for researchers. ECSTs strongly relied on social resources available to them, including peers, but felt material resources were lacking. Some ECSTs were further challenged by atypical classroom environments, such as *floating* and virtual spaces. ECSTs integrate a variety of technology into their practice for varied reasons, such as 'hooking' students into a lesson or displaying graphics. ECSTs were strongly challenged by issues with accountability measures, administrators, and scheduling.

Although nearly every study addressed instruction and learning environments in some capacity, the articles presented in this review reveal gaps in existing literature. Studies of participants during pre-service widely outnumber studies during in-service. While it is important to understand how PSTs are taking up coursework and developing before they enter the field, this review suggests contextual factors while in-service limit how ECSTs utilize what they learned during preparation. More studies, particularly longitudinal studies that cross from pre-service to in-service, are needed to understand the lasting effects of coursework on ECSTs eventual teaching practice. Additionally, participants' teaching practices were highly, and often negatively, influenced by school contexts. However, studies focusing on how participants mediate contextual factors were limited. Continuing research that unpacks how ECSTs continue to develop instructional practices while in-service will also offer feedback to improve preparation. Without understanding how ECSTs navigate the field, we cannot adequately prepare them for in-service work.

**Theme 2 – Challenges Related to Equitable and Justice-Oriented Teaching**

Theme 2, *equitable and justice-oriented teaching*, explores ECSTs' "understanding of how cognitive, linguistic, social emotional, and physical development occurs, with the recognition that learners are individuals who bring differing personal and family backgrounds, skills, abilities, perspectives, talents, and interests" (CCSSO, 2013, p. 8). In Appendix D "*All Standards, All Students,"* the NGSS address how teachers can make the standards accessible to *all* students through seven case studies. However, critics argue the NGSS and Framework fall short of their goal (e.g., Rodriguez, 2015b). The papers reviewed in this theme respond to the challenges: *How do ECSTs' understand and develop equitable instructional practices and learning environments? How do ECSTs work to become agents of social change within their role?*

I identified 29 papers for Theme 2 (see Table 1). Theme 2 studies tended to have fewer participants (9.3 on average) than other themes (15.9 participants average). While most papers in Theme 2 describe the experience of PSTs, a substantial percentage of the papers explored ECSTs in both pre- and in-service (17.2%). Theme 2 spread the largest percentage of papers to other themes (79%, Appendix A, Table 13) suggesting the challenges and experiences related to *equitable and justice-oriented teaching* are wide reaching. However, papers from other themes did not often spread to Theme 2 apart from Theme 3 (*Joining the Science Teacher Community*). The studies presented under this theme address: (a) *culturally relevant instruction*, (b) *teaching specific groups of learners*, and (c*) social justice teaching*.

### ***Culturally Relevant Instruction***

ECSTs work to develop culturally relevant practice. Studies focused on PSTs' culturally relevant practices found: (a) a course on culturally responsive pedagogy offered PSTs an affirming view of students, legitimized funds of knowledge, and expanded sociopolitical consciousness (J. Brown et al., 2018), (b) PSTs' descriptions of culturally relevant practice focused on academic success and cultural competence (Jones & Donaldson, 2022), (c) ways PSTs adjusted instructional units to improve multiculturality (J. Brown & Livstrom, 2020), (d) a course on culturally relevant teaching improved feelings of preparedness and shifted attitudes of power dynamics (Titu et al., 2018), and (e) reconciled tensions between colorblindness and the benefits of diversity in the classroom (M. Russell & J. Russell, 2014; Titu et al., 2018). Stepp and Brown (2021) conducted a sequential mixed methods study of nineteen novice science teachers enrolled in an induction program. The researchers found ECSTs' self-efficacy around culturally responsive teaching were high and stable across two years. However, the researchers found a disconnect between their observations using the *Culturally Responsive Instruction Observation Protocol* (CRIOP, Powell et al., 2016) and ECSTs' self-appraisals, suggesting self-efficacy might be inflated compared to practice. Participants across studies expressed challenges enacting elements of culturally relevant instruction. ECSTs described challenges building and maintaining relationships with students (Strom, 2015; Strom et al., 2018; Varelas et al., 2023; Windschitl, Lohwasser, Tasker, et al., 2021; Wray & Richmond, 2018).

Two studies investigated the overlap between Ambitious Science Teaching[10] (AST) and equitable teaching practice. Kang and Zinger's (2019) longitudinal qualitative case study followed three novice ECSTs during their first two years of teaching. The researchers focused on the role ambitious practices played in supporting culturally responsive instruction. They found ambitious practices helped ECSTs see 'struggling' students as capable learners and the core practices altered ECSTs' traditional views of teaching. However, the practices were not in and of themselves sufficient to increase ECSTs' critical consciousness about racism and systemic inequity. In a similar instrumental case study, Braaten and Sheth (2017) describe how tensions arose for a fourth-year teacher, Ms. Dawson, as she worked to take on AST practices and equitable pedagogies in her classroom. The researchers describe how Ms. Dawson was split between the realities of school and her ambitious, equitable goals and state Ms. Dawson "felt caught in a paradox between helping her students play the game of science in school and working on changing the game of science in school" (Braaten & Sheth, 2017, p. 158). Together these articles suggest ambitious and equitable practices commingle to improve science learning environments for students, but ECSTs need targeted support to master the practices and translate the skills to classrooms.

***Teaching Specific Groups of Learners***

As classrooms become increasingly linguistically diverse, ECSTs need to support science learning *and* language acquisition. Through coursework, PSTs learned instructional practices for teaching emergent bilingual students (Rutt & Mumba, 2023, 2020; Siegel, 2014; Tolbert et al., 2024). Tolbert and colleagues (2024) explored how PSTs positioned themselves while teaching emergent bilingual students and argue the positions functioned as tension management while

[10] https://ambitiousscienceteaching.org/

PSTs navigated racist-nativist policy and schooling environments. The authors found three positional themes: (a) deficit, (b) distancing, and (c) discerning. PSTs with deficit positions relieved tensions by lessening personal responsibility and shifting blame (e.g., meritocracy, barriers, lack of resources) and candidates with distancing positionality drew boundaries that placed tensions outside their locus of control. However, PSTs with discerning positions expressed high agency and high structural awareness. They directly engaged with tensions and responded to educational inequities. For example, a discerning PST learned science terms in her students' first language because they may have already learned the concept in their previous schooling.

Papers also described how ECSTs engaged with emergent bilingual students during fieldwork (Heineke et al., 2019; Rutt & Mumba, 2022) and early years of teaching (Ortega et al., 2013). For example, Rutt and Mumba (2022) used a mixed methods design to explore how three PSTs integrated language and literacy into science instruction during field experiences. The authors found the ways PSTs integrated instruction were mediated by working relationships, perception of student ability, willingness to participate in the community, past experiences, resources, and personal views or willingness to challenge traditional instructional norms. Additionally, they documented how a PST slipped into deficit perspectives because of friction between her understanding of good instruction and classroom management. Ortega and colleagues (2013) offer a longitudinal case study of an ECST whose position served over 75% English Language Learners. The authors found she was able to engage students in inquiry at various levels while simultaneously developing students' language domains. However, standardized testing and additional duty assignments constrained her execution of inquiry-based instruction.

A handful of articles explored how teacher education programs prepared ECSTs to work in high needs (i.e., urban, rural, low-income) schools (Bischoff et al., 2014; Kier & Chen, 2019; Mark et al., 2020; Moseley et al., 2014). Moseley and colleagues (2014) investigated the relationship between PSTs' teaching- and cultural-efficacy as they worked in urban schools. The authors found a mid-year decrease in teacher efficacy attributed to initial optimism and unrealistic expectations, followed by an end-year overall increase attributed to establishing positive relationships with students. Mark and colleagues (2020) used critical discourse analysis to explore how PSTs positioned themselves while teaching in a large, urban, culturally diverse high school. The researchers found five positionalities: embedded, peripheral, conflicted, critical, and problematic. Embedded PSTs described their roles as central and meaningful in the classroom. They used their expertise to actively improve instruction, such as connecting class material to popular culture. Candidates in peripheral positions observed classrooms but did not have opportunities to shape the environment. PSTs with conflicted positionalities felt constrained by school structures and feelings of powerlessness. In the study, candidates with embedded and peripheral positionalities challenged dominant deficit beliefs with critical positionalities. These PSTs expressed: (a) "effective teaching is about cultural responsiveness and cross-cultural understanding," (b) "effective teachers establish connections with students," and (c) "student motivation is there; you just have to look for it" (Mark et al., 2020, pp. 472–473). The PST with a conflicting positionality expressed both critical and deficit beliefs. His frustrations compounded deficit views into a problematic positionality wherein he indicated not all students can be successful. The authors argue these positionalities influence teaching and learning and as such should be addressed by teacher education programs and school sites.

One unique case study explored how two White, male first-year teachers promoted academic success in an all-Black, all-male high school (Rogers & Brooms, 2020). Rogers and Brooms (2020) found the teachers imposed meritocratic ideals into a counterhegemonic school space and therein perpetuated racist ideals. The teachers injected meritocratic ideology into the school site as they "(a) located the problem within Black boys' identities, (b) constructed race, masculinity, and social class as barriers to students' academic success and teachers' effectiveness, and (c) positioned themselves relationally away from their students and the problem itself" (Rogers & Brooms, 2020, p. 440). The researchers suggest the limits[11] of counterhegemonic schools to shift the development of Black students, as in this case the space was infiltrated by deficit ideology, because they are still situated within a larger system of racism.

***Social Justice Teaching***

Papers that extended equitable teaching from the classroom to also challenge systems of oppression explored how ECSTs develop as social justice educators and engage in social justice teaching. While in teaching programs, ECSTs worked to take up and enact justice-oriented ideals (Maulucci, 2013; Morales-Doyle et al., 2021; Steele & Jeong, 2023; Valdez & Bianchini, 2023). For example, Morales-Doyle and colleagues (2021) explored how PSTs took up the ideals of a justice-oriented teacher education program. They found although PSTs did not feel fully prepared to enact justice-centered pedagogies, the PSTs progressed their understandings of social justice within science education. The researchers suggest partnerships with local groups can effectively disrupt prejudices towards communities and mainstream cultures around schooling. Morales-Doyle and colleagues recommend other science teacher education programs

[11] Rogers and Brooms (2020) are not arguing against counterhegemonic sites, but rather suggesting they are not a cure all for systematic issues.

should include “opportunities for PSTs to question their disciplinary and pedagogical commitments, in part by viewing their content areas as structures that may uphold or disrupt inequities” ((2021, p. 58). For example, a candidate linked environmental racism with chemistry concepts through a discussion on Freddie Gray’s lead exposure as a child and his eventual death at the hands of police officers. A similar study of eight PSTs in a justice-oriented teacher education program found candidates expressed critical awareness and equitable academic expectations, as well as a focus on student-teacher relationships and the value of students’ ideas (Valdez & Bianchini, 2023). Rivera Maulucci (2013) describes a particularly apropos challenge when a justice-oriented PST experienced internal conflict when she found herself ‘becoming the oppressor’ because she wanted both to justly teach students and prepare them for an unjust world. The tension between preparing students for the world ‘as is’ and ‘should be’ is mirrored across many studies in this review (Braaten & Sheth, 2017; Marco-Bujosa, 2023; Varelas et al., 2023).

Longitudinal studies were able to track ECSTs as they transitioned from teacher education programs to the field. Across three articles, Macro-Bujosa and colleagues describe the experiences of their recent graduates chronicled from a larger study (Marco-Bujosa, 2023; Marco-Bujosa et al., 2020, 2023). First, Marco-Bujosa and colleagues (2020) describe the critical case of an urban science teacher preparation program. The case describes four ECSTs across two years. The researchers found the ECSTs’ social justice-aligned identities were limited by school structures in their first year of teaching. The authors argue science teacher educators need to prepare ECSTs to navigate complex school structures and provide a foundation of socially just teaching with political clarity and induction support so ECSTs can resist dominant school social pressures. In the second paper (Marco-Bujosa et al., 2023), the authors explore the experiences of three of the participants in the above study. The researchers describe how (a) ECSTs used personal identities and experiences as science learners to construct teaching goals, (b) ECSTs' learning about social justice depended on those goals, and (c) the challenges to enacting justice-oriented goals enhanced ECSTs' sociopolitical awareness. The last paper explores a case study of a Caribbean-American ECST's, Faith, experiences across her teacher preparation program and following two years of teaching (Marco-Bujosa, 2023). Faith struggled to meld the values of transmission-based strict instruction she experienced as a student in Jamaica, which she believes prepares students for life after schooling, with the active, hands-on learning she values from her out-of-school learning experiences, which she believes will instill a love of science in students. Faith's two cultures of schooling clashed in other ways as well. For example, she initially embodied a demanding approach with students focusing on high standards reflecting her meritocratic values. However, her students perceived her negatively and petitioned to have her removed from the class. Faith realized her attention to content exposure over relationships did not fit in her current American context and adjusted her approach to respond to students' lives, interests and academic needs. Additionally, Faith found the dominant culture of science serves as a barrier to socially just teaching and to be a justice-oriented teacher means making science learning relevant, as well as challenging the narratives that made her students see themselves as apart from science. Across these articles, Marco-Bujosa and colleagues document ECSTs' challenges and successes translating social justice ideals into practice.

ECSTs worked to change the system from within during their early years of teaching. Rodriguez (2015a) describes the case of an ECST's efforts to become an agent of social change during his first two years of teaching. The participant encountered institutional and sociocultural challenges. Institutional challenges included deeply entrenched school policies, such as standardized testing, and resistance to disruptive practices. Sociocultural challenges encompassed racialized interactions, such as deficit views, and students' low engagement and achievement. Rodriguez suggests when the ECST attempted to disrupt unequitable practices the challenges *pushed back* against his agency causing frustration and wearing down the ECST into conformity with dominant schooling narratives. A case study of recent graduates of a social justice-oriented teacher education program investigated how twenty ECSTs pursued social justice in their everyday classrooms (Kawasaki & Chang, 2023). Kawaski and Chang (2023) found participants: (a) "reflected on their positionality, (b) built restorative relationships with students, (c) developed students' critical dispositions, (d) built positive science identities, (e) increased students access to science, and (f) incorporated students' knowledge, experiences, and histories" (p. 1). The researchers conclude that although a justice-oriented program supported ECSTs' social justice practices, they continued to develop in some areas of social justice teaching and recommend teacher education programs continue to support ECSTs after graduation.

***Summary and Commentary for Theme 2***

ECSTs endeavor to understand and develop equitable instructional practices and learning environments. Courses focused on equity, justice, and/or culturally relevant pedagogy were successful in (re)aligning participants' mindsets towards course goals. However, researchers suggest participants' self-appraisals of equitable teaching practices were inflated compared to critical analysis. ECSTs struggled to form and maintain relationships with students, a critical equitable practice. Articles suggest ambitious (Theme 1) and equitable practices commingle to improve science learning environments for students, but ECSTs need targeted support to master the practices and translate the skills to classrooms. ECSTs were varied in ways they worked with language learners, in high-needs schools, and with minoritized communities. While supports, such as coursework or mentorship, generally improved ECSTs equitable and justice-oriented pedagogies, many ECSTs maintained deficit and/or colorblind perspectives. Studies focused on social justice found, unsurprisingly, that being an agent of change is challenging for ECSTs. ECSTs' justice-oriented identities and practices were often limited implicitly and explicitly by others and school contexts. As ECSTs pushed against inequitable systems, the system pushed back. Participants expressed a prominent tension between preparing students for the world 'as is' and 'as should be'. Overall, ECSTs found it challenging to translate their ideals into practice.

The articles presented in this review offer a lens into ECSTs' experiences related to equitable and justice-oriented teaching. But there are related areas that would benefit from additional research. Researchers often described how equity focused courses and programs improved ECSTs' practice. But what specifically about those courses and programs led to lasting change for ECSTs? As minoritized groups continue to be underrepresented in the sciences, how are we preparing ECSTs to promote equity in the sciences specifically, in addition to general equitable pedagogies? Without knowing how ECSTs engage in equity-focused reflection, others will be unable to replicate the success for others. Similarly, researchers described ways working with communities had positive effects for ECSTs practice, but pre- and in-service. But how ECSTs interacted with communities outside of school and brought communities into school is not adequately described. Additionally, deficit views were persistent or reemerged for some ECSTs. In what ways are ECSTs pushed to continue to reflect on how their practice may or may not support equity-oriented goals? Articles addressed how ECSTs learn to support high needs and emergent multilingual students. However, I was surprised no articles described how ECSTs support students with intellectual, emotional, or physical disabilities. Because science has particular elements not seen in other content areas (e.g., laboratory investigations, safety considerations) and schools are increasingly able to place differently-abled students in general education classrooms, ECSTs need to be prepared to teach this group of learners.

**Theme 3 – Challenges Related to Joining the Science Teacher Community**

At the onset of their careers, ECSTs not only need to learn the skills of teaching, but to also "identify with and conduct themselves as part of the science education community" (Morrell et al., 2020, p. 3). Theme 3, *joining the science teacher community*, depicts ECSTs as they enculturate into a new social group, as well as reconcile new elements of identity with their former selves. However, although necessary, the transition affords many opportunities for challenges to arise for ECSTs. This theme also explores subsets of ECSTs' WITH atypical experiences joining the science teacher community. The articles within this theme explore the challenge: *What affordances and constraints affect how ECSTs become members of the science teacher community? What happens when ECSTs do not adequately assimilate into new positions and/or roles?*

Theme 3 draws on 21 papers (see Table 1). Papers in Theme 3 were small (median 4 participants) with a few large studies (max 129). A larger percentage (42.9%) of studies focused on in-service ECSTs than the average across themes (26.6%). Theme 3 is well connected with roughly similar representation spreading to and drawing from other themes (Appendix A, Table 13). The studies presented under this theme portray: (a) *entering the profession*, (b) *professional identity*, (c) *career changers*, and (d) *out of field teaching*.

### *Entering the Profession*

ECSTs are faced with a variety of new experiences as they transition from K-12 students to students of education and eventually educators of students (Braaten, 2019; E. Kang et al., 2013; Strom, 2015; Strom & Martin, 2015; Windschitl, Lohwasser, Tasker, et al., 2021). Kang and colleagues' (2013) use a border crossing lens in their ethnographic study to explore eight PSTs' successes and struggles traversing the cultural border between science student and science teacher. The authors found PSTs were interested and willing to teach inquiry-based science lessons, whereas they expected salient challenges for PSTs as they negotiated the move from a traditional science learning culture to an inquiry-oriented science teaching culture. Revisiting the *two-worlds pitfall* (Feiman-Nemser & Buchmann, 1985), Braaten (2019) describes how 22 PSTs "reorganized, repurposed, and retooled" practices learned in an ambitious teacher education program for secondary classroom spaces (p. 62). Through her analysis, Braaten describes three areas of permeability teacher educators can use to support PSTs as they cross from teacher education to the field. First, small group interactions with students were less culturally reified and afforded more space to try out ambitious practices. Second, direct discussion about the limitations of transmission-based instruction encouraged PSTs to challenge traditional classroom norms. Lastly, instructional routines, such as eliciting student ideas, offered a counterscript to disrupt status quo cultural scripts of science teaching.

As ECSTs entered school spaces as teachers for the first time, they struggled against the established school culture and faced personal anxiety and explicit warnings from colleagues to not *rock the boat* (Braaten, 2019; Rodriguez, 2015a; Saka et al., 2013; Strom et al., 2018; Strom & Martin, 2015). For example, Strom and Martin (2015) use rhizomatic mapping and situational analysis to explore how one first year physics teacher translated his pre-professional learning into classroom practice. Although the ECST advocated inquiry-based, socially-just pedagogy, fear of negative administrator evaluation and possibly losing his job pressed him to mold his instruction to the traditional norms in his district. Additionally, Strom and Martin (2022) revisit the above challenge in a case study of three first-year teachers. They explored how the ECSTs navigated when and where they have agency versus when and where they need to carry out the larger school system's agenda. The found although ECSTs were able to occasionally act with agency, such as bringing in Nerf™ guns for physics demonstrations in an otherwise strictly ordered environment, the moments were fleeting as ECST were recaptured by structures, such as teacher evaluation, which worked to maintain the status quo (Strom & Martin, 2022).

### ***Professional Identity***

As ECSTs embark on new careers, they figure out how their identities fit into a new context and role. ECSTs' professional identities are multifaceted and include: (a) scientist and science teacher roles (Chung-Parsons & Bailey, 2019), (b) philosophies and beliefs (Britton & Tippins, 2015; Dogan et al., 2020), (c) resilience (Doney, 2013), (d) self-efficacy (Moseley et al., 2014), (e) agency (Mark et al., 2020; Norville & Park, 2021) and are influenced by (f) context (Stroupe et al., 2022; Wray & Richmond, 2018) and (g) others (Smetana & Kushki, 2021). Some ECSTs struggled to in their new role and experienced (a) anxiety (Cian et al., 2017; Kier & Chen, 2019; Snyder et al., 2013), (b) feelings of overwhelm (Binns & Popp, 2013; J. C. Brown et al., 2018; Navy, Jurkiewicz, et al., 2022; Saka et al., 2013; Tolbert & Eichelberger, 2016; Weinburgh, 2022), and (c) isolation (Balgopal, 2014; Doney, 2013; Moseley et al., 2014; Navy et al., 2020; Strom & Martin, 2015; Weinburgh, 2022).

At times, ECSTs experienced tensions at the intersections of their identities (Balgopal, 2014; Braaten et al., 2022; P. Brown et al., 2013; Marco-Bujosa, 2023; Saka et al., 2013; Tolbert

& Eichelberger, 2016; Varelas et al., 2023). Tolbert and Eichelberger (2016) share a counternarrative case study of Serina, a bilingual/biracial Peruvian-Anglo European PST, and her experience in a diversity-oriented teacher education program. Serina was vocal in her frustration with the *novice level* approach to social justice teaching in her program. However, instead of being receptive to her criticism, program actors worked to limit her voice through *institutional silencing* and Serina was eventually summoned for a disciplinary meeting regarding her 'unprofessional behavior.' During the program, Serina began to disengage in her courses as the program threw her teacher and social justice identities into conflict. Luckily, outside of her coursework Serina was able to "meaningfully connect her student teaching experiences to her identity as a change agent for underserved students" without the union "she may not have been able to conjure up the emotional energy she needed to carry on" with the program and left the profession (Tolbert & Eichelberger, 2016, p. 1036). Similarly, Saka and colleagues' (2013) case study describes a first-year teacher, Nathan, who negatively perceived his school context, particularly his interactions with school administrators. The authors argue his conflicting identities (e.g., as friend and champion of students vs. being the adult in the classroom) and weak social support drove Nathan to leave the school to find a new position.

Varelas and colleagues' (2023) phenomenological study explored how three first-year teachers of color drew on multiple identities to understand students, craft roles, and empower themselves to reform their education practices. Like Serina and Nathan, the participants had to grapple with opposing dialectical relationships including: (a) administrative demands vs. autonomy, (b) low level curricula vs. student ability, (c) current vs. future student needs, (d) lack of resources vs. enacting restorative practices, and (e) social justice focus vs. science content focus. However, unlike Serina and Nathan, the ECSTs in this study were members of a ‘community experience for teachers,’ a group where “new teachers apprentice in crafting relationships with communities and develop knowledge as they negotiate their insider and/or outsider identities vis-à-vis these communities with their teacher identities and create their own equity-excellence unit of meaning” (Varelas et al., 2023, p. 228).

***Career Changers***

A handful of articles explored the experiences of ECSTs who transitioned to education from careers in other fields (E. Burton & S. Burton, 2016; Izci & Siegel, 2019; Navy, Jurkiewicz, et al., 2022; Peters-Burton, 2016; Roychoudhury & Rice, 2013; Smetana & Kushki, 2021; Snyder et al., 2013; Tolbert & Eichelberger, 2016). The papers explore how career changers viewed elements of their work, how they drew on former experiences, and the ways they adjusted to a new profession. A multiple-case study of seven former professional scientists with five to thirty years of experience in varied fields examined how the career changers perceived how students’ learn (E. Burton & S. Burton, 2016). Burton and Burton (2016) identified two orientations: schema-centered teachers who regarded “student epistemology as an integral component of teaching students science” and activity-centered teachers who “expressed the need to show students how to think about science rather than allowing students to construct their own conception” (p. 375). Navy and colleagues (2022) explored how three career changers prior science-related and teaching-related career experiences offered coherences and tensions during an intensive teacher fellowship program, as well as salient transformations. The career changers benefitted from public speaking experience and connecting content to previous work. The ECSTs struggled with gaps in content knowledge, creating cohesion across lessons, planning for daily lessons, and classroom management. Across the fellowship, participants learned how to structure formal classroom environments, became more realistic, gained confidence in teaching ability, and improved hands-on lessons to also include data analysis.

Roychoudhury and Rice (2013) conducted a naturalistic study of two cohorts of a fifth year Master of Education program and were able to compare thirty PSTs who directly entered the program from undergraduate study with nine career changer PSTs. They found the direct PSTs adopted student-centered approaches and adjusted their views of teaching over the course of the program, whereas career changers took up teacher-centered approaches consistent with preliminary views of instruction. The career changers expressed a transmission-oriented point of view and "claimed students could not develop new knowledge unless teachers presented it to them" (Roychoudhury & Rice, 2013, p. 2208). The authors posit the origin of the difference lies in the longer period of time since career changers were secondary students themselves and argue the additional expertise in science domains does not ensure teachers will engage students in minds-on learning.

Authors also studied the personal changes career changers underwent during their early years in the teaching profession. Smetana and Kushki's (2021) study followed two career changers across a 13-month preparation program. The participants experienced disequilibrium from competing identity positions, such as a former environmentalist who found herself to be a part of the problem inherent in formal education she previously critiqued. However, ECSTs were able to restore equilibrium through deep independent reflection and integrating the intersections of identity, such as environmentalist, relationship-builder, and social justice educator. A three-year case study of four women who transitioned to teaching after six to fifteen years in STEM fields depicts the cognitive and emotional transformations the ECSTs underwent during a Master of Teaching program (Snyder et al., 2013). Snyder and colleagues (2013) found, similarly as above, participants transformed by integrating multiple personal identities. The ECSTs struggled with an initial decrease and subsequent reclamation of confidence as they developed their understandings of the social roles of science teachers and scientists.

Career changers decided to switch professions for a variety of reasons. Many were unsatisfied with their career and sought out teaching to overcome the sense of purposelessness (Smetana & Kushki, 2021; Snyder et al., 2013). Informal educators wanted to make the transition to formal secondary settings (Navy, Jurkiewicz, et al., 2022; Smetana & Kushki, 2021; Tolbert & Eichelberger, 2016). Some were drawn to fill the growing need for science teachers (Izci & Siegel, 2019). Others felt schools were failing to meet students' needs and aspired to serve as agents of change (Rodriguez, 2015a; Tolbert & Eichelberger, 2016). At times, career changers were challenged by friends and family who viewed the change negatively. For example, a former veterinarian was often questioned about "why she would want to take a pay cut" after spending many years in veterinary school (Smetana & Kushki, 2021, p. 176). Another experienced tensions in his marriage because his new position took up more of his time and offered a smaller salary in return (Rodriguez, 2015a).

***Out-of-Field Teaching***

Upon taking teaching positions, some ECSTs are assigned to teach outside of their field, such as a biology-focused graduate teaching chemistry courses (Napier et al., 2020; Nixon et al., 2016; Nixon, Luft, et al., 2017; Ozel & Luft, 2013; Saka et al., 2013; Strom, 2015; Strom et al., 2018; Strom & Martin, 2022). A large longitudinal study tracked the prevalence of out-of-field assignments across 137[12] ECSTs during their first five years in the classroom (Nixon, Luft, et al., 2017). Quantitative analysis suggested 21.7% of assignments were completely out-of-field and

[12]Some participants dropped out over the course of the study.

42.6% of assignments were a mixture of in- and out-of-field (e.g., teaching three sections in-field and two sections out-of-field) (Nixon, Luft, et al., 2017, p. 1207). Nixon and colleagues data set suggested ECSTs were more likely to teach out-of-field if they teach at: (a) a school with a higher percentage of emergent bilingual students, (b) a middle school, (c) an urban or rural school, and (d) if they have a teaching certification. Napier and colleagues (2020) qualitatively compared seven in-field and ten out-of-field physical science teachers. The researchers found out-of-field ECSTs experienced more challenges with and rarely incorporated scientific practices into instruction. When out-of-field teachers used scientific practices, they did so in isolation (e.g., writing procedures). The researchers' findings suggest ECSTs in out-of-field assignments were constrained from the start and did not progress instructionally, unlike their in-field peers. No studies explored teachers who came to science teaching from other non-science fields of study (e.g., English, art, math).

### *Summary and Commentary for Theme 3*

This review sheds light on how ECSTs become members of the science teacher community and what happens when they do not adequately assimilate into new positions and/or roles. Some ECSTs were able to continue building on and implement what they learned during preparation, but others were too limited by contextual factors to play out their vision. Many ECSTs were explicitly warned by colleagues or administrators not to *rock the boat* or challenge the status quo teaching cultural scripts. When ECSTs were at odds with their contexts, they experienced anxiety which negatively impacted their performance. ECSTs worked to navigate the political climate and cultures of their schools with mixed success. Their moments of agency were fleeting and limited. ECSTs professional identities are multifaceted and dynamic, influenced by context and others, but incorporating the new with the existing can be a challenge for some.  ECSTs' peers appear to have an overall positive impact on ECSTs' development and acclimation.  Tensions can occur at intersections of identity; at times this is exacerbated by context.  However, support helped make negotiating tensions more manageable.  Compared to peers, career changers tended to be more teacher-centered and experienced unique challenges, such as criticism for changing professional fields.  Across ECSTs, most teaching assignments included at least some out of field teaching.  Teachers in out of field placements experienced more challenges than in field peers.

The articles presented in this section suggest the two worlds pitfall (Feiman-Nemser & Buchmann, 1985) persists to pressure ECSTs to adapt to the contextual scripts of schools and make earlier learning liable to dissipate.  As the majority of the literature in this review focuses on PSTs learning, the strong—and at times explicit—pressure to unlearn the constructivist ideals of preparation and (re)learn transmission-oriented approaches is particularly concerning.  How are we preparing PSTs to work within or lead change of existing school norms?  What steps are needed to break down the divide between 'your way' and 'our way' of science teaching?  In what ways do we support ECSTs during these first years of teaching, particularly those without access to reform-focused induction programs?  Additionally, since out of field placements are common, how can we better prepare ECSTs to teach outside of their initial content area?

**Theme 4 – Challenges Related to Developing as a Professional**

Theme 4, *developing as a professional*, addresses how ECSTs "strive to continuously improve their knowledge of both science content and pedagogy" (Morrell et al., 2020, p. 3). ECSTs' learning "is enhanced by leadership, collegial support, and collaboration" (CCSSOs, 2013, p. 9).  The studies reviewed in this theme respond to the challenge: *What affordances and constraints affect ECSTs' professional development?*

This theme draws on 15 papers and is predominantly situated in pre-service contexts (73.3%, see Table 1). The studies are larger (on average 21.2 and median 15 participants per study) than the preceding themes. Theme 4 draws heavily on fellow themes (55 papers cross-referenced from other themes) and is most heavily related to Themes 1 and 2 (*Instruction and Learning Environments*, *Equitable and Justice-Oriented Teaching*) (Appendix A, Table 13). The strong connection is likely inflated by the high number of articles investigating PSTs during coursework and internships. The studies presented under this theme depict: *learning with and from others* and *learning with technology*.

***Learning With and From Others***

Many studies focused on formal environments of ECST learning. Researchers looked at secondary science teacher preparation programs overall (Bell et al., 2013; P. Brown et al., 2013; Heineke et al., 2019; Johnson & Mawyer, 2019; H. Kang, 2021; H. Kang & Anderson, 2015; Lyon, 2013b, 2013a; Marco-Bujosa et al., 2023; Meier et al., 2020; Morales-Doyle et al., 2021; Roychoudhury & Rice, 2013; Tolbert & Eichelberger, 2016; Valdez & Bianchini, 2023), as well as programs supported by Noyce grants[13] (Aminger et al., 2021; Bischoff et al., 2014; Kier & Chen, 2019; Marco-Bujosa, 2023; Marco-Bujosa et al., 2023; Meier et al., 2020). Studies covered multiple areas of ECSTs' coursework including: (a) science teaching methods courses (Barnhart & van Es, 2015; Bell et al., 2016; Borgerding & Dagistan, 2018; Braaten et al., 2022; J. Brown & Livstrom, 2020; E. P. Burton & S. Burton, 2016; Chakrin & Campbell, 2022; Cian et al., 2017; French & Burrows, 2018; Jaber, 2021; H. Kang, 2017, 2021; Kloser et al., 2019; Larkin, 2017; Mark et al., 2020; Mawyer & Johnson, 2019; Ozcelik & McDonald, 2013; Peters-Burton, 2016; Robertshaw & Campbell, 2013; Rutt & Mumba, 2019, 2020; Siegel, 2014;

[13] https://new.nsf.gov/funding/opportunities/robert-noyce-teacher-scholarship-program

Stroupe et al., 2022; Stroupe & Gotwals, 2018; Talanquer et al., 2013; Tekkumru-Kisa et al., 2022; Thompson et al., 2013; Voss et al., 2023); (b) a biology course (Balgopal, 2014); (c) an ecojustice course (Britton & Tippins, 2015); (d) culturally responsive and equitable teaching courses (J. Brown et al., 2018; Titu et al., 2018); (e) language and literacy courses (Cook & Dinkins, 2015; Pytash, 2013; Rutt & Mumba, 2023); and (f) a technology integration course (Habowski & Mouza, 2014). Scholars investigated ECSTs' experiences in fieldwork and internships (Binns & Popp, 2013; Braaten, 2019; Cian & Cook, 2020; Danielowich, 2014; Gallo-Fox & Scantlebury, 2015; Jones & Donaldson, 2022; Kilty & Burrows, 2021; Maeng et al., 2013; Maulucci, 2013; Norville & Park, 2021; Rutt & Mumba, 2023; Sezen-Barrie et al., 2014; Thompson et al., 2013; Wang & Oliver, 2023; Weinburgh, 2022; Whittington & Tekkumru-Kisa, 2020; Windschitl, Lohwasser, & Tasker, 2021; Windschitl, Lohwasser, Tasker, et al., 2021). Papers also explored several types of induction programs for ECSTs (Luft et al., 2022; McFadden et al., 2014; Navy et al., 2021; Ortega et al., 2013; S. Wong et al., 2013), conference attendance (Navy et al., 2019) and teacher evaluation (Wallace, 2019).

During their studies, PSTs work together to improve elements of their teaching practice. Gallo-Fox and Scantlebury (2015) provide insight on the struggles PSTs faced while co-planning, including using collective knowledge, identifying resources, and logistical challenges. PSTs also benefitted from peer feedback to support their learning (Braaten et al., 2022; Larkin, 2017). For example, Braaten and colleagues' (2022) case study explores how six PSTs engaged in a Critical Friends Group discussion format utilizing a conversation protocol and group norms (p. 4). The researchers found the Critical Friends Group structure created space for PSTs to discuss dissonance between their coursework and school sites, as well as opportunities for peers' perspectives to serve as resources for making sense of problems of practice. Additionally, PSTs participated in approximations of practice through microteaching (Sezen-Barrie et al., 2014) and macroteaching (Stroupe & Gotwals, 2018). Microteaching varies in format but is generally a short teaching activity with a few real students or peers. Sezen-Barrie and colleagues (2014) investigated PSTs' recorded microteaching episodes and subsequent reflections and found participants gave the most attention to mediating artifacts (e.g., instructional plans, materials, discourse) and less attention to the larger teaching community surrounding the event. Similarly, Dotger and colleagues (2018) explored how PSTs recognized and reacted to common misconceptions in a clinical simulation, teaching with an actor posed as a student. In efforts to improve PSTs' learning opportunities, Stroupe and Gotwals (2018) describe limitations of using microteaching (i.e., short thus inauthentic, small audience, too little student data for analysis, too spread out) and offer an updated model they call *macroteaching*. During macroteaching, PSTs work in groups to plan and teach an entire unit of instruction. The authors found six learning opportunities that emerged through macroteaching: (a) in-the-moment consultations, (b) time-out/time-in, (c) real-time instructional coaching, (d) rewind, (e) question and answer session at the end of each lesson, and (f) teaching team debrief at the end of the unit. Macroteaching offered PSTs the opportunity to encounter unanticipated student talk and actions and make decisive pedagogical responses in ways microteaching could not afford. Stroupe and colleagues (2022) expanded their study of macroteaching by following participants into their first-year teaching and found the practice positively shaped participants' experiences through a sense of community, feedback, and improved understanding to plan and enact a coherent unit of instruction.

ECSTs also work closely with and learn from their mentors. Bang and Luft (2014) explored how first-year teachers engaged with online mentors and found interactions were sporadic and participants sought advice and resources. Several studies described the alignment, or lack thereof, between mentors' and ECSTs' and/or teacher education programmatic goals (Binns & Popp, 2013; Braaten, 2019; H. Kang, 2017, 2021; Kier & Chen, 2019; Strom & Martin, 2015; Windschitl, Lohwasser, & Tasker, 2021; Windschitl, Lohwasser, Tasker, et al., 2021). Windschitl and colleagues' (2021) study examined how PSTs collaborated with mentors at various levels of perceived congruence of dimensions of instruction. The authors found in low congruence settings, PSTs expressed confusion, stated lessons felt disjointed, and how they were only able to make minor modifications to instruction. Conversely, PSTs in high congruence settings had opportunities to practice ambitious techniques with targeted coaching. Similarly, Kang (2021) conducted a multiple case study of 35 PSTs and their mentors to uncover more about how mentor-mediated experiences affected PSTs' learning. The study suggests even when mentors had low alignment with programmatic goals, PSTs progressed when they were highly encouraged to experiment and use program-recommended tools. Kang (2021) argues modeling, supporting experimentation, and providing feedback are not sufficient alone to support PSTs progress, and support of experimentation is critical by affecting PSTs' interactions with students.

Several participants across papers describe areas where colleagues and/or mentors limited their opportunities to learn. Many ECSTs were concerned by a lack of feedback (Strom et al., 2018; Windschitl, Lohwasser, Tasker, et al., 2021; Wray & Richmond, 2018) or paralyzed by too many sources of feedback (Cian et al., 2017). Additionally, ECSTs expressed concerns about *rocking the boat*, which limited their ability to try new strategies and improve their teaching practice. Strong resistance to change across school sites created tensions for ECSTs (Binns & Popp, 2013; Dubois & Luft, 2014; Marco-Bujosa, 2023; Marco-Bujosa et al., 2020; Norville & Park, 2021; Rodriguez, 2015a; Rutt & Mumba, 2023; Saka et al., 2013; Strom et al., 2018; Strom

& Martin, 2015, 2022; Stroupe et al., 2022; Varelas et al., 2023; Windschitl, Lohwasser, Tasker, et al., 2021; Wray & Richmond, 2018) with effects ranging from temporary unease to lasting anxiety of losing their teaching position.

### *Learning with Technology*

ECSTs are also engaged in learning opportunities facilitated by technology. The studies in this review focused on using video and simulated student avatars. Danielowich (2014) explored how PSTs reflected on their own and peers' video clips of instruction. He found PSTs' thinking became more change-directed and requests for feedback more specific as the course progressed. He argues video-framed contexts support goal-related, reflective teacher learning. Additional papers explored how analysis tools (Johnson & Mawyer, 2019) and software (McFadden et al., 2014) extended the benefits of using video. For example, Johnson and Mawyer (2019) investigated how PSTs used the Rapid Survey of Student Thinking tool (RSST; Windschitl & Thompson, 2015) to inform analysis of classroom instruction. The researchers found the tool supported sophisticated noticing of students' thinking. Participants also planned responses to student thinking in the videos and suggested offering a pedagogical move (e.g., more time, different structure), an additional science activity, or a learning scaffold. Overall, researchers found videos to offer an effective source for learning when paired with reflective strategies, tools, and software.

One article explored how six PSTs developed discussion skills through a course centered on teaching a water cycle lesson across three episodes with simulated avatar[14] students (Pecore et al., 2023). Course instructors provided feedback and skill development modules to PSTs between teaching episodes. Tracking PSTs' progress across the course, Pecore and colleagues

[14] https://www.mursion.com/services/education/

(2023) found candidates improved discussion facilitation skills across the avatar sessions. Additionally, PSTs reported the avatars were viable substitutes for ‘real-world’ students and limited anxiety through risk reduction. The authors argue the avatar intervention had an overall positive impact on participants’ skill competencies.

### *Summary and Commentary for Theme 4*

ECSTs must learn quickly and often on the job. PSTs’ learning during teacher preparation was widely addressed across studies; however, literature exploring formal learning after graduation was not as robust. Approximations of practice supported PST learning. Additionally, adjustments, such as macroteaching, can make approximations even more meaningful learning experiences. In addition to professors and more experienced colleagues, ECSTs learned from each other. For example, using a Critical Friends Group protocol helped structure ECSTs time together in a way that allowed them to work through problems of practice and use each other as resources. ECSTs often collaborate with mentors—ranging from occasionally to daily—with mentorship taking a variety of forms. Epistemological alignment with mentors matters for ECSTs’ development. When mentors’ stances were misaligned with preparation’s programmatic goals, ECSTs were often confused and missed opportunities to learn and try new strategies. Particularly during internships and early fieldwork, the space to experiment with instructional practices was critical to support PSTs progress. At times, mentors limited ECSTs’ opportunities to learn by prohibiting instructional experimentation—actions that are at odds with their role’s purpose. Technology-mediated learning, such as video clubs and avatars aided ECSTs development.

The studies explored in this review suggest ECSTs rapidly develop as professionals and learn with and from others. However, because most studies were situated in coursework or special programs the literature in this review offers limited understanding of the opportunities to learn for a typical ECST during their first years in the profession.  Although alternatively certified ECSTs were represented in this review, no studies specifically explored the learning opportunities during alternative preparation programs.

**Theme 5 – Challenges Related to Science Content and Disciplinary Practices**

The final theme, *science content and disciplinary practices*, refers to how ECSTs "must have a deep and flexible understanding of their content areas and be able to draw upon knowledge as they work with learners to access information, apply knowledge in real world settings, and address meaningful issues" (CCSSO, 2013, p. 8).  Under the NGSS, ECSTs are expected to understand and connect disciplinary core ideas, crosscutting concepts, and science practices with the nature of science (NRC, 2013).  The articles under this theme investigate the closing challenges: *How do ECSTs understand the content, practices, and nature of science?  In what ways does understanding inform or constrain their planning, instruction, or assessment within their teaching practice?*

Theme 5 holds the fewest papers (13, see Table 1).  A little over three-quarters of papers focused on PSTs.  The studies were generally mid-sized (median 10 participants) with two outlier large studies that skewed the mean (28.6 participants).  Theme 5 was the most isolated theme.  The studies presented under this theme illustrate: (a) *subject matter knowledge*, (b) *nature of science*, and (c) *teaching controversial topics*.

***Subject Matter Knowledge***

ECSTs' subject matter knowledge is critical to their work.  Nixon and colleagues' (2017) analyzed fifteen chemistry ECSTs' subject matter knowledge by comparing participant drawn concept maps from their first and fifth years of teaching.  The authors found subject matter knowledge did not significantly change over time and was lower than the authors expected. An additional study of chemistry ECSTs found more experienced teachers with chemistry degrees had more coherent, sophisticated, chemistry-focused explanations when posed questions about the conservation of mass and chemical equilibrium (Nixon et al., 2016). However, no teachers tapped into subject matter knowledge to determine the sequence of instruction when planning to teach the topics. Additional studies regarding ECSTs understanding of content and subsequent effect on instruction include the crafting scientific arguments (Robertshaw & Campbell, 2013), reactions to diverse types of organisms (R. Wagler & A. Wagler, 2015), and renewable energy (Antink-Meyer & Aldeman, 2021).

### *Nature of Science*

Three studies explored how PSTs developed understanding of the nature of science through coursework (Bell et al., 2016; Peters-Burton, 2016; Voss et al., 2023). For example, Voss and colleagues (2023) explored how PSTs developed understanding of the nature of science across a semester. The authors found PSTs' instructional views changed after explicit and reflective nature of science instruction. Participants began with an implicit view of nature of science instruction and moved towards an explicit-reflective view, as well as from decontextualized to contextualized instruction by the end of the course. Similarly, Peters-Burton (2016) investigated how sixteen career changer ECSTs viewed the nature of science across a course. She found career changers entered the course with a traditional perspective but became more sophisticated as time went on. Career changers significantly deepened their understanding of the nature of science regarding: "(a) knowing that a variety of scientific methods exist, (b) the role of theories and laws, (c) the use of imagination, and (d) the role of subjectivity and objectivity in science" (Peters-Burton, 2016, p. 148). Participants were surprised by their students' lack of expertise in the nature of science and felt a tension between the importance of the nature of science and the lack of support for it in the instructional standards.

### *Teaching Controversial Topics*

At times, ECSTs must address science topics deemed *controversial* by various communities (Balgopal, 2014; Borgerding et al., 2015; Borgerding & Dagistan, 2018; Larkin & Perry-Ryder, 2015; Menke et al., 2023). Borgerding and Dagistan (2018) interviewed thirteen members of a methods course about what topics they deem *controversial* and how they plan instruction of those topics. They found the most controversial biology topics were the history of Earth and evolution and the biology PSTs were most uncomfortable teaching modern genetics, variation, and population equilibrium and disequilibrium. Chemistry PSTs believed nuclear energy was a controversial topic and were uncomfortable designing instruction on the issue. The candidate in Earth science listed the history of the universe as controversial but was comfortable teaching the topic. The PSTs' shared anxiety was primarily related to societal misconceptions or students' religious conflicts. While teaching the above subjects, PSTs planned to use direct instruction, scientific literature, and student-driven research. The participants also recommended the teacher stay 'neutral' during discussions on the topics. A naturalistic inquiry of ten Midwestern ECSTs investigated which knowledge domains new teachers use when considering socio-scientific issues (Menke et al., 2023). The researchers found participants drew on numerous knowledge domains in tandem including: (a) science content, (b) personal experience, (c) domain-specific epistemological beliefs and the nature of science, (d) domain-general epistemological beliefs, (e) morals, values, and ethics, (f) economics, (g) sociology, (h) psychology, (i) politics, (j) media literacy, and (k) nature of technology. Participants most often drew on media literacy and nature of technology knowledge domains, while the nature of science played a limited role in PSTs thinking.

Three articles looked specifically at ECSTs and the topic of evolution. Through a multi-case study of three Midwestern PSTs, researchers explored participants' approaches to teaching evolution (Borgerding et al., 2015). Borgerding and colleagues (2015) found PSTs' approaches were influenced by: (a) state exams and standards, (b) cooperating teachers, (c) ideas about teaching and learning, (d) concerns about evolution controversy, (e) personal commitment to evolution, (f) knowledge and preparation for teaching evolution, and (g) their own evolution experiences. Larkin and Perry-Ryder (2015) describe how a pre-service biology teacher disengaged through lack of *assent to learn* evolution topics. They found the PST refused to take up evidence making evolution neither intelligible nor plausible, thus rejectable. Although he refused to learn about evolution in ways that conflicted with his beliefs, he could talk enough about the concept that his professors, supervisors, and cooperating teacher found his understanding acceptable, but it was not robust or sufficient. The candidate described learning about evolution as *opposition research*. The authors found his stance concerning for a biology teacher and call to redefine proficiency in teaching biology to not only include basic knowledge of evolution, but also understanding evolution to be a foundational theme of biology. Similarly, Balgopal (2014) investigated how six PSTs enrolled in an evolution course conceptualized their learning of evolution and the course learning environment. The participants described three areas of concern: "personal (learning evolution, being religious), professional (teaching evolution), and social (learning in this particular classroom environment)" (Balgopal, 2014, p. 43). Across participants, PSTs highly differed in how concerns affected their plans to learn and teach about evolution, from wanting to learn more even after the course and being excited to teach about genetics and variation to walking out of a class session in protest and resolve to integrate evolution and creationism during future instruction. Together, these papers suggest how ECSTs learn and plan to teach controversial issues is highly varied.

***Summary and Commentary for Theme 5***

In addition to pedagogical skills, ECSTs need to demonstrate mastery of their content areas. In this review, the number of studies specifically looking at subject matter knowledge was limited. ECSTs with coursework in specific areas (e.g., chemistry) had a more robust understanding than peers without content area preparation. ECSTs predominantly expressed a traditional view of the nature of science but developed more sophisticated understandings through coursework. When asked, ECSTs described being nervous about teaching controversial topics, such as evolution or socio-scientific issues. Challenges regarding controversial topics appear to be documented largely in the American Midwest.

Surprisingly, articles focused on challenges related to science content and disciplinary knowledge were the fewest in number in this review while it was the largest theme in Davis and colleagues' (2006) review. While many papers in Theme 1 addressed ECSTs' pedagogical content knowledge, few articles in this review focused primarily on ECSTs' subject matter knowledge. Many areas of subject matter knowledge (e.g., physics, geology) were not addressed in this review. As many are assigned out of field placements and science is an ever-updating field, how do ECSTs expand subject matter knowledge after graduation? Additionally, a handful of articles addressed ECSTs who found various core ideas, most commonly evolution, controversial. However, it is unclear how prevalent ECSTs with hesitancy towards science ideas are and how controversial topics are addressed in practice.

**Conclusions, Implications, and Further Directions**

This review aims to offer a systematic examination of the challenges ECSTs face while navigating their first years of teaching. Above I discussed the challenges of ECSTs across five themes— (a) instruction and learning environments, (b) equitable and justice-oriented teaching, (c) joining the science teacher community, (d) developing as a professional, and (e) science content and disciplinary practices. In these final paragraphs, I will discuss areas of support for ECSTs and recommendations for future research.

Across this review, I have described many sources of support for ECSTs, including courses, preparation programs, induction programs, peers, and contextual supports. Support for ECSTs should be designed with their actual needs and future contexts in mind. However, many supports described in the papers used in this review continue to focus on discrete skills. Ignoring contexts and the challenges derived from those contexts described in the above themes furthers the two-worlds pitfall's "fallacious assumption that making connections between [teacher education and schools] is straightforward and can be left to the novice" (Feiman-Nemser & Buchmann, 1985, p. 16). This review describes a handful of studies that worked to fill in the pit by not only exposing ECSTs to the realities of teaching contexts, but also offer strategies to reduce tensions and make connections between worlds. For example, Braaten and colleagues (2022) orchestrated a Critical Friends Group protocol where ECSTs transformed dissonance between preparation and practice into opportunities to learn with and from one another. Description and discussion of the support for ECSTs in this chapter is not intended to be exhaustive. Similar reviews described at the start of this chapter describe the supports and opportunities to learn for ECSTs in more detail (e.g., Luft et al., 2015; Navy, Luft, et al., 2022).

Understanding ECSTs' challenges and how ECSTs navigate those challenges is an important strand of research. Most research in this review looked at one or a few ECSTs from the same course or program. While this strategy permits researchers to make comparisons within small groups of ECSTs (e.g., a cohort), few studies allowed for comparisons to be made across groups. The small scope of participant recruitment, largely from researcher's own courses and programs, limits how we can generalize experiences from the few to the many. Additionally, studies of PSTs were overrepresented. Typically addressing a year or less of ECSTs' time, studies focused on PSTs outnumbered studies looking at a section of five years of experiences in service. Studies at the later end of early career experiences were particularly absent. Even when including longitudinal studies that spanned earlier years, only 8 of 128 articles addressed data collected during the fourth and/or fifth year of in-service teaching. Another way to widen our understanding of ECSTs would be to conduct more longitudinal studies, especially those that follow ECSTs across more than one year of teaching. Studies of courses and programs would particularly benefit from more longitudinal studies to address how their claims to improve areas of practice persist when ECSTs shift contexts and join school communities.

Becoming a science teacher is inherently challenging. At times, these challenges are exacerbated by conflicting visions of effective science teaching practice. As a field, science teacher educators, researchers, school communities, and stakeholders should aim to address the challenges ECSTs face—particularly the challenges we have created ourselves between competing goals. This review, by offering a window into how research currently understands ECSTs' challenges, aims to inform efforts to ameliorate those challenges.

# Chapter 3: Methodological Approach and Data

For this chapter, I describe the methods used to capture the case of early career science teacher (ECST), Alexa. Alexa is one case within a larger qualitative case study (NSF Grant: #1712220)[15]. The larger study investigated the experiences of pre-service teachers in a middle school math and science program. In the first year of the study, candidates (n = 13) were recorded in two methods courses, with relevant documents collected. Five candidates were selected for further observation and interviewed during the spring teaching internship. In the remaining years of the study, two participants, Alexa and Tina, continued with data collection into their first years of teaching. Tina is Alexa's peer in the middle school math and science program and taught math at a different school in the same district.

In this dissertation, I elect to limit my criticism of Alexa. Because she is a novice and still developing her craft and I do not want to contribute to deficit thinking about novice teachers. I feel offering criticism of the areas *I* see as needing improvement takes away from her story. I do my best in this work to portray Alexa's experience and identity development from her point of view by limiting my bias in describing her story to the best of my ability. I recognize that Alexa is not a perfect teacher[16], and I believe she would agree. At times, Alexa is self-critical, and I have included those descriptions in this work. When I describe Alexa's experiences, beliefs, goals, actions, and self-perceptions I do so from her point of view. Alexa's story is told from her perspective and should be read and considered as such. Therefore, in this work when I describe things that Alexa views as best practices or ineffectual (etc.), I do so from her perspective and not from my own nor a research and/or literature-based perspective. I am not

[15] In this section I will use the term "I" to refer to things I did myself, and "we" to refer to things undertaken by members of the project team, either myself with others or others without me.
[16] Because, who is really?

arguing Alexa is a perfect or exemplar teacher and that her identity is the standard we should seek to replicate in others. Like us all, Alexa has positive and negative qualities with a dynamic, developing, and, at times, uncertain, identity.

In the following paragraphs, I will argue why a qualitative case study is an appropriate method to answer the questions: *What challenges did Alexa face as an ECST?, How did Alexa's science teacher identity develop over time?,* and *In what ways do challenges shape Alexa's science teacher identity?*. Next, I will outline a description of the participant and contexts of the case. Lastly, I will describe data sources and collection methods, analytic approach and theoretical frameworks, and validity measures.

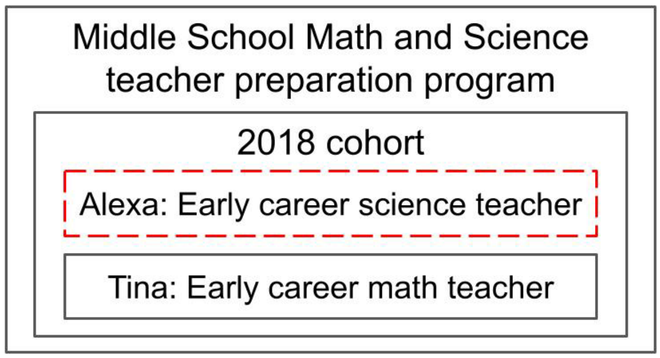
**Methodological Approach: Qualitative Case Study**

Case study methods are suitable for investigating the experiences of ECSTs for several reasons. Case study is an appropriate method for an in-depth investigation of contemporary phenomena, particularly when the boundaries between phenomena and context are indistinct (Yin, 2017). To fully understand Alexa's experiences as a developing ECST, we cannot separate her from the context. Interactions with key elements, such as peers, students, colleagues, and school environment, are instrumental in ECSTs' experiences, instruction, and development (Luft et al., 2015). A case study approach lends methods "to gain an in-depth understanding of the situation and meaning for those involved" (Merriam, 1988, p. 19).

Alexa is an embedded case within a larger, longitudinal case study (Yin, 2017, p. 48) (Figure 3). Yin (2017) suggests single-case studies, as presented here, are appropriate to capture longitudinal cases. Additionally, Kaplan and Garner (2017b) developers of the Dynamic Systems Model of Role Identity (described below) state the "optimal research design to evaluate the identity system and its change would be a comprehensive longitudinal case study that employs triangulation data from multiple methods to characterize and follow the dynamics of the participant's identity system iterations" (p. 2047).

**Figure 3**

*Graphic Depiction of Alexa's Embedded Case Study*




Alexa's case was selected because she stood out as a highly motivated and hardworking candidate dedicated to reformed science teaching. In this work, Alexa's case is bound to herself and the contexts and people she interacts with. For example, I might reference Tina if Alexa is responding to something she said or describe Alexa's classroom environment and students. Data sources where Alexa was not directly involved were not considered (e.g., an individual interview with a classmate). In the following section, I describe the theoretical frameworks, Alexa, and her case's relevant contexts.

***Theoretical Frameworks***

I integrate two theoretical frameworks to investigate the challenges of Alexa's early career. First, I will describe the Dynamic Systems Model of Role Identity (DSMRI) (Garner & Kaplan, 2019; Kaplan & Garner, 2018, 2017b; Vedder-Weiss et al., 2018). Next, I will outline the framework of productive friction (Hagel & Brown, 2005a; Ward et al., 2011).

**Dynamic Systems Model of Role Identity (DSMRI).** Kaplan and Garner (2019; 2018, 2017b) developed a framework of professional identity they have applied to teachers dubbed the

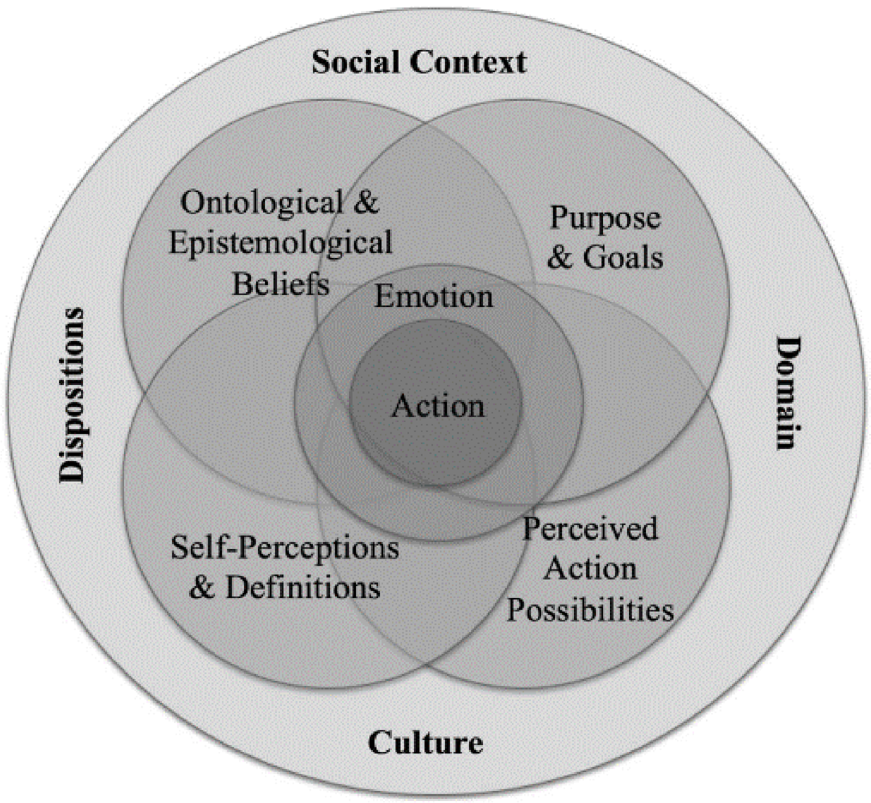
DSMRI. The DSMRI is based on a complex dynamic systems approach. A complex dynamic system is a "network of interdependent elements whose continuous, iterative, interaction gives rise to the system's behavior" (Kaplan & Garner, 2017b, p. 2037). Because the connections between elements are reciprocal and interdependent, changes in one area ripple across the system. As such, elements should not be siloed for investigation of parts, but rather studied as a full system. Additionally, unlike simple or complicated systems that can become stable, "complex systems are in perpetual movement and hence are in a continuous state of becoming" (Kaplan & Garner, 2017b, p. 2037).

The complex system of professional identity is especially important for teachers. Teacher identity is critical in various elements of their work, such as their conceptions of their roles, motivation, methods, and openness to change (Kaplan & Garner, 2018). In addition to the elements housed within the self, teacher identity is "meaning-based," "highly contextualized, dynamic, and mediated through social interactions" (Vedder-Weiss et al., 2018, p. 226). As such, how a teacher enacts their role in the classroom with students is heavily influenced by their identity. In this work, I understand professional, or role, identity to be a subset of our overall identities. For example, Alexa may consider being a teacher and a dog owner as critical components of her overall identity, but not consider being a dog owner as critical to her professional identity.

The DSMRI is a metatheoretical framework that is anchored in established identity theoretical constructs (Garner & Kaplan, 2019). Each component of the DSMRI is a conglomeration of constructs rather than an individual variable, "allowing the particular construct that is salient in the component to vary within the actor over time and between situations" (Kaplan & Garner, 2017b, p. 2041). The DSMRI (Kaplan & Garner, 2017b) consists of four components anchored by action and emotion: (a) ontological and epistemological beliefs, (b) purpose and goals, (c) self-perceptions and definitions, and (d) perceived action possibilities. These four components are situated in and mediated by (e) dispositions, (f) social context, (g) domain (e.g., science and science teaching), and (h) culture.

**Figure 4**

*Graphic Representation of DSMRI Framework* (Kaplan & Garner, 2017b)




*Ontological beliefs*[17] refer to what the teacher perceives as true related to the *world* of teaching and the context of their work. The beliefs hold knowledge learned in both formal and informal contexts about the teacher's work and context policies, events, and others (Garner &

[17] This definition, constructed for the DSMRI is different from a general definition of ontological beliefs, i.e., beliefs about the nature of reality (e.g., Greene et al., 2008; Schraw & Olafson, 2008). While Kaplan and Garner's definition is related to that general definition, it is specific to teachers' role identity. AS I am using their framework, I am using their definition.

Kaplan, 2019). Additionally, a teacher's ontological beliefs reflect their conceptions of cause and effect in the context, as well as if causes are stable or temporary, controllable or uncontrollable, and internal or external (Kaplan & Garner, 2017b). The teacher's certainty, credibility, and depth of the sources of their ontological beliefs construct their *epistemological beliefs*[18]. For example, an ECST may believe all students learn science best through hands-on activities (ontological belief); however, they may be uncertain if they can use hands-on approaches in a classroom with low student participation (epistemological belief).

*Purpose and goals* reflect the teacher's overarching commitments to teaching and related goals, objectives, and aims therein. These elements can vary across a variety of dimensions including intrinsic-extrinsic, mastery-performance-relational, self-other related, proximal-distal, specific-global, personal-interpersonal-collective, and individual-social with effects on motivation and emotion (Garner & Kaplan, 2019; Kaplan & Garner, 2018, 2017b). For example, a teacher may feel part of their purpose is to ensure students have positive experiences in science class and set goals to incorporate activities their students find fun and engaging.

*Perceived action possibilities* refer to the actions available to a teacher within their role, particularly to achieve purpose and goals framed by ontological and epistemological beliefs. These actions "exclude those actions that the actor perceives as inappropriate, ineffective, or impossible to perform in the role" (Kaplan & Garner, 2017b, p. 2041). For example, a teacher may work towards learning a new language (action) because they believe their emergent multi-lingual students will feel more valued through the effort (ontological belief).

[18] Garner and Kaplan (2019) define epistemological beliefs differently than the normative definition found in the personal epistemology literature, where epistemological beliefs are a person's beliefs on the nature of knowledge and learning (e.g., Schommer et al., 1997; Schommer, 1998; Elby & Hammer, 2001; Hofer & Pintrich, 2012, Elby et al., 2016). Garner and Kaplan offer their definition and cite Hofer and Pintrich as the source, but do not articulate how their definition reflects that of Hofer and Pintrich.

A teacher's *self-perceptions and definitions* draw on "personal and social attributes and characteristics that they consider relevant while occupying the role" (Kaplan & Garner, 2017b, p. 2041). It reflects physical attributes, such as race, social constructions, like gender, as well as inner-self perceptions. Key elements include self-concept, self-efficacy, personal world view, ideology, values, interests, and personality (Kaplan & Garner, 2017b). Additionally, this component reflects perceived group membership as it pertains to the role. This can include social groups, such as shared religion or language, as well as contextual groups, like a grade level team. For example, a teacher may have a stronger identity as a scientist than an educator or vice versa.

The DSMRI illustrates three facets that work within the identity system varying within a teacher across context and time. First, *content* is the "difference or change in the amount, kind, and complexity of the knowledge, beliefs, goals, emotions, self-perceptions, and perceived action possibilities in the role" (Kaplan & Garner, 2017b, p. 2042). Variability in content can also refer to rises and falls in salience of a construct. Second, *structure* "concerns the level of harmony between elements within the systems' components, the extent of alignment between the four components, and the degree of integration between the teacher role identity and other central role identities of the person" (Kaplan & Garner, 2018, p. 75). Low alignment in this area can result in feelings of uncertainty, ambiguity and tensions (Kaplan & Garner, 2017b). Lastly, *process* reflects the mechanism of change in a teacher's role identity. The process of role identity development is "continuously emerging but highly dependent on the history of the identity system, its characteristics, and its context, all of which could vary within an actor along time, as well as differ between actors" (Kaplan & Garner, 2017b, p. 2043). That is, because teachers come to a moment in time with different experiences and identities, how they process the same input or content will likely be different. In this work, I will argue that productive friction is one process through which teacher identity develops.

Teacher learning is intertwined with teacher identity. Additionally, Bianchini (2012) argues “learning to teach is a complex and demanding task” (p. 390). The DSMRI “depicts teacher learning as going beyond change in pedagogical knowledge and skills to encompass change in a network of components that constitute the teacher’s identity system” (Garner & Kaplan, 2019, p. 3). Like the four components and context cannot be fully teased apart, teacher learning is inseparable from identity formation. As such, identity development is particularly important for early career teachers. Future imagined role identities are budding in pre-service and beginning teachers as they start to have opportunities to enact their previously hypothetical professional identities by seeking out positive future selves and avoiding negative ones (Kaplan & Garner, 2017b). Vedder-Weiss and colleagues (2018) suggest:

> “Among early career teachers, teacher identity is likely to be characterized by less content and more fragmented structure. [Among new teachers] the relatively thin and fragmented teacher role identity is likely to manifest in confusion, identity tensions, uncertainty, and lower capacities for systematically and constructively framing, processing, and interpreting the meaning of events in ways that promote identity growth and integration.” (p. 228)

Therefore, attention to science teachers’ identity development is especially critical in the early years.

Kaplan and Garner also identify the key role of tensions in identity development. They argue role identities tend to self-organize toward coherence and stability. However, because role identity is complex and contextually situated it is constantly adjusting. Garner and Kaplan (2019) suggest:

> "When role identities are in tension, the teacher is likely to experience negative emotions, professional dilemmas, and diminished motivation. When different important role identities are integrated, and their components concord, the teacher is likely to experience personal coherence, high commitment and motivation in the roles, and overall well-being." (p. 6)

In this work, I will argue that tensions do not always result in professional dilemmas and lessened motivation through the construct of *productive friction*, described below.

**Productive Friction.** *Productive friction* (Hagel & Brown, 2005a) is a framework from the business and management literature. Companies improve faster when they work with others whose specializations are complementary to their own. Unanticipated tensions can create friction among players, but this can lead to innovation when each side utilizes their strengths and the other provides balance. Hagel and Brown (Hagel & Brown, 2005b) define productive friction as:

> Shap[ing] learning as people with different backgrounds and skill sets engage with each other on real problems if these people are provided with the right context. Productive friction is particularly valuable at boundaries because it exposes people to different ways of seeing problems and the potential solutions. (p. 5)

For example, Hagel and Brown (2005a) describe an instance where Sharp, a flat panel display company, worked with their glass supplier, Corning Glass, to make larger displays. At first, Sharp tried to keep the new plans a secret; however, after the initial product failure Sharp enlisted the help of Corning Glass to find out what went wrong. The two companies worked together to create a final product that was even higher quality than the original by implementing a new acid treatment.

Productive friction is enhanced when parties have a clear goal or vision and the success of productive friction depends on the specializations and perspectives of the players, which is often not the case between preparation programs and schools. Without relevant experience, they might be unable to solve problems. Hagel and Brown (2005b) acknowledge further problems can arise when friction becomes dysfunctional but suggest focus on a shared vision can help players overcome the struggle.

Ward, and colleagues (2011) suggest productive friction plays a significant role in how PSTs learn at the boundary between teacher preparation and practice. The authors define *productive friction in student teaching* as "**dissonance** experienced by teacher candidates when two or more social worlds conflict, **which initiates positive changes** in their use of high-leverage practices to improve student learning and understanding" (Ward et al., 2011, p. 15). They argue the learning potential of the boundary between teacher preparation and practice will not be realized unless PSTs reconcile the tensions between the two worlds.

The authors identify instances of (a) productive friction through feedback, (b) productive friction through pushback, and (c) a lack of productive friction. First, the authors describe a pre-service teacher (PST), Abe, who excelled at asking *questions for understanding* in cooperative learning groups but struggled with the skill in whole class teaching. They argue the mentor teacher and university supervisor supported Abe in reconciling how to *question for understanding*, his friction in whole class teaching, by providing critical feedback and formative assessment of his practice. They suggest the mentor teacher was able to support Abe in reconciling his friction productively by endorsing high leverage practices while pushing Abe to adapt them to real classroom contexts. However, the authors also point out for the feedback to result in productive friction, Abe needs to accept the feedback as supportive—rather than as challenges to the high leverage practices. They describe how Abe created a hybrid practice of both worlds, coursework, and classroom, rather than seeing the two as irreconcilable. Second, the authors describe a PST, Brett, who experienced productive friction through pushback. Ward and colleagues (2011) note the case is special because Brett had previous experience as an emergency-certified teacher, which created a third world (previous experience) that also interacted with preparation and practice in student teaching. Brett struggled with students' motivation to engage mathematically during instruction while also maintaining the procedural disciplinarian structure from his previous teaching experience. The authors argue Brett created his own productive friction when he reconciled his three worlds to realize students were "'easy to manage' while also engaged in a task"(Ward et al., 2011, p. 17). The authors credit Brett's reflection and later reconciliation to a 'jab' from his methods instructor who questioned him while he was "all hot about a thing"(Ward et al., 2011, p. 17). It is significant to note Brett entered the teacher preparation program with previous classroom teaching experience, which is atypical for PSTs. More research is needed to understand how PSTs without previous teaching experience can generate productive friction through pushback. Lastly, Ward, and colleagues describe two PSTs who did not experience productive friction. The authors argue when there is no friction or the friction is too great without sufficient resources and support, the PST will be unable to reconcile conflicts between the two worlds and thus would be unproductive. The PST, Caitlyn, attempted to use reformed math practices in her classroom; but when students resisted, she lacked support from her mentor and university supervisor. She was unable to adapt the practices to her placement and instead felt it was the students who were not ready for reformed math.  On the other hand, the PST, Dania, had autonomy in her teaching placement to try out reformed math practices.  However, although her mentor, a traditionalist, allowed her to try reformed methods, he did not provide her with critical feedback or pressure to use them.  Dania took up reformed math practices as 'fun' activities and was not compelled to make them a regular part of her practice.  Ward, and colleagues suggest PSTs can experience productive friction through feedback and pushback and a lack of productive friction can cause PSTs to reject reformed teaching practices.

### *Study Participant and Contexts*

At the onset of the study, Alexa[19] was at the start of her final year of undergraduate coursework.  Alexa is a White woman in her early twenties.  She is local to the mid-Atlantic region where she attends university and later begins her teaching career.  Outside of her professional life, she served as the chapter president of her sorority and loves hockey, roller coasters, and her family's two Yorkshire terriers.  Alexa wanted to be a science teacher from early on.  In her first interview, she describes teaching science at a summer school camp and loving the experience.

**State University.**  We met Alexa during her senior year at State University.  State is a large, mid-Atlantic university.  Alexa was enrolled in a dual degree and certification program aimed at preparing future middle school math and science teachers.  In the program, candidates take a variety of math, science, and education courses.  Education coursework focuses on general topics, such as supporting emergent multilinguals and culturally responsive teaching, as well as age and content-specific methods courses.  Our study follows Alexa during three courses:

[19] All names of people and places are pseudonyms.

Interdisciplinary Methods I (IDM I), Interdisciplinary Methods II (IDM II), and Middle Grades Science Methods (MGSM). IDM I and MGSM met in Fall 2017 and IDM II met in spring 2018.

In IDM I, candidates investigated issues of adolescents and middle grades teaching practices. Students also collected artifacts from early classroom placements to analyze teaching elements, such as school community and technology in the classroom. IDM II continued to develop candidates' understanding of middle grades classrooms. The course also supported candidates to prepare for their certification performance examination. Students recorded themselves in the classroom and brought clips to class for self and peer evaluation in areas such as leading a whole group discussion. Throughout the course, students focused on best teaching practices for early adolescent learners.

MGSM met only during the fall semester. The course focused on responsive, student-centered science teaching. Candidates also focused on engaging in scientific practices, such as modeling, and discussed how to bring those practices into their future classrooms. In the culminating activity, teacher candidates posed a science question (e.g., Why do leaves change color in the fall?) to simulated science learners. Through the course, candidates developed contemporary science teaching skills.

**Bumblebee Middle School.** The capstone experience in State's program is a semester-long teaching internship in a nearby middle school math or science classroom. Alexa completed her internship in an eighth-grade science classroom at Bumblebee Middle School (BMS) with mentor, Mrs. Grant. BMS[20] serves a predominately Latino (80.8%) and Black (10%) community in a large suburb. At the time of the study, 13.6% of students tested proficient in math and 22% of students tested proficient in English Language Arts. Most students at BMS (88%) receive free

[20] Data referenced here is from the state database of school information and reflects academic year 2017-2018. The information is not cited to maintain the anonymity of the school site.

and reduced meals[21] (FARMS). Many students (35.7%) are learning English as an additional language. BMS also provides a variety of school and community programs, such as a school greenhouse where students plant, grow, harvest, and sell produce.

Mrs. Grant is an experienced educator at BMS. She teaches courses in eighth grade comprehensive science. The course covers topics such as chemical reactions, weather and climate, and forces and motion. Mrs. Grant loves science and describes her favorite things as: "asking questions and finding answers about the physical world." At the time of the study, Mrs. Grant had eleven years of teaching experience. She is a career changer and previously worked as a lab technician. She was inspired to make the switch to teaching after seeing her children's science experiences in school.

**Panda Middle School.** After graduation, Alexa secured a position as a sixth-grade science teacher at Panda Middle School (PMS). PMS is a science magnet school which draws students from around the school district. However, unlike other magnet programs, which are largely segregated from the rest of the school population, at PMS all students, whether they applied or were zoned, partake in the magnet program. Each year, students engage in an interdisciplinary, cross-course project that is showcased at the end of the year. In Alexa's first year, students designed habitats for human colonization of Mars.

PMS is located in a large suburb. The school community[22] is predominately Hispanic (51%) with many Black (21%), Asian (15%) and White (10%) students as well. At the time of the study, 27.9% of students tested proficient in math and 41.5% of students tested proficient in

[21] FARMS are used as a proxy for low socioeconomic status when other family income data is not publicly available.
[22] Data referenced here is from the state database of school information and reflects academic year 2018-2019. The information is not cited to maintain the anonymity of the school site.

English Language Arts. Most students (65.3%) of students receive FARMS. PMS also has a sizeable emergent multilingual (18.7%) population.

### *Data Collection*

As Alexa moved through various sites and experiences, data collection methods were adapted to best capture the case within site permissions. Because data was collected in multiple forms over four years data organization was extremely important. I created a case study database (Yin, 2018) in an encrypted external hard drive. Data was organized by year, setting/participant, and type (e.g., interview, observation). Table 2, below, depicts an overview of data sources. The following sections describe data sources (Appendix B) and collection methods and are chronologically grouped by site.

**Table 2**

*Summary of Data Sources*

| Data Source | Count |
|---|---|
| **AY 2017-2018** | |
| Class observation: MGSM | 21 |
| Class observation: IDM I | 5 |
| Class observation: IDM II | 6 |
| Interview | 4 |
| Observation | 9 |
| Course Assignments | 11 |
| **AY 2018-2019** | |
| Interview | 3 |
| Observation | 3 |
| **AY 2019-2020** | |
| Interview | 1 |
| Observation | 4 |
| Joint Interview | 4 |
| Journal | 5 |
| Personal Case Narrative | 1 |
| **AY 2020-2021** | |
| Joint Interview | 4 |
| Journal | 6 |

**Fall 2017.** At the onset of Alexa's senior year, we conducted a video-recorded baseline interview (Appendix C). We also video-recorded the course sessions of IDM I and MGSM. I reviewed the videos for noteworthy moments including Alexa and created descriptive notes of the moments. I also collected Alexa's course assignments from IDM I and MGSM.

**Spring 2018.** In the spring of 2018, Alexa transitioned to a semester-long teaching internship at BMS. She gradually took over teaching responsibility from her mentor, Mrs. Grant, before phasing out at the tail-end of the semester. We observed and video-recorded Alexa teaching three consecutive lessons three times (nine lessons total). After each lesson set, we conducted a video-recorded stimulated-recall interview (Calderhead, 1981) (Appendix C) and wrote analytical memos afterward. We video-recorded the course sessions of IDM II and collected Alexa's course assignments.

**School Year 2018-2019.** I conducted three on site observations in Alexa's classroom during her first year at PMS. I used the Reformed Teaching Observation Protocol (RTOP) (Piburn & Sawada, 2000), which includes Likert-style prompts and field notes. I also conducted three audio-video recorded interviews (Appendix C): a general interview at the beginning of the year, a mid-year interview after an observation, and a summary interview at the end of the year.

**School Year 2019-2020.** Alexa's second year was interrupted by an abrupt transition to online learning to limit the spread of the COVID-19 pandemic. PMS's district halted outside research activities, and as such data collection methods shifted mid-year. I conducted four classroom observations using the RTOP and one audio-video recorded post-observation interview. Alexa also participated in four audio-video recorded joint interviews with Tina, the other embedded case within the larger study. Tina is a math-focused peer in Alexa's cohort. She works in the same district as Alexa, but in a different school, for the first two years and transferred to another state in the third.

In the spring, Alexa's role turned into more of a co-researcher and she began collecting her own classroom data. Alexa began to construct her own case studies (similar to those found in Levin et al., 2012) where she explored her teaching practice during the pandemic.

For the remainder of the year, Alexa wrote journals and updates through email approximately every two weeks. This alternative data collection strategy was predicated by school district policies during the pandemic which limited virtual and face-to-face access to teachers and students. Although Alexa had a larger hand in crafting her own story from this point on, she did not work on the research study outside of herself or attend research meetings.

**School Year 2020-2021.** COVID-19 restrictions remained in place during the final year of the study. Alexa participated in four audio-video recorded joint interviews with Tina via Zoom ©. Alexa continued recording her classroom experiences through journals.

### *Analytic Approach*

The grant team met regularly throughout the study, both formally and informally. We discussed what was happening in Alexa and others' cases to make decisions about ways to move forward with the project. During formal meetings, minutes were recorded. I often also wrote personal memos after informal chats that felt like they produced key or important ideas. We worked together to analyze data to reframe research foci, choose relevant data sources, and appropriate data collection methods.

To analyze Alexa's case, her data (Table 2) were copied and reorganized into a case database. I also reviewed cohort data sources for salient moments including Alexa, particularly if they seemed relevant to this study's research questions and added records of the moments to the case database. Where necessary, I transcribed audio and video data using InqScribe © and uploaded Alexa's data documents into a project in NVivo ©. The resulting case database/NVivo project was analyzed per the methods outlined in the below paragraphs.

Data will be analyzed chronologically to inform understanding of Alexa's stability and/or change over time. While analyzing data, I wrote memos to monitor my ideas and wonderings. As necessary, I revisited older data to confirm, adjust, or reject budding understandings.

I coded Alexa's case in two iterations. First, I drew codes from the systematic literature review presented in Chapter 2. This coding scheme informed the description of challenges and affordances Alexa faced in her early years described in Chapter 4.

The second iteration of coding drew from the DSMRI (Garner & Kaplan, 2019; Kaplan & Garner, 2018, 2017b; Vedder-Weiss et al., 2018) to look for elements of Alexa's developing science teacher identity. I coded for primary areas of role identity: (a) ontological and epistemological beliefs, (b) purpose and goals, (c) self-perceptions and definitions, and (d) perceived action possibilities. Kaplan and Garner also recommend double-coding relevant mediating factors as necessary: (e) emotions, (f) culture, (g) subject domain, (h) personal implicit dispositions, and (i) social context and interactions and provide a codebook (Kaplan & Garner, 2017a). Drawing salient challenges from Chapter 4, I explored how Alexa's identity shifted (or not) through productive friction. This coding scheme and analysis frame the work presented in Chapters 5 and 6.

### *Validity and Trustworthiness*

In qualitative research, all data and analysis flows through the researcher. Therein, it is especially important to monitor and limit possible entryways for researcher bias. Yin (2017) recommends four design tests for use on case study research: construct validity, internal validity, external validity, and reliability. In the below paragraphs, I outline ways in which the project team and I worked to maintain validity and trustworthiness.

Construct validity is the accuracy with which a phenomenon is studied as intended. Yin (2017) recommends improving construct validity in a case study by (a) defining specific concepts, (b) using multiple sources of evidence, and (c) engaging in member-checking. I began this study with construct validity in mind by applying bounds to Alexa's case. This limits the amount of muddying in the case as Alexa moves through multiple complex contexts. I also further narrowed the scope of analysis through multi-step coding processes (described above). We also collected multiple forms of data repeatedly across the four years of the study. By varying data type and collecting multiple examples, I have a better understanding of the nuances of Alexa's case. Lastly, we engaged in member-checking formally and informally throughout the project. Additionally, toward the end of the project Alexa acted more as participant researcher, lending further credibility to our understanding of her case.

Internal validity concerns the merit of conclusions drawn from data sources. I used methods suggested by Merriam (1988)—(a) triangulation, (b) member checks, (c) long-term observation, (d) peer examination, (e) collaborative modes of research, and (f) clarifying researcher biases—to improve internal validity in this chapter. First, the project utilized multiple investigators and data sources to triangulate data and confirm emerging findings. In doing so, I created a "holistic understanding of the situation to construct plausible explanations about the phenomena being studied" (Merriam, 1988, p. 204). Second, as discussed in the above paragraph, we engaged Alexa in member-checking throughout the study. Third, we used long-term observation to track Alexa across four years of early career experiences. Next, I utilized, and will continue, peer examination to critically assess findings. In addition to project meetings, peers and mentors provided feedback on early drafts of iterations of this work. Furthermore, I presented early findings of this work for community feedback at local and national conferences (e.g., Mesiner, 2022). Fifth, Alexa became more collaborative in the project throughout the study. Lastly, I offer insight to my experiences as an early career teacher through a researcher positionality statement (above) to provide transparency of my "assumptions, worldview, and theoretical orientations at the onset of the study" (Merriam, 1988, p. 205). These elements work together to support the internal validity and thus conclusions of this work.

External validity measures the extent to which findings are generalizable to other contexts. However, rather than developing theory or generalizations from scratch, case studies are more appropriate to apply, modify, or refine existing theory (Stake, 1995). Merriam (1988) further recommends using rich, thick description so future readers can determine how closely the case matches their situation, as well as noting elements of the case considered typical or unique.

To ensure reliability or consistency, as well as minimize errors and bias, I aim to provide a clear, detailed account of methods and analyses. However, because human experience is embedded in time and context, another study is unlikely to exactly match my findings—even if they directly follow my methodological approach. Lincoln and Guba (1985) suggest a qualitative study should instead aim for reliability by ensuring findings are consistent with the data presented. I am for readers to be able to follow my methodology, analyses, and chain of reasoning to develop conclusions relevant to the research questions. Additionally, elements to support validity structures (e.g., triangulation, rich description) work to improve the chapter's reliability. Through a well-designed, trustworthy case, I hope to make theoretical and practical contributions to the literature regarding early career science teachers.

# Chapter 4: The Challenges Alexa Faces

**Research Question #2: What challenges does Alexa face as an ECST?**

In this chapter, I use data from Alexa's qualitative case study to answer the question: *What challenges does Alexa face as an ECST?* Below, I describe the most salient challenges Alexa faces across the four years documented in this case study: (a) managing student behaviors, (b) working on a team, (c) leading classroom discussions, (d) adjusting due to COVID, (e) teaching specific groups of learners, (f) feeling like a newcomer, (g) working with colleagues, (h) working with a mentor, and (i) understanding argument. The summation of challenges Alexa faces presented in this chapter is used to explore her identity development in Chapters 5 and 6.

**Analytic Approach**

This section describes the analytic approach specific to this chapter. I describe my methodological and analytic approaches in more detail in Chapter 3. To identify the salient challenges of Alexa's early career, I coded data using *a priori* themes derived from the systematic literature review in Chapter 2. Table 3 presents the themes and salient codes used during the analysis described in this chapter. I read each data source (Appendix B, Table 14 and coded Alexa's statements, actions, and artifacts to answer the question: *What challenges did Alexa face as an ECST?*

**Table 3**

*List of Themes and Codes of Challenges*

| Themes | Codes |
|---|---|
| Instruction and learning environments | Managing student behaviors<br>Designing lessons with a team<br>Leading classroom discussions<br>Adjusting due to COVID |
| Equitable and justice-oriented teaching | Teaching specific groups of learners |
| Joining the science teacher community | Feeling like a newcomer<br>Working with colleagues |
| Developing as a professional | Working with a mentor |
| Science content and disciplinary practices | Understanding argument |

**Instruction and Learning Environments**

Across her early years, Alexa describes managing student behavior as a continuous challenge. During her internship, Alexa is critical of Mrs. Grant's classroom management and shares of BMS overall:

> "At Bumblebee they yell. The administrators yell. There'll be an assembly and a couple of kids will talk and the security guard will make that kid stand up and just basically publicly humiliate them in front of the whole school…it was just kind of like a jail."

While observing her lessons, we noticed students were often off task and Alexa in turn has trouble keeping the lessons on pace with her plans. Alexa largely attributes these challenges to the lack of procedures and organization in Mrs. Grant's classroom. For example, she is unable to circulate in the classroom well because the classroom arrangement does not give her space to move about. The following year, when she has her own students and classroom she describes her procedures as the area she is most excited about with her newfound freedom. She shares, "I love my procedures, [the students] know exactly what they need to do." While there are far fewer classroom management challenges for Alexa in her own classroom, she describes a few areas she struggles to manage during this time. Most often, she describes the last period of the day as an especially difficult section to manage because of their "big personalities." By her second year, Alexa is much more comfortable managing student behaviors and makes fewer references to classroom management challenges and describes ways she has improved her management style. For example, she shares:

> "Since we have a block schedule we are in there for an hour and a half and last year I would get really overwhelmed with a lot of movement in the class…so I didn't [permit movement] and I think that that contributed to a lot to the behavior issues. So, one of my goals for this year is to have them moving around as much as I can productively."

Later, the COVID-19 pandemic introduces new management issues for Alexa to address, discussed below.

At PMS, Alexa works with two colleagues, Pam and Dave, as part of a grade level team. She faces challenges designing lessons with her grade level team, predominately during her first year of teaching. First, she is critical of the district lessons. She is told the lessons are aligned with the NGSS, but she feels the lessons "fall short" of the goals of the NGSS and are more focused on notes and worksheets. Second, her grade level team is expected to mirror each other's instruction. She explains, "At my school now, it's like, I want you to have the same activities, the same grades, the same assessments, the gradebook to look exactly the same." The policy limits Alexa's ability to teach the way she would like to teach. Alexa is particularly frustrated by Pam who is unwilling to update lessons because she prefers to sit at her desk while students complete web quests. The curriculum was particularly challenging for Alexa because she "would get in these weak little lulls where the lessons just felt really, really dry and [she] wasn't excited to go teach them." Lastly, in addition to matching lessons the team needed to keep pace with each other. This policy created challenges for Alexa, particularly near the end of the year. Pam, the school's science specialist, pressures the rest of the grade level team to speed through content at the end of the year. Alexa is frustrated because she does not want to fall to Pam's pressure to just lecture and quiz students without any activities and Pam's belief "there's no reason [the students] shouldn't understand because we gave them the notes" to cover all the assigned standards before the end of the year. Additionally, because the three teachers had to maintain each other's pace throughout the year Alexa was forced to slow down her instruction at times to make space for her colleagues to catch up. For example, when Pam and Andy were on leave Alexa had to fill time with a documentary film instead of beginning a project she was ready to start. Tensions with her grade level team eased over time, largely due to staffing changes as Pam was replaced by Felicity in her second year and Dave was replaced by Eric in her third year. In Pam's absence, Alexa describes how she, Felicity, and Eric have more liberty to change lessons.

Alexa describes leading students in scientific discussions as a critical element of her teaching practice. However, she shares ways leading classroom discussions is challenging for her. This challenge is most salient for Alexa during her final year of study. During her baseline interview, Alexa is worried she will not be able to make sure all students master the content through discussion and investigations. She says, "Some people will have these aha moments, but how do I make sure that everyone has these aha moments?" When prompted to think about a solution, she hesitates and falls back on lecture because that is how she learned science herself but feels unsure if that is her only option. After leading simulated students in a science discussion during MGSM, Alexa realizes her goal to "get students to respond to each other's thinking and really listen to what they are saying" is "a lot easier said than done." She again describes her struggle to make sure each student learns the necessary information “without regurgitating information to the students in an ineffective way.” During her internship, Alexa works to incorporate discussion into her mentor’s transmission-centered instructional approach. She continues to worry about how to tell if students are “thinking about the phenomenon or completely checked out,” and listening to each other’s ideas. These challenges continue into her in-service teaching. For example, in her second year she shares she asked if students could repeat a classmate’s answer but found few were able to do so and most “were more focused and interested in their [own] ideas.” But by this time, she begins trying strategies to encourage students to better engage in discussions, such as starting discussions with a short writing prompt, so students have time to produce a response and compare their ideas to their peers. Overall, Alexa sees immense value in leading students in class discussions but struggles to ensure she can see what each student understands and for each student to meaningfully participate in the activity.

In Alexa’s second and third years in the classroom, she faced the sudden change to online schooling and gradual return to the classroom due to the COVID-19 pandemic. During this time, existing challenges heightened and new challenges arose. One challenge that continued to worry Alexa is if her students are mastering content or not. Her worries are compounded by poor student attendance and participation. She is initially hopeful when half her students attend her first Zoom© class session (more than she expected), but later describes how demotivating it is to have “one kid who turns on their camera on a good day.” She spends hours reaching out to students who have not ‘shown up’ to her online classroom and she worries about “the kids who aren’t getting it, or aren’t showing up, or are showing up but aren’t doing anything…it’s hard to figure out who’s doing the work, who’s getting it, who’s watching TV downstairs.” Another challenge Alexa faces is translating her in-person pedagogical knowledge for an online space. Much of how Alexa is expected to teach is unclear. She shares, "I feel like there isn't much direction between the science department at my school and [the district] …so I feel like I'm just waiting for someone to tell me what exactly I should be doing." Because PMS is a magnet school, the curriculum does not match up with the rest of Alexa's district. This means Alexa cannot use many of the district resources, but she sees it as a silver lining to have more freedom to create her own online lessons. Eventually, when the district begins to provide lessons Alexa can use she feels like her student-centered approach is lost and decides to stop using them because they are keeping her from what she wants to do because she just "focusing too much on the mundane [district] routine." She tries to incorporate more engaging activities into her virtual lessons, such as using discussion posts, but finds her goal difficult to accomplish. She shares:

> "I am trying to use a differing array of methods to get the point across to my students, but there is no way for me to know for sure if they are listening and understanding me. That part of it leaves me frustrated and with a small sense of hopelessness."

In this statement, Alexa describes how the challenge of designing an online learning space and worries of who is and is not learning are interlinked.

**Equitable and Justice-Oriented Teaching**

At BMS and PMS, Alexa serves communities with many emergent bilingual students. Alexa describes challenges she faces to ensure her emergent bilingual students master content and can fully participate in her course. Alexa shares most of her emergent bilingual students have moderate English fluency, except one student who recently emigrated from Brazil with extremely limited English fluency. When she picks an area of her practice to explore for a case study, she chooses to investigate how she can better support her emergent bilingual students during classroom science discussions because she worries they are not able to meaningfully participate with the strategies she is currently employing. Alexa identifies strategies she believes will reduce the challenges she and her emergent bilingual students face in the classroom, such as encouraging students to speak and write in their first language, use translators (both tools and peers), and write out answers before sharing aloud. However, sometimes Alexa's solutions introduce new problems. For example, when using an online translator to describe the ideal conditions for plant growth a student writes, "I think it *blessed* him to see a little nutrients and little sunlight because a lot of light makes the plant dry faster." Her response leaves Alexa to figure out what she meant by the term *blessed*. Later she faces additional challenges meeting her emergent bilingual students' needs during the pandemic because she "can't just show them where to find things, how to complete assignments, [or] how to submit them" because even when explaining in detail with screenshots she feels parts are still "lost in translation."

Some areas related to equitable instruction do not appear to rise to Alexa's consciousness through our discussions. Alexa teaches two inclusion sections of her course that serve students with special needs. However, she does not describe specific challenges related to teaching the sections outside of the behavior management challenges described above. Because she also does not describe how she differentiates her instruction to meet the needs of these students, as she does with her emergent bilinguals at length, it is possible she is unaware of how well she is serving this group—a challenge in and of itself. Additionally, Alexa does not reference a justice orientation or how her instruction can affect communities outside of her classroom.

**Joining the Science Teacher Community**

Upon starting her position at PMS, Alexa is excited to have control over her own space and no longer feel like a "guest" in someone else's classroom. But as a newcomer to the role, she quickly realizes there is still so much to learn. In her first interview that year, Alexa shares, "I feel like [I'm] playing catch up, and just figuring out all those things, but I didn't [realize] that I didn't know what I didn't know." She describes how her colleagues use acronyms she is unfamiliar with or know of upcoming tasks she is unaware of. In her second year, she reflects:

> "I think last year I felt like I was the little baby and…all of the other staff was the adult and I felt a disconnect because I felt like…they were talking to me as if I was the new teacher, not as if [I was] on the same level."

But she begins to stop feeling like she is just getting through each day and starts to be able to plan farther into the future. By her third year, she is the most senior member of her grade level team and as the "head guy" finally feels she can be proactive and has more control over her instructional environment.

At PMS, Alexa struggles working with a particularly challenging coworker, pushing through changes with colleagues she feels are stuck in their ways, and planning with colleagues who have different preparation styles. First, Alexa dislikes the teaching and management of her grade level teammate and immediate supervisor, Pam. She shares:

> "I think the thing that brings me the most frustration is my boss…she's a content specialist but I also plan with her…Because I think I know that she could be a really good teacher because I've seen her when she's getting observed I see what she does and it's great. But then when she's not being observed, she sits at her desk and her kids are on the Chromebooks and she's doing her work."

Pam's teaching approach is in strong contrast to Alexa, who prefers an active role in teaching and describes Pam's approach as "boring." Additionally, as her supervisor, Pam is tasked with observing Alexa and offering her feedback and guidance—something Alexa seeks to improve her teaching practice. However, Alexa describes how Pam's "laziness in the classroom" extends to her managerial responsibilities because when she observes Alexa it is only for five minutes and afterwards offers limited feedback and Alexa recalls when Pam tells her, "Realistically I (Pam) know that you're (Alexa) not gonna change much so I won't give you that much [feedback]." Alexa is frustrated with her point of view because she sees Pam as the person who was assigned to offer her support and help her improve her teaching practice. Second, Alexa struggles to settle into her position because she is not granted much agency in her teaching team she describes as "stuck in their ways." When Alexa describes the dynamic on her team, she shares:

> "I plan with two other teachers, and one has been teaching this class for four years, one has been teaching this class for ten years. So, they've had their slides for years…[and] we'll plan lessons together and I feel like they'll be like, 'Oh, so we did this last year.'…And then be like 'Okay, great, that's awesome.' But then I sit back and I'm like, 'I don't exactly, like I understand the activity, but what do you do? How do you introduce it and all that stuff."

During the interview the above quote is drawn from, Alexa describes stress planning with her team because they are very experienced with the course and want to get through planning lessons quickly, but it leaves Alexa confused about the flow of lessons. Additionally, in her first year working with Pam and Dave, Alexa describes how in the beginning she would try to introduce new ideas during co-planning, but her teammates would offer an alternative lesson instead of considering Alexa's ideas. This challenge was compounded by the requirement to teach the same lessons at the same pace and Alexa's feelings as a newcomer since they all need to agree on lessons and "since [Alexa is] new, [she is] the one that backs down." Later Alexa is excited when Pam is transferred to another grade level because “it was really frustrating when [Alexa] wanted to do fun stuff and [Pam] wouldn’t collaborate with [her].” Alexa later enjoys the lessons she creates with Felicity and Eric because she feels they are much more aligned with the way she would like to teach. Lastly, Alexa likes to plan farther in advance than her colleagues and it causes her frustration over the course of the study. Alexa describes this challenge as particularly salient during the pandemic. She shares:

> “Communication has always been a little frustrating between me and my planning cohort because I like to plan very far in advance, and they don’t. This worries me because I don’t want to sit and wait around for everyone else to be ready.”

Eventually Alexa begins to send her team lessons she created for them to use or not and finds colleagues outside of her team to collaborate with.

**Developing as a Professional**

During her internship at BMS, Alexa experiences many challenges with her mentor, Mrs. Grant. Alexa is critical of many of Mrs. Grant’s teaching practices including: (a) classroom management, (b) lack of patience, (c) teacher-centered instruction, (d) taking on too many roles and becoming over-extended, and (e) lack of student assessment. She goes so far as to say, “I think if anyone were to observe Mrs. Grant teaching, I don’t think they would have thought of her as an exemplary teacher.” After working with Mrs. Grant, Alexa describes her disappointment at not working with a mentor more aligned with her teaching vision because she feels she lost out on opportunities to learn and improve her practice.

**Science Content and Disciplinary Practices**

Alexa does not often describe challenges understanding the content and practices of science as it relates to her work and is generally scientifically accurate when observed. But during a series of lessons in her internship, her conception of *doing science in school* as different from *doing science in the real world* is challenged by Mrs. Grant publicly during a lesson.

Alexa makes a distinction between *science* and *school science*, wherein *science* is carried out by scientists conducting investigations to understand previously unknown phenomena, whereas *school science* is conducted by students trying to understand known phenomena and has more lax rules of sense-making. Alexa shares:

> "Yeah, I think it's something that I've been thinking about a lot because there's that, the sciencey, scientists wouldn't just jump in and bring random ideas into their claim, but I want [the students] to bring in different ideas as long as…it's relevant…I don't want them to bring in ideas about other things that aren't really relevant to science. But I also don't want to shut down their ideas either."

In these moments, Alexa aims to create a welcoming and supportive classroom environment conducive to student thinking and sense-making by encouraging the students to discuss their experiences and prior knowledge. She describes how she seeks to make *school science* more accessible for students and states, "I think a lot of times when I stand up and we're talking about…sciencey terms… [the students] are going to shut down." Conversely, Mrs. Grant would like students to do *science* in the classroom. She tells the students if they were "real" scientists, they would need to design experiments for every piece of evidence supporting their claim.

The tension comes to a head as students do an activity about an invasive plant species, purple loosestrife. Alexa encourages students to use their prior knowledge of ecosystems to reason why purple loosestrife is overtaking the orchids at a pond; however, Mrs. Grant believes the only evidence is data collected by the scientist[23]. Alexa and Mrs. Grant argue about what

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[23] Note: There was no investigation in this task. Students read a description of a pond and used the description as evidence. The students would not possibly be able to visit the 'pond' and collect more data.

counts as evidence publicly over multiple days, leading many students to become confused about the task. Mrs. Grant is bothered some students are making inferences based on prior knowledge when the data is not available. For example, the students suggest the purple loosestrife is stealing water from the orchids, there is more sunlight in the area with purple loosestrife, or the amount of purple loosestrife is changing because the weather is changing and warmer temperatures help the purple loosestrife grow. Mrs. Grant repeatedly tries to shut down the students' use of outside knowledge, telling them, "This is not Language Arts! You cannot bring in other information." However, Alexa argues that the students' inferences are sensible and should be allowed because it is true plants need water and sunlight to thrive and, in the students' temperate climate, plants often bloom as warmer weather arrives. Alexa is purposefully allowing students to bring in prior knowledge and experience to support their sense-making and understanding, but Mrs. Grant argues it will give the students an unrealistic understanding of how scientists do *science*.

The pair do not reach a consensus understanding of how students should use evidence while making scientific claims in school. After leaving BMS and moving into her own classroom, Alexa continues to encourage students to think about their lived experience and prior knowledge when sense-making and articulating scientific arguments.

**Overarching Summary**

In this chapter, I described the most salient challenges Alexa experienced between her final year of preparation and third year in the classroom across five themes. This section offers an overview of the challenges. I revisit these challenges later in Chapter 6 to explore how challenges shape Alexa's science teacher identity.

Across her early years, Alexa most commonly refers to challenges related to *instruction and learning environments*. She describes her challenges managing student behaviors, initially during her internship where she ascribes issues to poor school culture and Mrs. Grant, and later in her own classroom. She is eventually able to implement procedures and policies that make her more comfortable managing student behaviors and begins using strategies that previously overwhelmed her, like permitting student movement. Additionally, Alexa struggles to design lessons with her grade level team that match her vision of good teaching. This is due to a combination of district and school policies and hesitancy by her teammates. Alexa also describes her struggle to effectively lead students in scientific classroom discussions. She worries about how to figure out which each student understands and how to ensure the students are listening to each other and considering peers' ideas. Lastly, Alexa faces a variety of challenges attributed to the abrupt shift to online learning during the COVID-19 pandemic. Existing challenges, such as planning engaging lessons, are heightened and new challenges, such as inability to get in contact with students, arise.

Alexa aims to offer *equitable* instruction to her students. She struggles to figure out how to ensure her emergent bilingual students can master the content of her course and fully participate in lessons. Additionally, Alexa seems to not recognize challenges related to her two inclusion sections for special needs students or how her practice relates to issues outside of her classroom.

*Joining the science teacher community* poses a handful of challenges for Alexa. First, Alexa describes feeling like a newcomer and awareness that she still has much to learn. In addition to pedagogical knowledge, she realizes there are elements of her work that are specific to her school to figure out. Additionally, Alexa experiences tension working some of her colleagues at PMS. Alexa's teammate and supervisor, Pam, frustrates her because of Pam's low effort approach to both teaching and offering feedback and guidance to Alexa. She also struggles to enact her vision of good teaching because her teammates are resistant to change. Another element of this challenge is how Alexa's teammates prefer to prepare for lessons right before while she would prefer to prepare lessons farther in advance. This frustrates Alexa as she often finds herself sitting around and waiting for others to do their work.

Alexa is most frustrated in regard to *developing as a professional* when she feels others are limiting her ability to improve her practice. Alexa feels this challenge most distinctly with her mentor Mrs. Grant. Because Mrs. Grant's instruction differs so drastically from Alexa's view of good science teaching, she feels she did not learn as much during her internship as she would have with a mentor who was more aligned.

Alexa does not describe many challenges with *science content or disciplinary practices* outside of her disagreement with Mrs. Grant regarding what can count as evidence in a scientific argument in the classroom. Mrs. Grant challenges Alexa's notion that students can bring in prior knowledge and experiences as evidence in a scientific argument. Alexa defends her stance by envisioning a difference between how science is done by scientists and how science is done by students in a classroom.

# Chapter 5: Alexa's Science Teacher Identity

**Research Question #3: How does Alexa's science teacher identity develop over time?**

In this chapter, I use data from Alexa's qualitative case study to address the question: *How does Alexa's science teacher identity develop over time?* The DSMRI (described in detail in Chapter 3) provides a framework to map Alexa's science teacher identity and monitor how it changed, or stayed the same, over time. The DSMRI is comprised of four components anchored by action and emotion: (a) ontological and epistemological beliefs, (b) purpose and goals, (c) self-perceptions and definitions, and (d) perceived action possibilities. This chapter builds upon the analysis in Chapter 4.

**Analytic Approach**

I describe my methodological and analytic approaches in more detail in Chapter 3. Here, to locate elements of Alexa's developing science teacher identity, I coded data deductively using *a priori* codes adapted[24] from Kaplan and Garner's (2017a) *DSMRI Analysis Guide and Codebook*. Table 4 presents the codes and example quotes used during the analysis described in this chapter. I read each data source (Appendix B, Table 14) and coded Alexa's statements, actions, and artifacts to answer the question: *How did Alexa's science teacher identity develop over time?* I organize findings by DSMRI identity component then into three eras of Alexa's early teaching career: pre-service, first year in-service, and second- and third-years in-service.

[24] Adaptations focused on swapping generic terms to those specific to Alexa's science teacher identity (e.g., "true about the world" was changed to "true about teaching and students' learning")

***Table 4***

*List of DSMRI Codes and Example Quotes*

| *Code Name* | *Code Description* | *Example Quotes* |
|---|---|---|
| Ontological and epistemological beliefs about teaching | Statements that indicate beliefs, perceptions, and conceptions that the teacher seems to hold as true about teaching and students' learning | *By relating the topic to what is relevant for them (right outside their window), they are already getting into ideas that we are learning later in the class period* |
| Purpose and goals around teaching | Statements that express the teacher's purpose for action in teaching, as well as goals and objectives in teaching. This category includes general goals of teaching, personal goals, as well as specific objectives in particular contexts and situations | *I aspire to teach my students to be passionate about science*<br><br>*I do hope that in my classroom I will be a little more organized to keep students focused on the concepts behind the investigations* |
| Teaching self-perceptions and self-definitions | Statements that include reference to the self in relation to teaching. This includes how participants define themselves as teachers, what participants think about themselves as teachers, and as part of a teaching community, and how they think about their own functioning as a teacher (e.g., self-perceived abilities and efficacy, personal values, interests, personality, attributes, self-characteristics, and definitions) | *I feel a stronger sense of confidence and assurance in my teaching*<br><br>*I feel like I am a cohort of one doing all the planning by myself without any collaboration*<br><br>*I was the little baby and all the other staff was like the adult. I felt disconnected.* |
| Teaching perceived action possibilities | Statements that indicate an internal (e.g., thoughts, planning) and external behavior in relation to teaching. This code includes practices and strategies that one is aware of as possibilities or that one has put into practice, as well as indications for those actions that the person perceived as not possible for them to enact | *Today and yesterday, I spent most of my time helping students navigate [Canvas] and doing a lot of trial and error with the assignments I created. One issue that I've found myself in is that whenever my students answer me with questions, I want to answer right away. This proves to be an issue because I can spend forever answering their emails and I don't get other things finished* |

## Ontological and Epistemological Beliefs about Teaching

*Ontological and epistemological beliefs* refer to what the teacher perceives as true related to the world of teaching and context of their work, as well as the certainty, credibility, and depth of those beliefs. Below, I describe how Alexa's ontological and epistemological beliefs developed in the areas of: (a) beliefs about instruction and learning, (b) beliefs about students, and (c) beliefs about science. Because Alexa's beliefs are incredibly stable, I divided her experiences into only pre-service and in-service.

### *Pre-Service Experiences*

During pre-service Alexa describes her beliefs about instruction and learning. First, she explains what she believes are features of an effective science instructional environment. Alexa believes an effective classroom environment is built from mutual respect between students and the teacher. One way Alexa believes students and teachers can build mutual respect is by co-creating classroom expectations so "each student and [herself] as the teacher can be held accountable for the way we act and behave in class." In an assignment for IDMI, Alexa also describes the importance of including parents and the local community to make sure students are well supported outside of school. Next, Alexa describes general elements of effective instruction. Possibly the most central belief Alexa holds is around the need for student engagement. Alexa often uses the word *engaging* generally to mean the instruction and environment are fun and interesting to students or improve student participation. Many of her beliefs, and other elements of her science teacher identity, are judged against her foundational belief to see if student engagement improves or decays[25]. She believes directions and expectations should be clear to students and failure to do so leads to misbehavior and confusion.

[25] E.g., Leading students in scientific discussions is *good* because it increases student engagement. A disorderly classroom is *bad* because students are not engaged.

Alexa believes teachers should offer "varied and ongoing assessments in order to assess students' grasp on concepts." She believes teachers should use these assessments to measure student mastery and reteach concepts when students have misunderstandings. She also believes instruction should incorporate opportunities for student autonomy and peer collaboration, as well as be engaging for students. Lastly, Alexa describes how she understands effective instruction that is specific to science. Alexa believes science instruction should be relevant to students by making connections to students' interests and lives or letting students direct the flow of learning by encouraging them to ask and explore questions about the world. Alexa believes students ideas are resources for learning. When possible, she believes teachers should "use and build off of students' prior knowledge to foster deep understanding" rather than an amalgamation of disconnected science factoids. She elaborates on this belief when she discusses how students should be encouraged to use everyday language in addition to academic vocabulary because she believes it aids understanding. Alexa believes when teachers make space for students to share their ideas publicly "it could spark another thought in another student's thinking." She also describes how teachers can use students' ideas to guide their thinking and shares, "I think it's kind of like taking what they have in their heads and pointing them in [one] direction… and asking questions that use what they have to go this direction (indicates redirect)." Alexa also believes that effective science instruction makes space for students to explore a phenomenon before offering a canonical explanation and engage in scientific practices because "Students learn science best when they are encouraged to be critical about what they are learning and develop their own understanding about a concept." Although Alexa believes the teaching model described above is most effective for student learning in theory, she struggles to describe how she can guarantee all students have access to content other than lecture and direct instruction.

Alexa describes a variety of beliefs about students. In an assignment for IDMI, Alexa describes how students must feel safe and comfortable at school before they are able to focus on learning. She writes:

> "There are many ways students can be distracted from learning such as family, political, social, or emotional issues. If a student feels overwhelmed by such things, they will not be able to put their full focus on getting an education."

She also believes students need to be accountability to encourage them to put forth full effort in their schoolwork, such as needing to hand in an assignment for a grade instead of solely for their own reference. Alexa believes students learn best when they are engaged and that different students are engaged by different things. Some strategies Alexa identifies as engaging include giving students options, hands-on or fun activities, working with peers, and connections to students' lives outside of school. Alexa believes her students are capable learners when provided with an effective learning environment.

Alexa has positive views about science. She is excited to become a science teacher because she "[thinks] science can generally be more fun and applicable" and "science is happening all around us." Alexa does not disclose any beliefs that conflict with currently accepted canonical science (e.g., climate change denial). Alexa believes there is difference between the science done by professional scientists and students in science class. She believes that students should be encouraged to tap into their background knowledge and prior experiences as a source of evidence in their scientific reasoning. But she at times offers conflicting definitions of what constitutes evidence and/or justification. For example, in February she shares, "Students bring in their ideas or prior knowledge to help them support whatever argument they're trying to make" and two weeks later shares, "The evidence is like the cold hard facts and then the justification is what sums it all up together." This belief comes into conflict during her internship when her stance is challenged by Mrs. Grant, as described in Chapter 4.

### *In-Service Teaching Experiences*

Alexa's beliefs are stable moving into her first year of teaching and remain so consistent that it does not make sense to parse them into early career and later career beliefs. She does not describe any ways she has pruned a belief described in the above section on beliefs during pre-service. In the remainder of this paragraph, I describe ways Alexa builds on her beliefs from pre-service. Alexa's beliefs about instruction and learning remain focused on student-centered, responsive lessons and environments. During her first year, she adds the phrase *hands on* to describe another way students can be engaged in science class. She continues to feel uncertain about her belief that lectures are necessary for science learning and challenges her previous thinking to argue to say direct instruction is necessary, but not sufficient. She shares, "I don't think just giving them the notes is equivalent to them understanding the concepts."

Regarding students, she links her beliefs about student engagement to student behavior. She states, "[My students are] most engaged when we are having…discussions. They acted out most when we're doing readings…and they just didn't do anything." This suggests that in addition to feeling comfortable and accountable, Alexa believes students' misbehavior originates in boredom and that using engaging activities is an element of classroom management. She also describes how students will follow the path of least resistance and at times appear to be going along with what their peers say or an obvious answer instead of critically thinking about a phenomenon. For example, when describing students' responses to a science question on a discussion forum she shares, "I find that when I do the collaborate board a lot of them write down the exact same thing. So, I don't know if (laughs) they're really thinking on their own."

Alexa also bolsters her broad belief that all students are capable learners to a more contextualized idea that all students can excel when their diverse needs are met. For example, she writes in her case study, “Providing sentence frames can make a crucial difference in students who don’t have the language skills to form their own sentences. By providing these frames, students who normally struggle with syntax are not at a deficit when it comes to learning and participating in science.”

Additionally, she continues to describe the difference between science carried out by professionals and science carried out by students. She shares:

> “Evidence and data are a lot more important when there’s a scientist out there researching a study or…trying to prove a theory, obviously. I think evidence is more important there. For a science classroom, you are just trying to get [the students] to use what they know and learn a concept. So, in that sense, the evidence is a little less [strict].”

Here she deepens her reasoning around her belief by arguing that because professional scientists and students have different goals (to create new knowledge vs. learning a known concept) it is reasonable that they have different thresholds for empirical rigor.

### ***Summary***

Alexa’s beliefs are incredibly stable throughout her early career (Table 5). Alexa often uses the word *engaging* generally to mean the instruction and environment are fun and interesting to students or improve student participation. She does not swap any beliefs from pre-service for new beliefs in-service but bolsters them by adding elements or context. In this section, I categorize Alexa’s beliefs into three categories: (a) beliefs about instruction and learning, (b) beliefs about students, and (c) beliefs about science.

Alexa's beliefs about instruction and learning center around classroom environment, as well as general and science-specific teaching practices. First, Alexa believes an effective science classroom environment is built on respect and accountability and includes parents and communities. She adds to this belief during in-service to describe how student engagement is connected to classroom management. Second, Alexa describes her understanding of effective teaching practice in general and widely focuses on the importance of getting students engaged. She believes teachers should give clear directions and hold clear, apparent expectations. Teachers should engage in ongoing, varied assessment and use the information to re-teach content as necessary. Alexa believes students benefit when teachers offer students autonomy and incorporate collaboration into instruction. She adds a particular focus on increased engagement through hands-on activities when she is at PMS. Lastly, Alexa illustrates her beliefs that are specific to science instruction and learning. She believes instruction should be relevant to the lives of students. This paves the way for students to use prior knowledge and experiences as resources for learning. She believes it is critical to allow students to explore science concepts before she explains answers to them. She is hesitant to say lecture is an effective teaching strategy but often comes back to direct instruction when pressed to think about how she can ensure students master content. Later during in-service, she adjusts this belief to explain that direct instruction is necessary, but not sufficient.

Alexa's beliefs about students are positive and asset based. She believes students need to feel safe and comfortable in order to learn. She believes students need to be accountable for their work and actions. Alexa thinks students learn best when they are engaged and in a related vein, that students are easier to manage when they are not bored. Additionally, she believes some students will often follow the path of least resistance and need to be pressed to engage in critical thinking. Lastly, Alexa describes how all students can excel when their diverse needs are met.

Alexa believes that science is fun and applicable. She also describes ways that professional science is different from science students conduct in the classroom. She describes the difference as due to the distinct goals of professional scientists (to create new knowledge) and students (to understand known concepts). Her discussion of this difference is more specifically addressed in Chapter 4.

**Table 5**

*Alexa's Salient Ontological and Epistemological Beliefs Across Early Career*

| Ontological and Epistemological Beliefs | Experiences as an Early Career Science Teacher | |
|---|---|---|
| | Pre-Service | In-Service |
| Beliefs about instruction and learning | *Environment*: Built on respect and accountability; Includes parents and communities<br><br>*General teaching practice*: Engaging, Clear directions and expectations; Ongoing assessment; Re-teach when necessary; Incorporate student autonomy and collaboration<br><br>*Science teaching practice*: Be relevant; Student ideas are resources for learning; Explore before explain; Direct instruction is necessary | Previous column AND<br><br>*Environment*: Student engagement is connected to management<br><br>*General teaching practice:* Hands on activities are engaging<br><br>*Science teaching practice:* Direct instruction is necessary, but not sufficient |
| Beliefs about students | Need to feel safe and comfortable to learn; Need accountability; Learn best when they are engaged | Previous column AND<br><br>Are easier to manage when they are not bored; Follow the path of least resistance; Can excel when diverse needs are met |
| Beliefs about science | Fun and applicable; Professional science ≠ classroom science | Previous column AND<br><br>Professional science ≠ classroom science *because* goals are different |

## Purpose and Goals Around Teaching

A teacher's *purpose and goals* reflect their overarching commitments to teaching and related goals, objectives, and aims therein. Below, I describe how Alexa's purpose and goals developed in the areas of: (a) instructional purpose and goals, (b) classroom environment purpose and goals, and (c) goals for students.

### *Pre-Service Experiences*

At the start of MGSM, Alexa writes in her positioning paper about five elements she aspires to incorporate into her science teaching practice: "(a) applicability, (b) providing reasoning (don't just tell 'what', explain 'why', (c) communication, (d) curiosity, and (e) open mindedness." At the end of the course when tasked with revisiting her position, Alexa left these 5 aspects unchanged. These goals are reiterated in interviews and artifacts across the year. Alexa's first aspiration, (a) applicability refers to engaging students in material that is relevant and applicable to their lives. For example, while critiquing a local district's curriculum for a course assignment in MGSM she suggests changing the metaphor used in the unit (relating the functions of organelles to a *cell city*) to something students are more interested in and familiar with. This connects to another of Alexa's goals: ensuring students have agency in their learning. In this example, she argues letting students select their own metaphor will make the lessons more "relevant to students' lives and to allow them agency in their learning experiences" which will in turn better build conceptual understanding. Alexa also aims to make sure students understand (b) how we know something in addition to what we know. Alexa describes her goals to engage students in scientific practices, particularly constructing explanations and engaging in argument from evidence, as a way to position students as epistemic agents. She shares, "that science can be even more engaging if it is less straightforward and relies more on scientific inquiry rather than scientific fact" and "it is when students feel most engaged in instruction that they will internalize and remember what they learn and understand." Together these quotes suggest Alexa's goal is to engage students in scientific practice *because* it is engaging *because* engaging lessons lead to stronger conceptual understanding[26], with engagement as the foundational

[26] As opposed to engaging students in scientific practices *because* they lead to stronger conceptual understanding and *happen* to be engaging.

purpose of the goal. Third, Alexa does not elaborate on what she means by (c) communication and (e) open mindedness in her paper. I interpret them to reflect her goal to encourage students to share their ideas and listen to others. Alexa strives to incorporate discussion in her class lessons. During these lessons, her goal is for students to draw on what they have previously learned, what they have observed in class, and their prior experiences. Her goal is for students to share their ideas and deeply reflect on their peers' ideas. When watching videos of other classes during coursework, Alexa often comments on how the depicted students are not really listening to and considering each other's ideas. Lastly, Alexa aims to capitalize on students' curiosity to expand their thinking and learning. She shares:

> "When you're put through science classes where you just sit there and listen to lectures you kind of forget about the magic of science and how it explains everything around you. I think if my students left after a year being curious in science and wondering about things that are going on around them and what's causing those things, and asking these questions, then I think I would be okay. I'd be happy."

In this quote, Alexa shares her goal of (re)inspiring lasting curiosity and interest in science among her students.

Additionally, Alexa describes her goals to encourage a positive classroom environment. First, she describes how she would like to support students' behavioral growth. She describes how she wants her students to be prepared for the responsibility of adulthood and at times this goal supersedes mastery of content. She shares:

> "I think in middle school it's more about inspiring a learner and teaching them how to go into high school because a lot of the content that they're gonna learn in a science classroom, they're gonna learn in…the next four years of high school. So, I obviously

want them to understand the content, but I think it is a lot about being an adult and being responsible and respectful."

Alexa also strives to manage her classroom well and for her students to participate. However, she is critical of the management strategies she encounters at BMS, which focus primarily on raised voices and punishments.

***First Year Teaching Experiences***

In her first year, a goal at the forefront of Alexa's mind is to improve her classroom environment. This draws primarily from her experience during her internship where she had little say in the class procedures or environment. She wants her procedures to provide the structure for an orderly classroom so she can work on other goals as well. She couples this goal with her aim to make students feel valued and comfortable in class. She wants her students "to realize that [she is] strict on them because [she] cares, not because [she doesn't] care." She tries to reduce students' feelings of being overwhelmed by breaking activities and instructions into smaller pieces and encouraging students. For example, during a class in February of her first year she tells students, "I know it's overwhelming, but we are going to work as a class. We are going to go step by step. It's going to be more attainable than you think." She continues to strive for students to be engaged, interested, curious and "excited to come to school and be in the classroom."

As the newcomer on her team, Alexa's opportunities for lesson planning are limited (described in Chapter 4), but she still aspires to provide students opportunities to engage in science practices. She is most interested in facilitating ways for students to share their ideas with peers and consider their peers' ideas, primarily through class discussion. She wants to "give more students opportunity [sic] to share their answers without feeling like they are wrong" and offer lessons where "there's no Point A to Point B, it's a little array of whatever you think it could be." Alexa also aims to give students agency when possible.

A new goal Alexa develops during her first year is to better serve her special education and emergent bilingual students. She shares:

> "I think one of my biggest goals is with my special education and [emergent bilingual] students. I feel like right now I'm not doing them justice. I'm not giving them everything that they should get…I don't like seeing some kids struggle a lot more and then feeling like I'm not doing anything to give them that extra help."

This goal connects to her aspiration for all of her students to feel valued, happy and to learn in science class.

### ***Later In-Service Experiences***

Alexa's goals and vision of good teaching remain relatively stable in her third- and fourth-years teaching, but the shift to online learning does cause her to shift the ways she envisions some of her goals. Alexa continues to aim to create a positive learning environment for her students. She wants her course to be engaging, interesting, and fun. She wants to provide some normalcy for students during the pandemic and writes, "My students are very eager to start learning and I want to give them something to focus on instead of just video games!" She aims to develop relationships with students who feel isolated during the pandemic. She shares, "[My students] feel really disconnected…so, I hang out with a lot of kids during lunch bunch, more than I would have probably in school." She struggles with student participation in her online classroom however and wants to increase student participation. Although she does not have a physical space to manage during online instruction, Alexa aims to implement procedures to maintain an orderly online classroom environment. For example, she creates a tutorial for how students can contact her for help.

Although Alexa's lessons continue to be limited by accountability to her team, and later by the challenges of teaching online, she aspires to make adjustments to improve her instruction when possible; she especially wants the science content in her course to be relevant to her students' lives. For example, she works with students to investigate the effects of habitat destruction in their local area and encourages a student to share her knowledge of natural resources in the Amazon rainforest where the student visits a grandparent. Alexa wants to engage students in scientific practice but feels limited in the online context. So, she adjusts her goals and even more narrowly focuses on supporting student-student discussion, argumentation, and constructing explanations because she feels these goals are more attainable in a digital space.

When selecting a topic of her own teaching to investigate and write about for a case study, she chooses to explore how she can better meet the needs of her emergent bilingual students. She believes their limited English proficiency has limited their ability to participate in classroom discussions, which occur in English. She aims to incorporate strategies, such as encouraging first language use in class, in order to help emergent bilingual students feel more comfortable sharing their ideas in class and learning science content.

***Summary***

I identified three groupings of purpose and goals across Alexa's early years (Table 6): (a) instructional purpose and goals, (b) classroom environment purpose and goals, and (c) goals for students. Her instructional purpose and goals are fairly stable across the four years. At each stage, she discusses her goal to support students' participation in classroom discussion. In her pre-service and first year of teaching, she also describes fostering curiosity and making space for student agency as instructional goals. During her in-service years, she feels unable to support her emergent bilingual and special education students to a standard she desires and aims to improve that element of her teaching practice. Alexa discusses making science content relevant during pre-service and in her later years, perhaps because during these time periods she feels more able to design and adjust lessons in her course. She specifically describes wanting to improve the lessons she is provided during her later in-service years. Alexa's purposes and goals for the classroom environment are extremely stable over the years. Each year she aims to create an environment that is open and safe for ideas, orderly and organized, as well as fun and engaging. Alexa aims for students to enjoy science and being in science class. During pre-service she also describes her goal for students to truly listen to each other's ideas and take on personal responsibility for their actions and schoolwork. Later, she discusses her strong desire for students to feel valued and comfortable in her classroom. After the shift to online learning, many of Alexa's goals for her classroom needed to be re-envisioned for an online environment, but the underlying goals remained constant. One new goal emerges during this challenging time: Alexa wants her students to simply show up to class and participate.

**Table 6**

*Alexa's Salient Purposes and Goals Across Early Career*

| Purpose and Goals | Experiences as an Early Career Science Teacher | | |
|---|---|---|---|
| | Pre-Service | Early In-Service | Later In-Service |
| Goals for Instruction | Relevant science content; Provide explanations; Foster curiosity; Support discussion; Make space for student agency | Foster curiosity; Support discussion; Make space for student agency; Supporting special education and emergent bilingual students | Improve district lessons; Relevant science content; Support discussion; Support emergent bilingual students |
| Goals for the Classroom Environment | Open and safe for ideas; Orderly classroom; Fun and engaging | Open and safe for ideas; Orderly classroom; Fun and engaging | Open and safe for ideas; Orderly classroom; Fun and engaging; |
| Goals for Students | Value each other's thinking; Personal responsibility; Enjoy science and science class | Feel valued and comfortable; Enjoy science and science class | Participate; Feel valued and comfortable; Enjoy science and science class |

**Teaching Self-Perceptions and Self-Definitions**

A teacher's *self-perceptions and self-definitions* draw on how they see themselves in relation to teaching. This includes ways they define themselves as teachers, as members of a community, and how they think about their own functioning as a teacher (e.g., self-perceived abilities and efficacy, personal values, interests, personality, attributes, self-characteristics, and definitions). Below, I describe how Alexa's self-perceptions and self-definitions developed in the areas of: (a) perceptions of herself as a teacher, (b) personal values and attributes related to teaching, and (c) as a school community member.

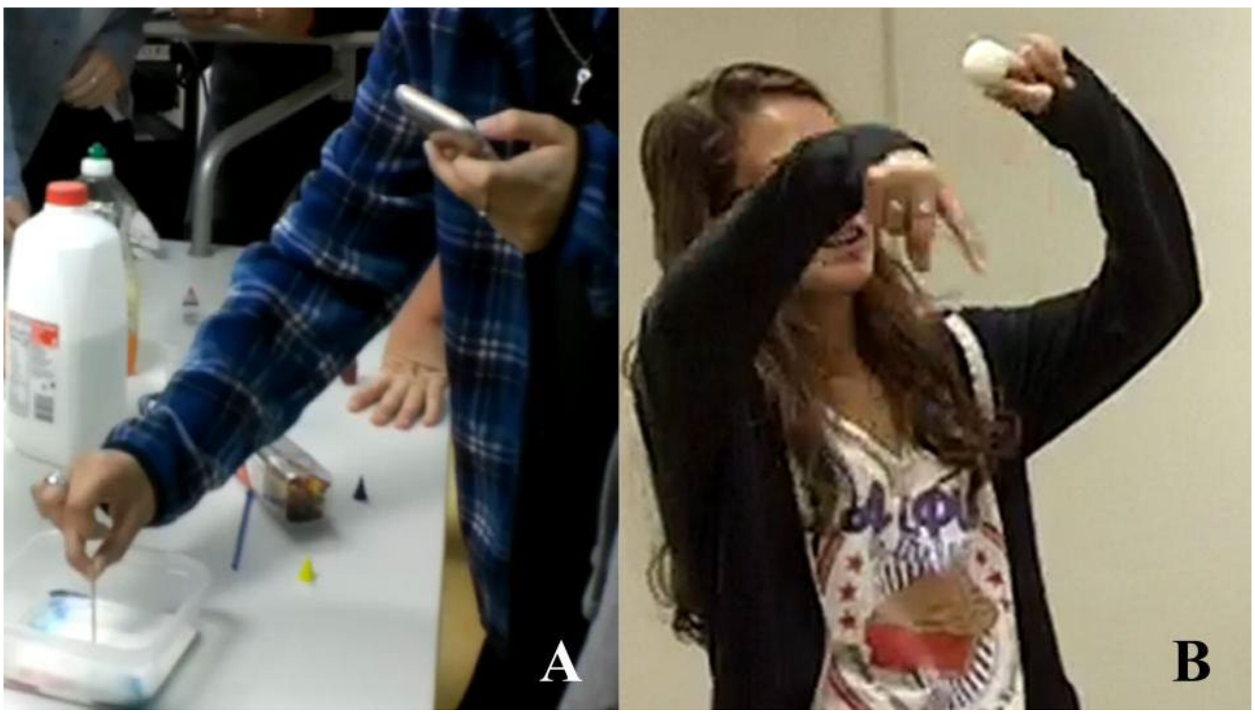
***Pre-Service Experiences***

Alexa is detail-oriented and organized. She views her science ability positively and is often eager to engage in scientific reasoning with her peers during coursework. Figure 5 depicts

Alexa during MGSM while she is exploring scientific phenomena with her peers. In image A, Alexa takes photos of *The Cat's Meow*, an investigation of the interaction between milk, food coloring, and dish soap. In image B, Alexa uses a ping pong ball and her peers' bodies (not pictured) to model how her group figured out the direction of the Earth's rotation. Alexa is often a leader during small group interactions and volunteers her ideas during whole group interactions. She sees herself as a curious person and is excited to encourage that worldview in others.

**Figure 5**

*Alexa Enjoying Scientific Exploration and Reasoning in MGSM*




In her baseline interview, Alexa describes how her interest in teaching developed from a very young age. She says, "Even when I was little, I was always like I'm going to grow up to be a teacher." While in high school, she worked as a science and math teacher at a camp run by a Catholic organization for "inner-city" students in a Mid-Atlantic city. During this experience, Alexa formed nascent conceptions of her science teacher identity. She began watching her teachers and deciding "when I'm a teacher, *I'm not* going to do that. When I am a teacher, *I am* going to do that. Little things like that." She describes these earliest experiences teaching to include activities and experiments and says when she did not like the materials that were available, she made her own or found new materials. During this time, she has not yet often described herself as a *teacher*. She describes feeling like a "guest in someone else's classroom" and states her students saw her as a *student teacher* and not *their teacher*.

Alexa often defines herself in various ways in the context of classroom discussions. During a post-observation interview, she describes her role during discussions initially as a "transcriber," keeping track of students' ideas without shutting down any ideas or providing her own ideas, but then adjusts her description to that of "facilitator" as the conversation progresses because she wants to be "the person who is guiding the discussion and making sure everyone can say what they want to say." She elaborates:

> "I guess I'm less of a transcriber and more of a discussion facilitator, like kind of facilitating the argumentation between students and then also, when they give me their hypothesis or their claim I don't just write it down, I ask them to explain why."

Alexa perceives by taking on the role of discussion facilitator she creates space for her students' ideas to be heard, valued, and used for scientific sensemaking.

### *First Year Teaching Experiences*

In her first year of teaching, Alexa describes herself as inexperienced. She shares she feels like the "little baby" compared to her colleagues and feels disconnected because she perceives they are talking to her as the "new teacher" and not a peer on the "same level". Alexa describes how she is not currently teaching at the high level she expects of herself, particularly with her students with additional needs (e.g., language).

Alexa describes how she navigates her new role as a member of the PMS community. She feels valued and welcomed by her school's administrators who are focused on supporting teacher morale, and she gives examples of administrators providing teachers with treats and organizing a new teacher get-together. She is also a member of the sixth-grade teaching team. She struggles to collaborate with her teammates, Pam and Dave, for a few reasons. First, she perceives a strong difference in professional approach and shares, "our styles of planning are very different in that I'm really, really organized and they are very, like, ahhhhhhh I'll just go with the flow." Second, Alexa also feels like Pam and Dave are hesitant to change and resist her ideas. This leads Alexa to feel like she is not considered as much a teammate as Pam and Dave. This hesitancy limits Alexa's ability to act as a discussion facilitator, but she works to incorporate classroom discussion when she can. Lastly, Pam and Dave treat Alexa as both a novice and expert simultaneously when they dismiss her ideas and fail to provide feedback, respectively.

***Later In-Service Experiences***

As she continues teaching, Alexa describes herself as more secure in her teacher role. In her first case study[27] she writes, "Starting my second year, I feel a stronger sense of confidence and assurance in my teaching." She also takes on new roles related to teaching. When her school shifts to a hybrid model during the COVID-19 pandemic, Alexa is tasked to supervise a classroom of students while they participate in their scheduled online classes. She refers to this task as "babysitting." Additionally, she also serves as a mentor during her third year when she hosts a student teacher in her classroom.

[27] Note: Recall Alexa conducted self-case studies as part of the research project

Alexa continues to work at PMS and remains a member of the school community. She maintains her positive relationship with school administrators and shares her principal has been helping her figure out her professional plans for the future. When Pam and Dave are replaced by Felicity and Eric on Alexa's grade level team she becomes the most experienced member of the team. When she becomes the "head guy" she feels she can lead her team to be more proactive in planning lessons, as opposed to the team's previous last-minute approach. However, her new teammates have similar planning styles to the previous group which leaves Alexa frustrated. She shares, "I feel like I am a cohort of one doing all the planning by myself without any collaboration." So, although she now has the status as a full, experienced member of the grade level team, she continues to feel isolated by lack of collaboration. Alexa continues to design lessons that include classroom discussion, within the constraints discussed in Chapter 4, and acts as a discussion facilitator.

***Summary***

I identified three themes of Alexa's self-perceptions and self-definitions across her early career (Table 7): (a) perceptions of herself as a teacher, (b) personal values and attributes related to teaching, and (c) school community member. Alexa's perceptions of herself as a teacher greatly change across the four years of the study. At the onset, she focuses on observing *real* teachers and views herself as a student teacher. Later she views herself as an inexperienced teacher and eventually as an experienced teacher, so much so that she hosts a student teacher. Over the years in the study, she envisions herself as a discussion facilitator while teaching. Although her ability to lead discussion is limited at PMS, she does her best to fit it in when she can. She also transforms as a school community member. At BMS, she views herself primarily as a guest and outsider of the community. At PMS, she feels valued by school administrators, but not fully accepted by her team. In her third year, although she feels like a fully-fledged member of her grade level team, she continues to struggle with effectively co-planning with her peers and feels isolated. In this area, Alexa's experiences are mixed because while she feels more accepted into the school community over time, she also continues to feel isolated and without collaboration. Alexa's personal values and dispositions are the most stable. Over the years, she maintains her detail-oriented and organized focus. Although Alexa does not describe feeling science-able in later years, this is likely due to interview questions focused on pedagogy and no longer observing her as a science student. She does not make statements indicating she feels less positively about her ability to do science.

**Table 7**

*Alexa's Salient Self-Perceptions Across Early Career*

| Self-Perceptions and Definitions | Experiences as an Early Career Science Teacher | | |
|---|---|---|---|
| | Pre-Service | Early In-Service | Later In-Service |
| Perceptions of Herself as a Teacher | Teacher observer; Student teacher; Discussion facilitator | Inexperienced teacher; New teacher; Discussion facilitator | Teacher; Student teacher host; *Babysitter;* Discussion facilitator |
| Perceptions of Her Personal Values and Attributes Related to Teaching | Detail-oriented; Organized; Science-able | Detail-oriented; Organized | Detail-oriented; Organized |
| Perceptions of Herself as a School Community Member | Classroom guest | Valued by administrators; Limited by teammates | Valued by administrators; Experienced team member; Most proactive team member |

## Teaching Perceived Action Possibilities

*Perceived action possibilities* refer to the internal (e.g., thoughts, planning) and external behaviors in relation to teaching. This section describes practices and strategies that Alexa is aware of as possibilities or that she has put into practice, as well as indications of those actions she perceives as not possible to enact. Below, I describe how Alexa's perceived action possibilities changed between actions Alexa perceives as available and those that are limited (unavailable or restricted).

### *Pre-Service Experiences*

During pre-service, Alexa feels she has many action possibilities available to her to the extent she wishes there was more structure to guide her as a novice. Before entering the program, she perceived she would have high autonomy and characterized the actions of her own teachers as those she would take up and those she would not. Mrs. Grant, her mentor, allows Alexa to design lessons and typically offers feedback on things like leaving time to clean up, rather than requesting Alexa change the core activities of the lesson. Alexa uses this agency to engage students in activities she believes will better facilitate student learning, particularly encouraging classroom discussion, constructing explanations, and engaging in argument from evidence.

Alexa does describe a few limitations on her action possibilities during her pre-service year. First, she identifies a personal limitation at the beginning of the year regarding designing learning experiences. When asked how she would ensure students master content, she mentions lecture but expresses uncertainty about it. She shares:

> "I learned science where you go to class, and you take notes, and you have your PowerPoints© and everything. I don't know if I'm stuck in that, but I feel like in some cases that's the only way to do it."

Alexa also feels very limited in her ability to change the classroom management style set in place by Mrs. Grant. She describes Ms. Grant's classroom management as non-existent and feels she cannot implement new policies and procedures in Mrs. Grant's class. She does her best to manage her students' behavior and engagement by circulating and talking to students. She shares the following statement suggesting she perceives her current limitations will be lifted in the future:

> "In my future classroom, I will work with students to create expectations for behavior in our own classroom. This way, each student and myself as a teacher can be held accountable for the way we act and behave in class."

***First Year Teaching Experiences***

Alexa feels very limited during her first year of teaching. She widely attributes her low agency to school and district policies, as well as her grade level colleagues. At PMS Alexa is expected to teach the same lessons as her grade level colleagues. She perceives that when she has an idea that conflicts with one of her more experienced colleagues, hers will be the one to fall to the wayside. When describing why she has not been able to continue with the discussion-based lessons she used during her internship, she shares:

> "I feel like that takes collaborative planning, if we're supposed to be doing the same thing, then [my colleagues] have to be willing to sit down and listen to my ideas and give feedback and talk about it—where I don't think we have that right now."

But she does feel like she is able to make small adjustments to the prescribed lessons in her classroom. She describes this as *spinning* and states:

> "I take what they give me and then I spin it a little bit. So for example, for photosynthesis…[my colleagues] have their activities to introduce photosynthesis…but for my warm-up, I'm just going to have them do that question we did [in MGSM], Why do leaves change color in the fall?...And it's not like a big change to the lesson plan or

> anything, but it kind of brings in that asking questions, trying to like, think about what's happening before I go into teaching it."

Across her first year, these small warm-up discussions are where she is best able to fit in teaching the way she envisions herself. Near the conclusion of her first year, she describes how she creates space to teach the way she wants:

> "What I have to teach, it's laid out and given to me and there's a little bit of room for doing what I want to do, but…we don't have time for extra stuff, so to kind of use what I learned, given the constraints that I have…I just feel like short discussion questions do that"

To summarize, Alexa says, "It's my warm-up and I can ask whatever I want [laughs]." Alexa also describes being able to adjust the delivery of lessons at times to better align them with how she envisions good science teaching. For example, swapping the order of activities so students explore images of plants before taking notes on the anatomy of the plant.

Although Alexa is working in a very prescribed environment, she finds areas where actions are open and available to her. First, in the initial interview of her first year she shares that the area of her newfound freedom she's most excited to take advantage of is classroom management and procedures. Figure 6 depicts ways Alexa has utilized available actions to her to implement procedures and norms to create an orderly and welcoming classroom. Image A depicts an area of the classroom where Alexa has displayed classroom expectations she co-created with her students, which includes expectations of herself. Image B depicts Alexa's daily schedule for students to reference on the front white board in the classroom. Image C shows an area of the classroom where students can pick up work if they are absent. Image D shows how

Alexa has labeled students' tables to facilitate organization.  Each table grouping also has a group name hanging from the ceiling above it.

**Figure 6**

Images of Alexa's Classroom


Another area Alexa exercises agency is in selecting professional development opportunities for herself.  Through her school district she enrolls in weekend professional development classes that she finds helpful.  For example, she enrolled in one new teacher training class with two of her peers from State University who also teach in the district that focused on classroom management.  Additionally, Alexa purchased a teaching book to read before the start of her first year.  She shares, "I got a book and I read it before I started teaching and that gave me a ton of information that really helped.  But it was really interesting that I'm reading this and I'm taking really in depth notes." Alexa goes on to describe elements of teaching she felt were missing in her teacher education thus far and how the book was able to address them.

***Later In-Service Experiences***

Later in Alexa's career, she continues to feel limited by the constraints of her district and her school colleagues on her instruction but finds ways to break the mold. The district continues to expect Alexa and her grade level team to teach the same lessons at the same pace. This constraint limits Alexa's ability to plan lessons, as she reflects on a district-wide science teacher meeting:

> "They also talked about how we should not be doing anything different than our [team]...Communication has always been a little frustrating between me and my planning cohort because I like to plan very far in advance, and they don't. This worries me because I don't want to sit and wait around for everyone else to be ready. I'd rather just get going as soon as possible!"

However, because Pam is no longer on her grade level team Alexa is excited to try out new ideas with Pam's replacement, Eric. She shares, "I feel like there's a lot more freedom this year than last year where I'm not having someone looking over my shoulder making sure that I'm doing everything that they want me to be doing." To this end, Alexa shifts her perceived action possibilities from *spinning* to *fixing*. She shares:

> "Last year was like okay, what am I teaching and what is everyone else teaching and making sure that we're all teaching the same stuff. And then now it's like, now I know what I'm teaching, but how can I change it to actually be better? Be what I want it to be. So, it's a lot of taking what I already know and now I'm fixing it."

Alexa *fixes* her lessons by making them (a) more engaging, (b) using an *explore before explain* strategy, (c) adding substantial discussions with argumentation, (d) making activities more accessible to emergent bilingual students, and (e) allowing more student choice and agency. She eventually decides to simply disregard the district materials and go her own way regarding lesson planning. She shares, "The week after spring break, I decided to just not even look at their lesson and make my own, which I'm excited about."

Alexa has similarly mixed affordances and constraints regarding her classroom environment during her later years. She continues to employ procedures and classroom management strategies of her choosing early in year three, and when school shifts online she is able to choose between two online learning management systems. She does feel some limitations, however, as she must re-envision aspects of her teaching without a physical space, such as keeping track of student ideas on a whiteboard. Additionally, she struggles to effectively communicate with her students. Many students do not attend her synchronized lessons and those who do often stay muted with their cameras off. She finds herself worrying about whether present students are even truly in front of the computer, and she worries about how to get in touch with absent students. She can reach out to students and she does so by making videos, such as a tutorial on how to reach her through email, and by contacting students' parents. Through these avenues she can increase communication with her students and is even able to help one family get Wi-Fi access through the school district.

### *Summary*

Alexa's perceived action possibilities shift drastically across the four years of the study (Table 8). In this section, I organized Alexa's perceived action possibilities into those that are available and those that are limited. Initially, Alexa feels she has high control over the lessons she uses with her students at BMS to the point she wishes there were more resources and structure available from the district. But when she begins work at PMS, she feels limited by the, often teacher-centered, lessons required by her district. However, she can initially adjust her instruction in small ways through *spinning* and later in more significant ways by *fixing*. With Mrs. Grant, Alexa feels stuck in Mrs. Grant's classroom environment with little room to make changes. Conversely, when she has her own classroom at PMS classroom management and procedures is the area she has the most freedom and she is excited to shape her classroom environment to match her teaching vision. It is interesting that Alexa's control over the two areas she describes the most, instruction and management, swap places between pre-service and her first-year teaching. In later years, Alexa sees more available actions regarding lesson planning and instructional strategies even though the constraints limiting her are still present. This is largely because she feels comfortable enough with the curriculum to begin making significant changes and begins to disregard some district mandates. Additionally, Alexa sees opportunities for action by enrolling herself in professional development experience during her first-year teaching. Alexa does not discuss enrolling herself in optional professional development in later years, presumably because social distancing requirements halted the program. A new perceived action limitation is introduced during the pandemic when Alexa has difficulty communicating with her students. Although she tries a variety of avenues to get in touch, at the end of the day she cannot control if someone is listening on the other end.

**Table 8**

*Alexa's Salient Perceived Action Possibilities Across Early Career*

| Perceived Action Possibilities | Experiences as an Early Career Science Teacher | | |
|---|---|---|---|
| | Pre-Service | Early In-Service | Later In-Service |
| Available actions | Lesson planning and instructional strategies | Spinning small aspects of lessons; Classroom management; Professional development | Disregarding (some) district expectations; Some lesson planning and instructional strategies; Designing an online space of learning |
| Limited actions | Instructional best practices; Classroom management | Lesson planning and instructional strategies | Some lesson planning and instructional strategies; Communication |

**Overarching Summary**

This analysis sought to discern how Alexa's science teacher identity developed across four years between pre-service and in-service. Using the DSMRI as a framework, I mapped how Alexa's identity was stable in some areas and was modified in others. First, Alexa's self-perceptions and definitions were stable regarding seeing herself as a detail-oriented, organized person. But she altered her self-conceptions from a classroom guest to a valued member of the school community and from an observer of teachers to an expert and mentor of teachers. Second, Alexa's ontological and epistemological beliefs are incredibly stable. She maintains the beliefs she develops during pre-service and expands on them during in-service. For example, Alexa believes a positive classroom environment is built on respect and accountability and includes parents and communities during pre-service; and she later adds on the belief that student engagement is connected to classroom management. Third, Alexa's purpose and goals are relatively stable, but she makes adjustments based on contextual changes. For example, her instructional purpose and goals are relatively stable and related to enacting what she believes is good science teaching.  When she finds the district curriculum does not align with her existing goals, she adds the goal to improve district lessons.  She consistently aims to provide an open, safe, and orderly classroom that is fun and engaging for students.  She also consistently wants for students to value each other's ideas, feel valued and comfortable, and enjoy science and science class.  Lastly, Alexa's perceived action possibilities shift drastically across the four years.  She perceives high control over her lessons during her internship but loses control when she must teach a prescriptive curriculum at PMS.  Eventually, Alexa begins to reclaim control through spinning and fixing[28].  During her internship she perceives minimal leverage over classroom management or arrangement.  However, when she starts her position at PMS one of the things she is most excited to control are actions related to classroom management and environment.  In the upcoming chapter (6), I expand on this analysis to explore the ways challenges shaped Alexa's science teacher identity.

[28] Discussed in depth in Chapter 6

# Chapter 6: Productive Friction and Role Identity Development

**Research Question #4: In what ways do challenges shape Alexa's science teacher identity?**

Productive Friction is a framework initially from the business and management literature (Hagel & Brown, 2005b). Ward, and colleagues (2011) later adapted the framework for education and offer the definition: *productive friction in student teaching* is "**dissonance** experienced by teacher candidates when two or more social worlds conflict, **which initiates positive changes** in their use of high leverage practices to improve student learning and understanding" (p. 15). The authors describe productive friction driving change through *feedback* and *pushback*. Feedback describes scenarios where a candidate takes up advice to reconcile seemingly conflicting goals. For example, a candidate struggling to balance classroom management and engaging students in conceptual discourse can reconcile the two goals after receiving feedback from a university supervisor, who might, for example, offer suggestions on how the candidate can question students for understanding in the field effectively. Pushback describes scenarios where a candidate's beliefs are challenged, and the candidate reflects on and reconsiders their beliefs. For example, a candidate with deficit views may have those views pressed on by a course instructor causing the candidate to reflect on their ideas and possibly re-envision their beliefs. Productive friction is described in greater detail in Chapter 3. Below, I describe how Alexa experiences productive friction during pre-service and in-service teaching when challenges (discussed in Chapter 4) drive the process of change in her science teacher identity (discussed in Chapter 5) to answer the question: *In what ways do challenges shape Alexa's science teacher identity?*

**Productive Friction in Student Teaching**

During her internship, Alexa experiences tensions as she tries to bring her developing teacher identity to fruition. She experiences some difficulty trying to implement NGSS-aligned instruction with actual students. She also makes sense of classroom science in relation to her teaching role. She experiences these tensions alongside her mentor, Mrs. Grant, as they both navigate their first student teaching internship as a mentor and mentee, respectively.

***Opposing Identity Components and Instructional Challenges.***

Alexa actively tries to implement what she learned through coursework (contributing to her ontological beliefs) into her teaching practice. As discussed in Chapter 5, Alexa feels what she learned in her coursework, particularly MGSM, aligns well with how she makes sense of other elements of her teacher identity (e.g., purpose and goals). During her internship, Alexa is enrolled in a course, IDMII, where she talks about her internship and works through problems of practice with her peers and an instructor. They work together to develop and try out strategies to help Alexa better employ her vision of teaching, in which she engages students' curiosity, enjoyment, and fosters equity. Alexa regularly uses talk moves (Michaels & O'Connor, 2015), such as eliciting responses, revoicing, asking for elaboration, and polling to promote discussion. She often prompts students to agree, disagree, or add during class discussions. She also uses scaffolds to support students as they engage in science practices. For example, Alexa provides her students with sentence starters as they make sense of how to craft an argument.

Alexa often uses lessons she experienced in MGSM in her teaching practice. For example, she engages students in argumentation-based discussions on an invasive plant species, purple loosestrife, and a symbiotic relationship between screech owls and thread snakes. While Alexa prefers lessons that focus on scientific practices, particularly argumentation, she has some difficulty implementing them as she would like in the classroom. For example, she criticizes the culture of silence Mrs. Grant has created in the classroom as it is not conducive to discussion or group work. She finds that she can use what she learned in her coursework to shift content instruction from "straightforward" to student driven, however. Alexa continues to measure the success of her lessons with student engagement, which she uses widely and loosely defines.

However, while Alexa prefers the responsive style of teaching she learned in her coursework, she has some continuing difficulties with implementation in her student teaching. First, reformed teaching practices can be hard for students who are used to traditional methods simply because they are so different and new. Alexa shares:

> "I noticed that the discussion group went really well, but then when I asked them to work on it on their own, they shut down and weren't as productive…when I asked them to use evidence, to think about the types of evidence that they could have collected, I think that's where they got confused."

In this example, Alexa notices students readily participate in a discussion facilitated by the teacher, but when left to their own devices are unsure how to continue their investigation by identifying the types of evidence necessary to support a claim. Second, Alexa is unsure how to lead a class discussion most equitably. She shares, "It's tough because you want everybody to contribute, but then you also want people to talk one at a time, so that's a contradiction." She also struggles with centering the students' conversation, as they jump from idea to idea. Alexa wants to support all students' engagement and participation but feels like it is hard for students to keep track of all the various ideas as they move quickly from one to the next. Lastly, Alexa is worried what the students are learning does not appear to be *sticking*. She describes, "[The students] thought in depth about it. But then, what I would see is a couple weeks later, it was just, poof, gone. Which I guess, isn't like the, since my goals isn't really the content, I think that's not the biggest problem." One of the primary reasons Alexa is fond of what she learned in her coursework is that she feels it is supportive of students and allows them to apply what they are learning to their lives (and their lives to their learning). And while she is not particularly upset because her goal is student engagement, not understanding content, she still would have liked for students to excel in both areas.

Alexa's beliefs and goals described in Chapter 5 are often in opposition with her mentor's beliefs and goals. First, although Alexa is initially impressed with Mrs. Grant's teaching methods and style the NGSS-aligned practices fell away as the year went on. For example, she praises her mentor asking the students, "What questions do you have?" after viewing a density demonstration of a Coke™ sinking and a Diet Coke™ floating in water and the next day using the questions to investigate density further at the start of the year. Alexa later criticizes:

> "Towards the middle and end of the year, her hands on turned into, like, simulations where it was just like drag [an object] and if you don't drag to the right place, it just bounces back until it gets to the right place."

Although Alexa and Mrs. Grant[29] share an ontological belief, *science instruction should be NGSS-aligned*, they differ in their epistemological beliefs that make them take up the statement as true. Alexa believes science instruction should be NGSS-aligned because it is fun, engaging, and student-centered, while Mrs. Grant believes science instruction should be NGSS-aligned because it provides access to content knowledge. So, when Mrs. Grant perceives students are not mastering content through NGSS-aligned instruction, she is open to reducing NGSS-aligned instruction and increasing the amount of direct instruction. Conversely, when

[29] Understanding of Mrs. Grant's identity are derived from Alexa's perceptions of her and limited interactions during classroom observations and should be considered with these limitations in mind.

Alexa is struggling to incorporate NGSS-aligned instruction into her lessons, she resists moving towards direct instruction because it would not be fun, engaging, or student-centered and content mastery is not a high tier goal for her.

Productive friction does not work to improve NGSS-aligned instruction between the pair because of their divergent epistemological beliefs. Mrs. Grant does not offer feedback on how to make lessons more NGSS-aligned—and instead offers feedback on how to efficiently get content across—or pushback on Alexa's instructional methods.

However, perhaps productive friction works through resistance in this case to strengthen and reinforce Alexa's beliefs. Although she does not get the necessary support from Mrs. Grant to make her instruction more NGSS-aligned, Alexa uses Mrs. Grant as a non-example of good teaching and uses the opportunity to reflect on her beliefs. In this example, although reconciliation did not occur, the friction between Alexa and Mrs. Grant was still productive. Table 9 displays a summary of Alexa and Mrs. Grant's opposing identity components in relation to the goal of NGSS-aligned instruction and productive friction.

**Table 9**

*Summary of Alexa and Mrs. Grant's Opposing Identity Components Related to the Goal of NGSS-Aligned Instruction*

| Challenge | Goal: NGSS-aligned instruction | |
|---|---|---|
| Identity Component | **Alexa** | **(Perceived) Mrs. Grant** |
| Ontological and Epistemological Beliefs | Respectful environment<br>Re-teach when necessary<br>Incorporate student autonomy and collaboration<br>Be relevant<br>Student ideas are resources for learning<br>Explore before explain<br>Students learn best when they are engaged<br>Science should be fun | Students should know science facts<br>Students need a rigid environment to learn and be successful |
| Purpose and Goals | Foster curiosity<br>Make space for agency<br>Support discussion | Teach students science<br>Maintain order |
| Self-Perceptions and Definitions | Discussion facilitator<br>Classroom guest | Teacher<br>"Draconian" |
| Perceived Action Possibilities | Lesson plans and activity design | As a mentor:<br>Create space for Alexa to try teaching strategies<br>Offer feedback<br><br>As a teacher:<br>Lesson plans and activity design<br>Classroom management |
| Level of Success in Focus Goal | Continues to try to incorporate NGSS-aligned instruction into her lessons but, without feedback or support often flounders. | Shelves goal in favor of different goal: Teach students science |

| | | |
|---|---|---|
| Productive Friction | Resists Mrs. Grant's practices and uses Mrs. Grant as a non-example to strengthen her commitment to related identity components because she sees the effect of NGSS-unaligned instruction | - |

Note: Because this case study has limited data from Mrs. Grants point of view, the identity presented here is built from Alexa's perceptions and a handful of interactions and should be considered as such.

***Opposing Identity Components and Science Challenges***

Alexa and her mentor often, cordially, butt heads throughout her student teaching. The two teachers embody their roles as teachers differently—Alexa as a champion of students and facilitator of learning, and Mrs. Grant as a science 'purist' and content deliverer. These contrasting self-perceptions drive disagreements about the possible distinction between *science* and *school science*.

When describing her role, Alexa sees herself as a facilitator. Her primary goals are for students to be excited about science, to feel that she values them, and to engage in sensemaking. Conversely, Mrs. Grant's primary goal is to deliver science content. She describes herself as a 'purist' who is dedicated to science and tends to overlook the student. Mrs. Grant's identity causes tensions for Alexa as she watches her teach. Alexa shares:

> "If someone were to say something…that wasn't right, but made sense, I think she would be quick to say 'No, this is the right answer' rather than 'think about it.' And I think having them think about it and explain their reasoning is more important than them getting the right answer."

Alexa also believes that even if a student's response is incorrect, it may spark thinking in another student and therefore still adds value to the lesson.

In her conception of science teaching, Alexa makes a distinction between *science* and *school science*, in which *science* is carried out by scientists conducting investigations to understand previously unknown phenomena, as compared to *school science* where students are trying to understand known phenomena and have more lax rules of sensemaking. Alexa shares:

> "Scientists wouldn't just jump in and bring random ideas into their claim, but I want [the students] to bring in different ideas as long as…it's relevant…I don't want them to bring in ideas about other things that aren't really relevant to science, but I also don't want to shut down their ideas either."

In these moments, Alexa is making an instructional decision that aligns with her science teacher identity to create a welcome and supportive classroom environment conducive to student thinking and sensemaking by encouraging the students to discuss their experiences and prior knowledge. She describes how she seeks to make *school science* more accessible for students and shares, "I think a lot of times when I stand up and we're talking about…sciency terms… [the students] are going to shut down." However, Mrs. Grant would like students doing *science* in the classroom. During Alexa's lesson on purple loosestrife, she tells the students if they were 'real' scientists, they would need to design experiments for every piece of evidence supporting their claim.

The conflicting belief comes to a head as students do an activity about an invasive plant species, purple loosestrife. Alexa encourages the students to use their prior knowledge of ecosystems to reason why purple loosestrife is overtaking the orchids at a pond; however, Mrs. Grant believes the only evidence is data collected by the scientist[30]. Alexa and Mrs. Grant argue about what counts as evidence publicly over multiple days, leading many students to become

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[30] Note: There was no investigation in this task. Students read a description of a pond and use the descriptors as evidence. The students would not possibly be able to visit the 'pond' and collect more data.

confused about the task. Mrs. Grant is bothered that some students are making inferences based on prior knowledge when the data is not available. For example, the students suggest the purple loosestrife is stealing water from the orchids, there is more sunlight in the area with purple loosestrife, or the amount of purple loosestrife is changing because the weather is changing and warmer temperatures help the purple loosestrife grow. Mrs. Grant repeatedly tries to shut down the students' use of outside knowledge, telling them, "This is not Language Arts! You cannot bring in other information." However, Alexa argues that the students' inferences are sensible and should be allowed because it is true that plants need water and sunlight to thrive, and in the students' temperate climate plants often bloom as warmer weather arrives. Alexa is purposefully allowing students to bring in prior knowledge and experience to support their sensemaking and understanding, but Mrs. Grant argues it will give the students an unrealistic understanding of how scientists do *science.*

Although Mrs. Grant pushes back on Alexa's conception of *school science*, the tensions between them are not productively reconciled to change Alexa's belief. However, Alexa experiences productive friction through resistance by pushing back against Mrs. Grant's 'purist' take on classroom science which leads Alexa to reaffirm and strengthen her other identity components. On a surface level, Alexa is arguing with Mrs. Grant about what science should look like in their shared classroom. But, under the surface Alexa is fighting to maintain her self-perceptions, goals, and other beliefs. For example, by permitting students a wide definition of evidence she reaffirms that students' ideas are resources for learning (beliefs). She is also making students feel valued and comfortable (goals) and strengthening her self-perception as a facilitator of learning. Table 10 displays a summary of Alexa's and Mrs. Grant's opposing identity elements in relation to their beliefs on *science* and *school science*.

Additionally, Mrs. Grant is pressed to reflect on her beliefs after working with Alexa[31]. She reflects, "I think I started seeing that ["the humanity of a person is equally, if not even more important" than the content], to be honest with you, in seeing Alexa…You know I do have to admit that being engaged more with the child as opposed to the [content] is important." Although not the focus of this study, based on the available data Mrs. Grant's reflection suggests that productive friction may have worked to initiate a change in her professional role identity.

[31] This data is drawn from a separate study under the Negotiating the Transition umbrella. Primary findings from this study are published in Tang et al (2022)

**Table 10**

*Summary of Alexa and Mrs. Grant's Opposing Identity Components Related to the Opposing Beliefs of Science vs. School Science*

| Challenge | Belief: Professional Science vs. School Science | |
|---|---|---|
| Identity Component | **Alexa** | **(Perceived) Mrs. Grant** |
| Ontological and Epistemological Beliefs | Student ideas are resources for learning<br>Science ≠ school science<br>Students shut down when overwhelmed<br>Science is all around us | School science should be the same as professional science |
| Purpose and Goals | Get students excited about science<br>Make students feel valued and comfortable<br>Facilitate sensemaking | Deliver science content<br>Correct misconceptions |
| Self-Perceptions and Definitions | Champion of students<br>Facilitator of learning | Science 'purist'<br>Content deliverer |
| Perceived Action Possibilities | Lead discussions<br>Allow students to use prior knowledge and experience as evidence | Push back on Alexa's conception of *school science* |
| Productive Friction | Resists Mrs. Grant's pushback to reaffirm other identity components | Reflects that perhaps the humanity of students may be more important than content (change through pushback) |

Note: Because this case study has limited data from Mrs. Grants point of view, the identity presented here is built from Alexa's perceptions and a handful of interactions and should be considered as such.

**Productive Friction In-Service: Teaching the way I want**

Alexa envisions herself as a responsive, reformed science teacher, but she experiences multiple roadblocks in carrying out her vision (as discussed in Chapters 4 and 5). First, Alexa feels like a newcomer at PMS where her colleagues know how things are done but fail to give her direction. Second, Alexa's closest colleagues, the sixth-grade team, are hesitant about the suggestions Alexa makes to modify the curriculum. Lastly, the district-provided curriculum does not align with Alexa's views of high-quality science instruction. Alexa still feels it is possible to bring her teaching vision to light, however, and shares:

> "I'm trying my best to work with what's already there to make it into the teaching that I want to do. But I think hopefully in the future I can, instead of using what's there and fitting it to a mold, I can make my own mold."

To make her practices more aligned to her professional role identity, Alexa engages in *spinning* and *fixing*. Alexa describes spinning as, "I take what they give me and then I spin it a little bit." In these examples we see Alexa use the bulk of a district or sixth-grade team lesson but alter small moments, so they are more aligned with her teaching vision. Alexa spins lessons in three primary ways: (a) adding short activities, (b) facilitating short, open-ended discussions, and (c) creating a low-stakes classroom environment. Beginning in her second year, Alexa begins the process of *fixing* her instruction. *Fixing* and *spinning* are similar but differ in time and effort. When Alexa is fixing, she spends ample time altering old lessons and creating new lessons; while she is *spinning,* she often quickly makes small changes while leaving the bulk of the lesson untouched or changing things outside of the lesson, like the classroom environment.

***Spinning***

Although Alexa feels very limited regarding her instruction, she finds ways to fit strategies aligned with her ideal ways of teaching into her lessons. In some instances, Alexa adds activities to mandated lessons. For example, she describes a lesson she altered and shares:

> "When we were learning about parts of a plant, [my team selected] a note sheet with fill-in-the-blanks and then [the students] fill in the blanks with parts for each part of the plant. And before I even gave them that note sheet, I gave them a 'card sort' with pictures of the part of the plan with the definitions."

In this example, Alexa takes a team lesson and adds an activity she feels will make the lesson more meaningful to students. Although the card sort and fill-in-the-blank activities are both matching tasks, the addition of pictures makes the lesson more engaging and accessible for students. Alexa also adds short activities separate from the team-selected lessons. For example, Alexa describes adding a visual demonstration to a lesson on organelles and shares:

> "There's a way you can blow a bubble inside of a bubble, so I did that. And I was like 'This bubble on the inside is like the organelle and this bubble on the outside is like the cell.' So [the students] had that visual and that only took five minutes, and they loved it and I think it really helped them."

Again, Alexa moves to make the lesson more visual and engaging for students. Through these short additions, Alexa can alter her lessons in ways that support her science teacher identity.

Another strategy Alexa uses to spin her instruction is facilitating short, open-ended discussions. She shares, "I want to use little discourse opportunities in class to make it as engaging as I can with the curriculum that I have to follow." One question Alexa discusses often in her interviews is "Why do the leaves change color in the fall?" She used the question during her avatar simulation in her senior year (Walkoe & Levin, 2018) and cites the experience as inspiration for the way she introduces the topic of photosynthesis. She believes by adding the question as a warm-up at the start of the topic "is not going to be a big change to the lesson plan or anything, but it kind of brings in asking questions, trying to think about what's happening before I go into teaching it." Alexa facilitates the discussion about leaves during her second year of teaching. She displays the question on the board and students share a variety of possible answers: weather, temperature, wind, amount of water, snow, seasons. Alexa asks students to elaborate on the idea of seasons and presses students to think about what happens as the seasons change that might cause the leaves to change color. The conversation ends without consensus or resolution when Alexa says, "That was our last comment. We are going to talk about this later on today when we learn about photosynthesis." This move suggests Alexa uses the discussions to get students interested in and thinking about a topic, but not to teach the content of a topic. Alexa also suggests the discussion questions help students draw together concepts from multiple units, across courses, and their everyday experiences. By incorporating short discussions into small time frames, such as warm-ups, Alexa embeds meaningful instruction into otherwise teacher-centered lessons.

The lessons the sixth-grade team uses leaves little room for students to grapple with new information. However, Alexa is often able to alter her delivery of the materials to better align the lesson with how she wants to teach. She creates a low stakes environment through talk moves. Alexa often asks questions every student can successfully answer, such as "What do you see when you look at the picture?" Even when the prompt has a concise, declarative answer, such as "Guess if the following are multicellular or unicellular: potato, amoeba, and tree", Alexa explicitly reminds students of the lowered stakes by purposefully using the word *guess* and explaining why she use the word to students. Alexa revoices what students share then prompts them to agree, disagree, or comment on their peers' ideas across multiple observations. Alexa uses wait time well and reiterates to students that it is okay to take time to consider a question or problem. She tells the students she is going to wait until she sees as many hands up as possible to start calling on people. Alexa is also explicit that it is okay to not know the answer sometimes. When discussing a new topic, she tells them, “I don’t expect you to get these right, I just want you to give your best answer.” While Alexa cannot entirely control which lessons she teaches, she fosters a low-stakes classroom culture that supports her in *spinning* lessons to be more aligned with her science teacher identity.

### ***Fixing***

Alexa describes two reasons she can make drastic changes to her instruction in her second year where she was unable in her first year. First, Pam transfers to another team leaving Alexa with more freedom than in her previous year. She shares:

> “So last year [Pam] was on our team and she was watching us and making sure we were all doing the same stuff. But now she’s not on our team, so we’ve all taken a little bit more liberty. So, I think some of the teachers are stuck in their ways, but myself and the new teacher are more together trying to change stuff.”

Additionally, with a year of experience Alexa feels more comfortable with the curriculum. She describes the effect on her practices and shares:

> “Last year was like, ‘Okay, what am I teaching?’ and ‘What is everyone else teaching?’ and making sure we’re all teaching the same stuff. And now it’s like I know what I’m teaching, but how can I change it to actually be better, be what I want it to be. So, it’s a lot of taking what I already know and now I’m *fixing* it.”

With colleagues who are more open to change and the wherewithal to start *fixing* the curriculum, Alexa moves forward making alterations to old lessons and introducing new activities.

At times, Alexa heavily alters the delivery of lessons to fix them. She shares, “The worksheets and the activities I think can [align with teaching the way I want] if they’re put in different order or they're changed a little bit. I think it can fit…but if I just go with what is given to me that is not." For example, Alexa describes how she changed a WebQuest into a collaborative station activity with various tasks like a video and a book section. Alexa observes how the students enjoyed the new lesson much more than the previous year. Alexa also discusses altering lesson formatting to make it more understandable, such as redesigning the station card used during an activity where students compared yeast in sugar water with Alka Seltzer © in water under a microscope. By altering the format or sequence of lessons, Alexa can fix some of the curriculum.

Alexa also fixes some lessons by designing or finding new activities. At the end of Alexa's first year, we asked if there were any instances where her idea for a lesson was taken up by the sixth-grade team. She could only think of one example: a flower dissection lab. The first time she taught the lesson she was restricted by budgeting constraints but was overall pleased with the lesson. She shares:

> "When we were learning about pollination and different parts of the flower…I wanted to do, cause I remember it in my middle school, flower dissections…so each table got their own flower and then we dissected it to see the different parts, but before we started to talk about pollination, so that they could really understand what is happening."

In this example, Alexa is drawing on her experience as a science learner and expertise as a science educator. She knows she enjoyed flower dissection as a student; so, she expects her students to be similarly positively engaged in the activity. She is also very clear about when and why the activity should take place—before direct instruction so students can explore before hearing the explanation.

Alexa also fixes her instruction by improving the spinning she used the previous year. She describes the way she updated her above-mentioned card sort activity for parts of a flower and pollination. The first year, Alexa has students match the definition of a part of a flower to a picture. Alexa extends and amplifies the activity in her second year when she changes it from a matching to a sorting activity. She shares:

> "Last week we learned about pollination…it was a sorting activity. They had 8 pollinators and 8 flowers. The pollinators talked about what kind of flower they want to pollinate. The kids had to match flowers to pollinators, but it was really frustrating for them because they wanted a right or wrong answer and I wanted them, I said 'I don't care what you're pairing as long as you have a reason to support, like two reasons to support why'. So, it was actually really interesting to see how well they were engaged in the activity. And then when we discussed it…the discourse came to them naturally. They were talking about why they made the decisions they made versus what was right or wrong."

Alexa extends the content from parts of a plant to also include ideas about pollination. Students look at images of plants to identify how their characteristics might attract various types of pollinators. She also augments the activity by increasing the cognitive demand from identification to argumentation. As there are multiple reasonable answers, such as a daffodil being pollinated by both bees and butterflies, the students needed to provide strong reasoning to support their responses. Students engaged in argumentation by listening to each other's arguments and agreeing or disagreeing based on available evidence.

### ***Spinning and Fixing During a Pandemic***

Just as Alexa begins to feel she has her feet under herself, she is forced to drastically change her instruction as schools quickly shift to fully online instruction. Frictions she felt she had overcome were reintroduced all at once. She shares:

> "[My administration] talked about how we should not be doing anything different than our [team]. While this makes sense, it adds another layer of stress with me. Communication has always been a little frustrating between me and my planning cohort because I like to plan very far in advance and they don't. This worries me because I don't want to sit and wait around for everyone else to be ready. I'd rather just get going as soon as possible!"

Alexa again struggles to teach the way she wants while required to have total instructional alignment with her sixth-grade colleagues. She finds it difficult to get in touch with her colleagues to collaborate on lessons and shares, "I am still getting radio silence from my planning cohort. I have no idea what they are teaching and if we are on the same track." These two tensions compound each other and leave Alexa feeling "like a cohort of one doing all the planning by [herself] without any collaboration."

With the switch to completely online instruction, Alexa needs to either adapt previous lessons or find new lessons. The district provides lessons for teachers to use, but Alexa does not want to use them because they are not aligned with how she wants to teach. She shares, "I think a lot of people in [the district] can be paper pushers and just want to have worksheets and once the worksheet is done you have a quiz and then class is over." The fixing Alexa did earlier needs to be completely re-worked for online or she spends time fixing the new district lessons. She shares:

> "I think something I felt the past two weeks is that [the district] gives us virtual lessons and then we'll update them and I feel like I've been getting stuck in [the district's] lessons. And instead of doing the things that I want to do in my lesson, I just take theirs and update it. So, it felt like what I was used to and what I like doing was lost."

Additionally, while working to fix lessons Alexa needs to find new strategies that she can use during online instruction. She wonders, "how to promote discourse and engaging lessons" online. She tries to engage students in a discussion of the Owls and the Snakes (Levin et al., 2012) through a discussion board, but students struggle to understand the prompt and do not respond to each other on the board. Alexa is also unsure how to assess students fairly and equitably. She worries "how to ensure that students will not just Google the answers" and feels guilty for giving a quiz when she is not "fully aware of where [her] students are in understanding the content." Even when she can assess students well, she is not sure what to do with the data. She shares:

> "I have been giving exit cards at the end of and in the middle of lessons to serve as a check for understanding. I can use them as a measurement tool to see what are common misconceptions that students have and what do they understand well. It has been helpful to see what students are not getting. However, I don't know what to do next."

She tries to incorporate new online resources to make her lessons engaging but worries they are becoming mundane.

As things begin to settle, Alexa again turns her attention towards fixing. She shares, "It's been nice to look at our curriculum with fresh eyes and really pick out what's important and what we can focus on since we have less time." However, she describes the process of fixing during COVID-19 as different than before. She shares, "I think this year is a little bit different just because it's not really fixing, it's just making it work online. But it's a little bit of both, but it's kind of just like redoing everything." She settles into a lesson routine that begins with a phenomena-based warm-up followed by notes in an editable Google Doc. Next students do some sort of practice with the material, such as a discussion board, Kahoot ©, or Desmos ©. The final part of the lesson is a check for understanding, like an exit card or automated-graded quiz. Alexa eventually stops using the district lessons all together and shares:

> "I decided to just not even look at [the district's] lesson and make my own, which I'm excited about. So, I think the only thing that's been keeping me from doing what I want to do…is just focusing too much on the mundane [district] routine."

Similarly to pre-pandemic, Alexa feels she is most able to teach the way she wants when she rejects the district lessons and creates her own using the 5E instructional model (Bybee et al., 2006). Additionally, the structure of Alexa's school day changes and provides Alexa more time for planning. She shares she uses this "opportunity to find new things, relying on internet resources in a productive way…It's finding internet resources and different things that we can use to amplify our teaching rather than bog it down."

Alexa uses multiple technological tools to fix and create new lessons. She relies heavily on the program Nearpod ©. Nearpod © allows teachers to import or develop a slide deck that they can advance on linked students' devices during a lesson. Alexa embeds images of phenomena into the slide deck to prompt discussion. For example, she shows an image of an owl moth to prompt a discussion on mimicry asking students, "What is this picture of? Why does it look like this?" Teachers can also embed widgets into the slide deck. Some widgets Alexa uses often include a collaboration board, a drawing board, short answer responses, and videos. Nearpod © allows Alexa to anonymously share student responses in real time. Another tool

Alexa uses are the investigation simulations from Discovery Education ©. Alexa developed a lesson based on students' virtual outdoor education experience using a simulation called Mystery of Potter's Pond. In the simulation, the fish in Potter's Pond are dying and students investigate by comparing the effects of pH on fish in a fish tank to the pH of Potter's Pond. Other tools Alexa uses often to spin and fix lessons include Kahoot ©, Desmos ©, Canvas ©, and EdPuzzle©. She shares:

> "I think I was always afraid of using computers in school because then you have to deal with the kids that go on games and then it's like a whole issue…but I could see myself using Nearpod © more often in the classroom setting. And then just like the different random online resources that I found for different [uses]. I've searched the whole, foraged the whole internet…and now I have [tools] and I can use them whenever I think they're helpful."

Alexa believes using these tools will become a regular part of her teaching even when students transition back to in person. In this example, Alexa is resolving friction through exploration. She notices there is misalignment between her identity and her actions and that she does not have access to more knowledgeable peers for feedback or pushback[32], so she instead goes exploring for tools that can re-align her teaching with her identity.

An affordance of the various technological tools is they provide Alexa with a multitude of formative data to draw upon in her practice. For example, she describes monitoring students' responses to a multiple-choice review question. She can see in the moment what percentage of and which specific students got the answer correct or incorrect. She uses this data to clarify or reteach the misunderstanding. Additionally, Alexa uses the data to drive phenomena-based discussions. She shares she is able to "pick out a certain kid's answers and ask them to share"

[32] And resistance to the nature of living during a pandemic was futile (though many tried).

drawing upon the ideas she learned in IDMI to purposefully select and order student responses to drive productive science discussions (Smith & Stein, 2011). The data Alexa has access to in the online environment allows her to better target her instruction towards her students' needs.

Since Alexa cannot have students do hands-on activities, she begins to use more and stronger connections to students' everyday lives. For example, students made connections to their lives through discussions about natural resources and conservation. They asked questions and made statements like, "The parts of a Happy Meal © come from nature, so is it a natural resource?", "Is a tree a natural resource because humans need to plant the seeds?", and "A bird is natural, but it's not a resource." Students worked together to draw upon their everyday knowledge to work out what makes something a natural resource or not. The discussion Alexa describes is richer than I typically observed during pre-pandemic, in-person visits. Additionally, as a worldwide science-related current event, COVID-19 itself became a topic for Alexa's students to draw everyday knowledge. While discussing adaptations, Alexa asks students the ways humans adapt to their environment. A student brings up the behavioral adaptations we made in response to the pandemic, such as mask wearing and social distancing.

***Summary***

Productive friction works to reduce tensions in Alexa's science teacher identity. As a new teacher, Alexa struggles to teach the way she wants. This is primarily caused by limitations imposed by her district, colleagues, and later the online teaching environment. Productive friction resolved through resistance allows Alexa to push back against prescriptive and un-engaging curriculum by taking space where it is not given. Productive friction through exploration allows Alexa to adjust identity components, such as hesitancy to have students work on computers (beliefs), to make her science teacher identity function in a new context. Table 11 displays a summary table of Alexa's identity components related to the challenge of teaching the way she wants.

**Table 11**

*Summary of Alexa's Identity Components Related to the Challenge Teaching the Way She Wants*

| Challenge | Teaching the way I want to |
|---|---|
| Identity Component | |
| Ontological and Epistemological Beliefs | District curriculum is not high-quality science instruction<br>Colleagues are hesitant to change<br>Science class should be fun and relevant<br>Student ideas are resources for learning<br>Teachers should let students explore before explaining<br>Teachers should use assessment data to inform instruction<br>Technology can be used to improve lessons<br>The pandemic will have a lasting effect on the way we teach |
| Purpose and Goals | Keep students engaged<br>Make science accessible to students<br>Create a comfortable and safe learning environment<br>Promote discourse and create engaging lessons online<br>Be fair and equitable |
| Self-Perceptions and Definitions | Responsive, reformed teacher<br>Newcomer → Expert teacher<br>Former middle school science student<br>Cohort of one |
| Perceived Action Possibilities | Spinning - Small adjustments to existing lessons<br>Fixing - Large adjustments to existing lessons or adding completely new lessons or building on previous spinning |
| Productive Friction | Resists prescriptive and un-engaging curriculum by creating space where it is not given<br>Explores new options to enact her science teacher identity when the pandemic imposes quick and drastic contextual changes |

**Discussion**

Ward and colleagues (2011) describe two drivers of productive feedback identified in their study: (a) feedback, constructive criticism and advice from mentors, course instructors, and supervisors, and (b) pushback, a challenge to one's actions or understanding. In this work, I extend the framework past student teaching and into in-service teaching. Additionally, instead of focusing on the boundaries of social worlds I look at the components of Alexa's science teacher identity through the DSMRI. I make this change because Alexa's science teacher identity is carried with her from context to context and is shaped by the social worlds she inhabits. The DSMRI addresses the importance of context and how a dynamic identity shapes (through actions and perceived action possibilities) and is shaped by (through beliefs, self-perceptions, and goals) the social worlds we navigate. When there is conflict between the components of teacher role identity, such as a teacher who views themselves as a social agent (self-perceptions) being required to use a whitewashed curriculum (perceived action possibilities), tensions, or frictions, will occur at the overlap of those identity constructs. Kaplan and Garner (2019) suggest, "When role identities are in tension, the teacher is likely to experience professional dilemmas, and diminished motivation." Lastly, I focus on Alexa's identity development rather than her use of high leverage practices, Ward and colleagues' (2011) focus. I consider our aims to be rather aligned, however. Ward and colleagues (2011) are focused on how PSTs *learn* high leverage practices and I consider teacher identity a powerful lens to study teacher *learning* and development (Avraamidou, 2014). In the remainder of this discussion, I will build on Ward, and colleagues' (2011) definition of productive friction and explore (a) productive friction through resistance, (b) productive friction through exploration, and (c) productive friction without reconciliation, within Alexa's developing science teacher identity.

Alexa experiences productive friction through resistance throughout her early career. First, Alexa experiences friction around her aim to provide students with NGSS-aligned instruction (goals). Although she initially believes her mentor shares this goal, Mrs. Grant later clearly shelves reformed practices in favor of direct instruction. Alexa continues to try to incorporate NGSS-aligned instruction into her lessons, but without feedback on how to do so from Mrs. Grant she struggles to improve. Ward, and colleagues (2011) argue, "Lack of friction, when there is permission without critique or pushback, can fail to challenge novices' naïve conceptions and simplified practice" (p. 19). However, although Mrs. Grant creates space for Alexa to try NGSS-aligned instruction without related feedback, Alexa resists taking up Mrs. Grant's simplified practices.

Alexa experiences productive friction through resistance by using Mrs. Grant as a non-example of good teaching to strengthen commitment to related identity components (e.g., fostering curiosity (goal), science should be fun (belief), etc.) because she sees the effects of instruction that is not aligned NGSS. Without considering her identity, it is unclear why Alexa so strongly favored reformed teaching practices over the teaching practices of her mentor; and not only did she have a preference, but she also actively worked against Mrs. Grant's teaching by choosing to implement her own lessons, activities, and norms. It would have been simpler for Alexa to take up Mrs. Grant's practices, but instead she was openly resistant to Mrs. Grant's methods because it did not align with her developing science teacher identity. However, Alexa does later describe how she feels she would have been better served by a mentor who provided her with feedback on NGSS-aligned instruction.

Second, Alexa also experiences friction through resistance when she counters Mrs. Grant's pushback on her belief that *science* and *school science* are different. When Mrs. Grant presses on the idea that students can use their prior knowledge and experiences as evidence, Alexa considers her point of view but maintains her initial stance. Encouraging students to use prior knowledge and experiences as evidence aligns with many of Alexa's identity components (e.g., making students feel valued (belief), science is all around us (belief), facilitating sensemaking (goal), etc.). Therefore, when Mrs. Grant pushes back on the idea that students are accountable to different science rules in the classroom, Alexa weighs a 'pure' notion of science against her other beliefs and is firm that students can use prior knowledge and experiences as evidence. In this example, Alexa resists Mrs. Grant's pushback to reaffirm other identity components.

Third, Alexa experiences productive friction through resistance when she resists prescriptive and un-engaging curriculum by creating space where it is not given. Alexa is required to teach using the same curriculum as her sixth-grade team colleagues that is not aligned with her science teacher identity. She is further constrained because those colleagues are hesitant to change the curriculum. Eventually, this friction drives a change in Alexa's science teacher identity regarding her perceived action possibilities. Alexa is generally a rule follower. But prolonged teaching (action) in ways that did not align with her identity components (e.g., keep students engaged (goal), science class should be fun (belief), student ideas are resources for learning (belief), etc.) drives Alexa to begin to disregard the district and her science content specialist's expectations to teach what her colleagues teach. She first resists in small ways, *spinning*, and later in more drastic ways, *fixing* because she reconsiders her limited perceived action possibilities and expands them even though the underlying constraint has not changed.

Alexa also experiences productive friction through exploration. When the pandemic imposes quick and drastic contextual changes, she explores new options to enact her science teacher identity. Although Alexa has taken up spinning and fixing as a way to expand her perceived action possibilities, she faces uncertainty in providing students with instruction that is aligned with her science teacher identity in a digital environment. Veteran and novices alike were unprepared for online instruction during the pandemic and therefore novices could not lean on their more experienced colleagues for support (Weinburgh, 2022). So, instead Alexa goes "foraging" on the internet. For example, when she cannot hold discussions because few students will unmute themselves she finds Nearpod © widgets that let students share their ideas with their peers non-verbally. In this way, she maintains some identity components (e.g., students' ideas are resources for learning (belief)) and adjusts others (e.g., re-envisioning classroom discussions to be written instead of verbal (goals)). By using exploration as an avenue to reduce friction in her online teaching, Alexa productively realigns her science teacher identity to a new context.

Additionally, Alexa experiences productive friction without reconciliation. Ward and colleagues (2011) argue "friction is productive when it occurs at the boundary of social worlds and when resources are available to help novices reconcile the values and practices of those worlds." But in Alexa's case, she is able to make frictions productive to increase harmony in her own science teacher identity without available resources nor reconciliation. For example, during her internship she states she would have preferred a mentor who modeled and offered feedback on NGSS-aligned instruction. Although she lacks those resources, she makes the experience productive by using Mrs. Grant's teaching as a non-example to strengthen and reaffirm her science teacher identity because she sees the effects of NGSS-unaligned instruction. Additionally, at PMS Alexa makes space for herself to teach in ways aligned with her science teacher identity by disregarding district and school rules about the ways she must teach. She does not find ways to adjust her beliefs and goals to be more compatible with the prescriptive curriculum (reconciliation), but instead forges new perceived action possibilities by breaking the mold (resistance).

Productive friction created opportunities to change, deepen, and harmonize Alexa's science teacher identity. However, it is not definite that friction will be productive. Friction can also drive ECSTs out of the profession or initiate negative change. Saka and colleagues (2013) outline the experience of Nathan, and ECST, as he navigates the tensions in his first year of teaching. Nathan had strong tensions with his administration and did not feel like a member of his school community. The tensions he experienced in his self-perception leaked into other areas of his practice as his motivation decreased. His instruction shifted to be teacher-driven. His learning environment became unproductive as classroom management broke down. His equitable teaching began to deteriorate as he began to feel his students were not capable of appropriate behavior and thus could not be challenged with high cognitive demand tasks. Eventually, Nathan moved to a new district in a different state. Although both Alexa and Nathan experienced pronounced tensions, they had very different reactions. Additionally, if the teacher does not experience an event or series of events as a tension then no opportunity change is created. For example, Cohen (1990) describes the case of Mrs. Oublier, a math teacher committed to reformed instruction. However, observations of Mrs. Oublier's teaching reveals she is using new, reformed materials in old, traditional ways. Cohen identifies tensions between the envisioned and enacted curriculum, but Mrs. Oublier does not. Because Mrs. Oublier does not feel the tension between the envisioned and enacted curriculum, there is no drive to reduce the friction nor adjust teaching practice. Because of the great effect tensions play on ECSTs practice, teacher educators and systems of support should take notice of if, how, and when frictions are playing out productively.

# Chapter 7: Conclusion and Implications

In this dissertation, I offer insight into the challenges ECSTs face and how those challenges affect ECSTs work, identity and experiences. This research is grounded in the notion that challenges, tensions, or frictions are not inherently negative and should be reconsidered in teacher education research (Zeichner, 2010). In the remainder of this final chapter, I provide a summary of my research. Next, I explore implications of the findings of this study for teacher education researchers and teacher educators. Third, I outline limitations of the study. Lastly, I describe possible directions for future research on the challenges and identities of early career teachers.

**Summary of Research**

In Chapter 2, I presented a systematic literature review to address the question: *What challenges do ECSTs face while navigating their first years of teaching?* I conducted a search in nine prominent educational research journals and the ERIC database for articles focused on US secondary ECSTs. The search resulted in 128 peer-reviewed research articles included in the review. I read each selected paper, summarized key findings, and used constant comparative analysis to identify the challenges ECSTs faced during their first years. I identified five overarching themes: (a) instruction and learning environments, (b) equitable and justice-oriented teaching, (c) joining the science teacher community, (d) developing as a professional, and (e) science content and disciplinary practices. Challenges related to instruction and learning environments included pedagogical content knowledge, reformed and inquiry teaching, attending and responding to student thinking, assessment, classroom environments, technology integration, reading and writing in science, and larger school structures. ECSTs struggled to enact equitable and justice-oriented teaching regarding culturally relevant instruction, teaching specific groups of learners, and social justice. As ECSTs joined the science teacher community they were challenged in regard to issues related to entering the profession and their professional identities and some were challenged with experiences as career changers and with out-of-field teaching. While developing as professionals, ECSTs grappled to learn with and from others and learn with technology. Challenges associated with science content and disciplinary practices included subject matter knowledge, nature of science, and teaching controversial topics. After illustrating the selected literature in the above themes, I discussed areas of support for ECSTs and recommendations for future research.

In order to answer my remaining research questions, I conducted a qualitative, longitudinal, embedded case study of an ECST, Alexa. Over four years, the Negotiating the Transition team and I conducted interviews, observations, and collected artifacts of early career middle school math and science teachers. This dissertation focuses on one participant of the larger study, Alexa, across three contexts: State University, Bumblebee Middle School, and Panda Middle School. Analysis of the data to answer research questions #2, #3, and #4 is described below. Attention to issues to validity and trustworthiness included member-checking, triangulation, long-term observation, multiple sources of evidence, and peer examination (Lincoln & Guba, 1985; Merriam, 1988; Stake, 1995; Yin, 2017).

In Chapter 4, I responded to the question: *What challenges does Alexa face as an ECST?* Building on the systematic review conducted in Chapter 2, I coded data for *a priori* themes drawn from the review and organized the findings into nine salient challenges Alexa faced as an ECST: (a) managing student behaviors, (b) working on a team, (c) leading classroom discussions, (d) adjusting due to COVID-19, (e) teaching specific groups of learners, (f) feeling like a newcomer, (g) working with colleagues, (h) working with a mentor, and (i) understanding argument (Table 3). In some areas the challenges Alexa faced line up with the systematic review presented in Chapter 2, such as teaching specific groups of learners. But, other experiences were more novel, such as understanding argument. The challenges catalogued in this chapter are referenced again in Chapters 5 and 6.

In Chapter 5, I explored the question: *How did Alexa's science teacher identity develop over time?* Using the DSMRI framework, I analyzed data using *a priori* codes adapted from Kaplan and Garner's (2017a) *DSMRI Analysis Guide and Codebook (*Table 4). I organized findings by DSMRI identity component (i.e., beliefs, goals, self-perceptions, perceived action possibilities), then into three eras of Alexa's early teaching career: pre-service, first-year in-service, and second- and third-years in-service. The analysis offers a deep, ethnographic understanding of Alexa's science teacher identity that at times was incredibly stable and others profoundly challenged by colleagues and contexts. Alexa's science teacher identity development catalogued in this chapter is referenced again in Chapter 6.

In Chapter 6, I considered the question: *In what ways do challenges shape Alexa's science teacher identity?* The developers of the DSMRI call for longitudinal cases to "characterize the structural and process characteristics of complex dynamic systems that may best capture diverse identity phenomena" (Kaplan & Garner, 2017b, p. 2047). I answer this call by using what I found in Chapters 2, 4, and 5 to explore how the process of productive friction (Hagel & Brown, 2005a) worked to shape Alexa's science teacher identity. Previous work suggests that productive friction can improve novices' practice through processes of feedback and pushback leading to reconciliation (Ward et al., 2011). Although Ward and colleagues (2011) explore change by looking at novices' practices, I find their analysis lines up well with my use of the DSMRI. This is because teaching practices can be considered the actions driven by beliefs, goals, self-perceptions, and perceived action possibilities described within the DSMRI. Through analysis of Alexa's case, I recommend expanding our understanding to also include ways learning processes involving productive friction work to shape identity through resistance and exploration, as well as ways in which productive friction does not lead to reconciliation. Because of the great effect tensions play on ECSTs' practice, teacher educators and systems of support should take notice of if, how, and when frictions are playing out productively.

## Implications

### *Implications for Teacher Educators*

This dissertation explores the challenges ECSTs face and how science teacher identity develops in the context of those challenges. The systematic review in Chapter 2 offers teacher educators a broad understanding of the contemporary challenges faced by ECSTs. Teacher educators should consider these challenges when designing learning experiences for ECSTs. Turnover is especially prevalent among beginning science teachers with 18% of new science teachers leaving the profession after only one year (Ingersoll et al., 2014). To better prepare science teachers, and hopefully reduce attrition, teacher educators should develop programs of study with the challenges of the field at the forefront of mind. Additionally, teaching practice is inherently uncertain, and tensions are endemic to the profession (Ball, 1993). Teacher educators should incorporate strategies of dealing with challenges that ECSTs can carry into their future practice. For example, Braaten and colleagues (2022) orchestrated a Critical Friends Group protocol where ECSTs transformed dissonance between preparation and practice into opportunities to learn with and from one another. The systematic review also contains additional articles that illustrate ways teacher educators have endeavored to prepare ECSTs for challenges that other teacher educators may find useful.

The case study presented in this dissertation explores the challenges and identity of an ECST, Alexa, including her time in a teacher education program. ECSTs do not enter teacher education programs as blank slates waiting to be filled with knowledge. ECSTs' experiences shape how they view teaching and learning (e.g., Lortie, 1977). Their identities coexist and conflict with teacher education programs and eventual teaching experiences. Luehmann (2007) argues:

> "Becoming a science teacher who values and engages in reform-based practices involves much more than acquiring a new set of knowledge and skills, and that this process could be better understood and supported once we think of it as developing a new professional identity" (p.823)

I wholeheartedly agree identity is an effective lens to understand teacher learning. Teacher educators should take advantage of on the growing literature on ECSTs' identity (e.g., Chung-Parsons & Bailey, 2019; Helms, 1998; Luehmann, 2007; Sachs, 2005) to inform effective practices in science teacher preparation and leverage ECSTs identities as opportunities for learning. ECSTs need time and space to harmonize elements of their emergent teacher professional identities effectively during a rapid introduction to world of science teaching.

Productive friction suggests tensions at boundaries can foster growth and learning. In their work, Ward and colleagues (2011) demonstrate how feedback and pushback can result in productive friction which helps ECSTs rethink naïve conceptions of teaching in favor of reformed practices. My work expands the understanding of productive friction to illustrate how productive friction can initiate positive change through resistance or exploration, or remain unreconciled. Teacher educators should rethink how we consider and attend to the challenges, frictions, and or tensions our ECSTs face (Hebard, 2016; McNally et al., 2008; Zeichner, 2010) and how we can transform them into opportunities for development. Additionally, we should explore how to better train and prepare mentor teachers so they can support PST identity development.

***Implications for Education Researchers***

The systematic review in Chapter 2 of this dissertation offers education researchers a wealth of information on the state of the field regarding the challenges ECSTs face. Additionally, it sheds light on areas that are under- and over-represented in the literature. First, studies of PSTs widely outnumbered studies of new in-service teachers. Although understanding how teacher educators train and support future science teachers during pre-service years is important, we would be remiss to fail to monitor the results of our efforts in those teachers' first years in the classroom. In-service teachers in their first years of teaching are different than pre-service and more veteran peers and deserve the attention of researchers. Second, the studies of in-service teachers first-year teachers heavily outweigh studies of second- through fifth-year teachers combined. Beginning teachers continue to have high rates of attrition with nearly 45% of new teachers leaving the profession in the first five years (Ingersoll et al., 2018, p. 20) and should be the focus of research efforts. Third, few studies identified participants with alternative or missing certifications. The National Survey of Science and Mathematics Education found 15% of middle school and 26% percent of high school studies were alternatively certified and 10% and 17% had no teaching credentials respectively (Trygstad, 2020, p. 19). This is not an insignificant portion of the overall ECST population and should have an adequate focus of research efforts. Lastly, there was a surprising lack of studies with participants identified as middle school teachers. Middle school is a time of exceptional cognitive, physical, and behavioral development for students (Association for Middle Level Education, 2024) and as such the challenges and experiences of middle school teachers is different than their high school peers and should be addressed in the literature.

Chapters 4, 5, and 6 employ little used theoretical frameworks, the DSMRI (Kaplan & Garner, 2018) and productive friction (Hagel & Brown, 2005a), to explore an ECST's challenges and identity development. Avraamidou (2014) calls for research on science teacher identity to address "(a) studying teacher identity as a process; (b) connecting science teacher identity research and reform recommendations, (c) conducting…longitudinal…studies, and (d) examining teacher identity enactment in school classrooms." This dissertation addresses the above recommendations and offers insight into how the DSMRI and productive friction can be used as an effective framework for understanding science teacher identity and identity development.

**Limitations**

This case study of Alexa's experiences and identity is limited in several ways. First, as a single case, it should not be considered universal or typical. Using the same methods and frameworks, the study of a different ECST, even one from the same cohort, may have offered different findings and drawn a different set of conclusions. Second, the Negotiating the Transition project was focused on how ECSTs translate responsive teaching practices from pre-service to in-service. As such, my investigation of challenges and identity was not initially a consideration in study design. Lastly, for one and a half years of this study Alexa and her students were stuck in the atypical environment of a global pandemic. This required adjustments to data collection and Alexa became the sole collector of any observation data of herself or her students. Using a participant as a data collection tool has limitations, but at the time it was the only available avenue.

There are elements of Alexa's developing science teacher identity that are lightly explored in this dissertation. For example, in Chapter 4 while discussing the challenges Alexa faces regarding equitable teaching, I acknowledge that she does not reference a social justice orientation or how her instruction can affect communities outside of her classroom. From the available data, it is unclear if she truly does not consider social justice as part of her practice or if it simply did not come up because our research design did not ask specific questions about her justice orientation. Additionally, we cannot discern the efficacy of Alexa's instruction because the districts in which this research occurred would not permit researchers to collect any student data. We similarly did not have access to Alexa's colleagues at PMS to gather their side of the story and as such Pam, Eric, Felicity, and Dave are all drawn from Alexa's point of view. We did have limited data from Mrs. Grant, as she was present and an active participant in the classroom during the observations of Alexa's internship and thus, I was able to illustrate a more robust portrayal of her.

## Directions for Future Research

To continue my understanding of ECSTs' challenges and identities, I would like to complete more rich case studies to further build on this dissertation. The analysis in this built up to an investigation of ways productive friction operated through a process through by Alexa harmonized components of her science teacher identity. I am interested to further dig into the structure and processes described in the DSMRI. In this dissertation, I did not pay particular focus to constructs of structure, emotion, or how the identity is embedded within dispositions, social context, domain, and culture as described by Garner and Kaplan (2018). I think it would be particularly interesting to focus on the structure, or harmony, between identity components. I considered including an analysis of the structure of Alexa's identity to map the alignment and misalignment of her identity (e.g., beliefs vs. purpose) in this dissertation, but with deadlines bearing down cooler heads prevailed. Additionally, I have been interested in the significance of affect and emotion regarding science teaching and learning since working with Lama at FSU. I think considering the role of affect, or epistemic affect (Jaber & Hammer, 2016), in identity development could yield an interesting line of research.

In the Negotiating the Transition Project, we had two wonderful participants, Alexa and Tina, who were willing and able to continue with our research project during a time of great uncertainty in their lives (all our lives?). I am interested in digging into their pandemic experiences and drawing out an understanding of how the pair continued to provide (or at least really tried to provide) students responsive, reformed instruction. I was surprised when I finished the selection process for the systematic review that only one article (Weinburgh, 2022) focused on how ECSTs, particularly a PST to first-year teacher, handled the pandemic. Additionally, it would be nice to reconnect with the pair to see how they are faring in their now **SIXTH** year in the classroom (Geez! Does time fly or what). Alexa is now a team leader at her school, and it would be interesting to check in on how her identity has continued to develop, particularly around her new role.

When I initially proposed this dissertation, I suggested completing a complementary constructivist grounded theory (CGT, Charmaz, 2008, 2014, 2015) study that would complement the case presented in this dissertation. I do still think the study could yield an interesting line of research and am excited that the time I spent pouring over grounded theory literature is of use to this dissertation. CGT methods provide a framework for analyzing the actions and meaning of participants without being overly influenced by existing theory and others' data. This is important because of the perceived disconnect between the academy of teacher education, research, and the lived experiences of ECSTs (e.g., two-worlds pitfall, Feiman-Nemser & Buchmann, 1985). This approach is novel because otherwise, as a teacher educator inhabiting one world, I would be constrained from seeing *other worlds* and their involvement in the challenges of ECSTs. In doing so, CGT avoids attempting to force round data into a square theoretical understanding. By grounding analysis of ECSTs challenges in the data, I could illuminate ECSTs actions and decision-making processes.

# Appendix A

## Systematic Literature Review Summary Tables and Figures

**Table 12**

*Systematic Literature Review Summary Table*

| Article | *n* (Participants) | Years of Experience During Study | Grade Band | Primary Theme | Related Theme(s) |
|---|---|---|---|---|---|
| (Bell et al., 2013) | 26 | P | SEC | 1 | |
| (Binns & Popp, 2013) | 7 | P | SEC | 1 | 3, 4 |
| (P. Brown et al., 2013) | 4 | P | HS | 1 | 3, 4 |
| (Doney, 2013) | 4 | 1 | HS | 3 | 1 |
| (Kang et al., 2013) | 8 | P | SEC | 3 | |
| (Lyon, 2013a) | 11 | P | SEC | 1 | 4 |
| (Lyon, 2013b) | 11 | P | SEC | 1 | 4 |
| (Maeng et al., 2013) | 27 | P | SEC | 1 | 4 |
| (Maulucci, 2013) | 1 | P | HS | 2 | 4 |
| (Ortega et al., 2013) | 1 | 1-3 | SEC | 2 | 1, 4 |
| (Ozcelik & McDonald, 2013) | 7 | P | SEC | 1 | 4 |
| (Ozel & Luft, 2013) | 44 | 1 | SEC | 1 | 3 |
| (Pytash, 2013) | 5 | P | SEC | 1 | 4 |
| (Robertshaw & Campbell, 2013) | 7 | P | SEC | 5 | 4 |
| (Roychoudhury & Rice, 2013) | 39 | P | SEC | 3 | 1 |
| (Saka et al., 2013) | 1 | 1-2 | HS | 3 | 1, 4 |
| (Snyder et al., 2013) | 4 | P-2 | SEC | 3 | |
| (Talanquer et al., 2013) | 43 | P | SEC | 1 | 4 |
| (Thompson et al., 2013) | 26 | P-1 | SEC | 1 | 4 |
| (S. S. Wong et al., 2013) | 61 | P/1-5 | SEC | 1 | 4 |
| (Balgopal, 2014) | 6 | P | SEC | 5 | 3 |
| (Bang & Luft, 2014) | 2 | 1 | HS | 4 | 1 |

| Article | *n* (Participants) | Years of Experience During Study | Grade Band | Primary Theme | Related Theme(s) |
|---|---|---|---|---|---|
| (Bischoff et al., 2014) | 22 | P | SEC | 2 | 4 |
| (Danielowich, 2014) | 6 | P | SEC | 4 | |
| (Dubois & Luft, 2014) | 3 | 1 | HS | 1 | 4 |
| (Habowski & Mouza, 2014) | 14 | P | HS | 1 | 4 |
| (McFadden et al., 2014) | 16 | 1, 2 | SEC | 4 | |
| (Moseley et al., 2014) | 5 | P/1 | SEC | 2 | 1, 3 |
| (M. Russell & J. A. Russell, 2014) | 35 | P | SEC | 2 | |
| (Sezen-Barrie et al., 2014) | 23 | P | SEC | 4 | |
| (Siegel, 2014) | 23 | P | SEC | 2 | 4 |
| (Stroupe, 2014) | 5 | 1 | SEC | 1 | |
| (Raven & Jurkiewicz, 2014) | 21 | P | SEC | 1 | |
| (Barnhart & van Es, 2015) | 24 | P | SEC | 1 | 4 |
| (Borgerding et al., 2015) | 3 | P | HS | 5 | 1 |
| (Britton & Tippins, 2015) | 4 | P | SEC | 3 | |
| (Cook & Dinkins, 2015) | 5 | P, P/1 | SEC | 1 | 4 |
| (Gallo-Fox & Scantlebury, 2015) | 4 | P | SEC | 4 | 1 |
| (Kang & Anderson, 2015) | 14 | P | SEC | 1 | 3 |
| (Larkin & Perry-Ryder, 2015) | 1 | P | HS | 5 | |
| (Rodriguez, 2015a) | 1 | P-2 | HS | 2 | 1, 3, 4 |
| (Sickel & Friedrichsen, 2015) | 1 | P-2 | HS | 1 | |
| (Strom, 2015) | 1 | 1 | HS | 3 | 1, 2, 4 |
| (Strom & Martin, 2015) | 1 | 1 | HS | 3 | 1, 2 |
| (R. Wagler & A. Wagler, 2015) | 204 | P | MS | 5 | |
| (Bell et al., 2016) | 70 | P | SEC | 5 | 4 |
| (E.P. Burton & S. Burton, 2016) | 7 | P | SEC | 3 | 4 |
| (Gotwals & Birmingham, 2016) | 7 | P | SEC | 1 | |
| (Nixon et al., 2016) | 6 | 1,2,3 | SEC | 5 | 3 |
| (Peters-Burton, 2016) | 10 | P | SEC | 5 | 3, 4 |
| (Stroupe, 2016) | 5 | 1 | SEC | 1 | |
| (Tolbert & Eichelberger, 2016) | 1 | P | MS | 3 | 4 |

| Article | *n* (Participants) | Years of Experience During Study | Grade Band | Primary Theme | Related Theme(s) |
|---|---|---|---|---|---|
| (Braaten & Sheth, 2017) | 1 | 4 | 7 | 2 | |
| (Cian et al., 2017) | 4 | P | HS | 1 | 3, 4 |
| (H. Kang, 2017) | 8 | P | SEC | 1 | 4 |
| (Larkin, 2017) | 33 | P | SEC | 4 | 1 |
| (Maeng, 2017) | 1 | 2 | HS | 1 | |
| (Nixon, Hill, et al., 2017) | 15 | 1 & 5 | SEC | 5 | |
| (Nixon, Luft, et al., 2017) | 74 | 1, 2, 3 | SEC | 3 | |
| (Stroupe, 2017) | 3 | 1 | SEC | 1 | |
| (Borgerding & Dagistan, 2018) | 13 | P | SEC | 5 | 4 |
| (J. C. Brown et al., 2018) | 18 | 1, 2, 3, 4, 5 | SEC | 2 | 1, 3, 4 |
| (Dotger et al., 2018) | 13 | P | SEC | 4 | |
| (French & Burrows, 2018) | 41 | P | SEC | 1 | 4 |
| (Sickel & Friedrichsen, 2018) | 3 | P-1, 1-2 | SEC | 1 | |
| (Strom et al., 2018) | 2 | 1 | HS | 1 | 2, 3, 4 |
| (Stroupe & Gotwals, 2018) | 17 | P | SEC | 4 | |
| (Titu et al., 2018) | 8 | 1, 2, 3 | SEC | 2 | 4 |
| (Wray & Richmond, 2018) | 3 | P-1 | SEC | 3 | 1, 2 |
| (Braaten, 2019) | 22 | P | SEC | 3 | 1, 2, 4 |
| (Chen et al., 2019) | 2 | 3 | MS | 1 | |
| (Chung-Parsons & Bailey, 2019) | 3 | P | SEC | 3 | |
| (Heineke et al., 2019) | 1 | P | SEC | 2 | 3 |
| (Izci & Siegel, 2019) | 1 | 2 | HS | 1 | 3 |
| (Johnson & Mawyer, 2019) | 15 | P | SEC | 4 | 1 |
| (H. Kang & Zinger, 2019) | 3 | P | SEC | 2 | 1 |
| (Kier & Chen, 2019) | 6 | P | SEC | 2 | 1, 3, 4 |
| (Kloser et al., 2019) | 8 | P | SEC | 1 | 4 |
| (Mawyer & Johnson, 2019) | 13 | P | SEC | 1 | 4 |
| (Navy et al., 2019) | 68 | 1-2, 2-3, 3-4 | SEC | 4 | |
| (Rutt & Mumba, 2019) | 11 | P | SEC | 1 | 4 |
| (Wallace, 2019) | 1 | 1 | HS | 4 | 1 |

| Article | *n* (Participants) | Years of Experience During Study | Grade Band | Primary Theme | Related Theme(s) |
|---|---|---|---|---|---|
| (J. C. Brown & Livstrom, 2020) | 17 | 1, 2, 3 | SEC | 2 | 4 |
| (Cian & Cook, 2020) | 6 | P | HS | 1 | 4 |
| (Dogan et al., 2020) | 1 | 1 | HS | 3 | |
| (Marco-Bujosa et al., 2020) | 4 | P-1[33] | SEC | 2 | 1, 4 |
| (Mark et al., 2020) | 5 | P | HS | 2 | 1, 3, 4 |
| (Meier et al., 2020) | 7 | P | SEC | 1 | 3, 4 |
| (Napier et al., 2020) | 17 | 1-3 | SEC | 3 | 1 |
| (Navy et al., 2020) | 15 | P, 1, 2, 3 | SEC | 1 | 3 |
| (Rogers & Brooms, 2020) | 2 | 1, 3 | HS | 2 | |
| (Rutt & Mumba, 2020) | 11 | P | SEC | 2 | 4 |
| (Whittington & Tekkumru-Kisa, 2020) | 7 | P | SEC | 1 | 4 |
| (Aminger et al., 2021) | 16 | P | SEC | 1 | 4 |
| (Antink-Meyer & Aldeman, 2021) | 13 | P | SEC | 5 | |
| (Hutner et al., 2021) | 3 | P | SEC | 1 | |
| (Jaber, 2021) | 1 | P | SEC | 1 | 4 |
| (H. Kang, 2021) | 35 | P | SEC | 4 | |
| (Kilty & Burrows, 2021) | 8 | P | SEC | 1 | 4 |
| (Morales-Doyle et al., 2021) | 10 | P | SEC | 2 | 4 |
| (Navy et al., 2021) | 129 | 1-2 | SEC | 1 | 4 |
| (Norville & Park, 2021) | 2 | P | SEC | 1 | 3, 4 |
| (Smetana & Kushki, 2021) | 2 | P | HS | 3 | |
| (Stepp & Brown, 2021) | 19 | 1, 2, 3 | SEC | 2 | |
| (Windschitl, Lohwasser, & Tasker, 2021) | 65 | P | SEC | 4 | 1 |
| (Windschitl, Lohwasser, Tasker, et al., 2021) | 65 | P | SEC | 3 | 1, 2, 4 |
| (Braaten et al., 2022) | 14 | P | SEC | 4 | 1, 3 |
| (Chakrin & Campbell, 2022) | 10 | P | SEC | 1 | 4 |
| (Jones & Donaldson, 2022) | 10 | P | SEC | 2 | 4 |
| (Luft et al., 2022) | 4 | P | SEC | 1 | 4 |
| (Navy, Jurkiewicz, et al., 2022) | ≤129[34] | 1-5 | SEC | 3 | |

[33] One participant began the program with 2 years of experience putting her at P/3-4

| Article | *n* (Participants) | Years of Experience During Study | Grade Band | Primary Theme | Related Theme(s) |
|---|---|---|---|---|---|
| (Rutt & Mumba, 2022) | 3 | P | SEC | 2 | 1 |
| (Strom & Martin, 2022) | 3 | P | SEC | 3 | 1, 2, 4 |
| (Stroupe et al., 2022) | 10 | P | SEC | 1 | 4 |
| (Tekkumru-Kisa et al., 2022) | 5 | P | SEC | 1 | 4 |
| (Weinburgh, 2022) | 1 | P-1 | HS | 1 | 3, 4 |
| (Marco-Bujosa, 2023) | 1 | P-2 | SEC | 2 | 1, 3, 4 |
| (Menke et al., 2023) | 10 | 1, 2, 3, 4, 5 | SEC | 5 | |
| (Pecore et al., 2023) | 6 | P | SEC | 4 | 1 |
| (Rutt & Mumba, 2023) | 3 | P | SEC | 2 | 1, 4 |
| (Steele & Jeong, 2023) | 23 | P | SEC | 2 | |
| (Valdez & Bianchini, 2023) | 8 | P | SEC | 2 | 4 |
| (Varelas et al., 2023) | 3 | 1 | HS | 3 | 1, 2, 4 |
| (Voss et al., 2023) | 14 | P | SEC | 5 | 4 |
| (Wang & Oliver, 2023) | 5 | P | SEC | 1 | 4 |
| (Kawasaki & Chang, 2023) | 20 | 3,4,5 | SEC | 2 | |
| (Marco-Bujosa et al., 2023) | 3 | P-1 | SEC | 2 | 1, 3, 4 |
| (Tolbert et al., 2024) | 6 | P | SEC | 2 | |

Notes:

- P years of experience indicates the participants were in teacher preparation. This includes both traditional and alternative programs.
- A hyphen (-) in years of study indicates a longitudinal study that tracked participant(s) across multiple consecutive years. For example, a study investigating a teacher in their first through third years of teaching would be marked 1-3.
- A comma (,) in years of study indicates a study in which participants had varied years of experience. For example, a study in which some participants were in their first year for the length of the study and others their second year would be marked 1, 2
- A slash (/) in years of study indicates concurrent experiences. For example, a study with a participant who completed their first year of teaching during an alternative program would be marked P/1.
- An ampersand (&) in years of study indicates participants were studied in non-consecutive years. For example, a study who surveyed the same teachers in their second and fifth years of teaching would be marked 2 & 5.

[34] Some participants dropped out over the course of the longitudinal study

- SEC in grade band represents a study of secondary teacher.  This includes both studies who noted specific participants grade levels between 6 and 12, as well as studies who described the participants as secondary.
- HS in grade band represents a study of high school (9-12) teachers.
- MS in grade band represents a study of middle school (6-8) teachers.

**Figure 7**

*Representation of Journals in Systematic Review*

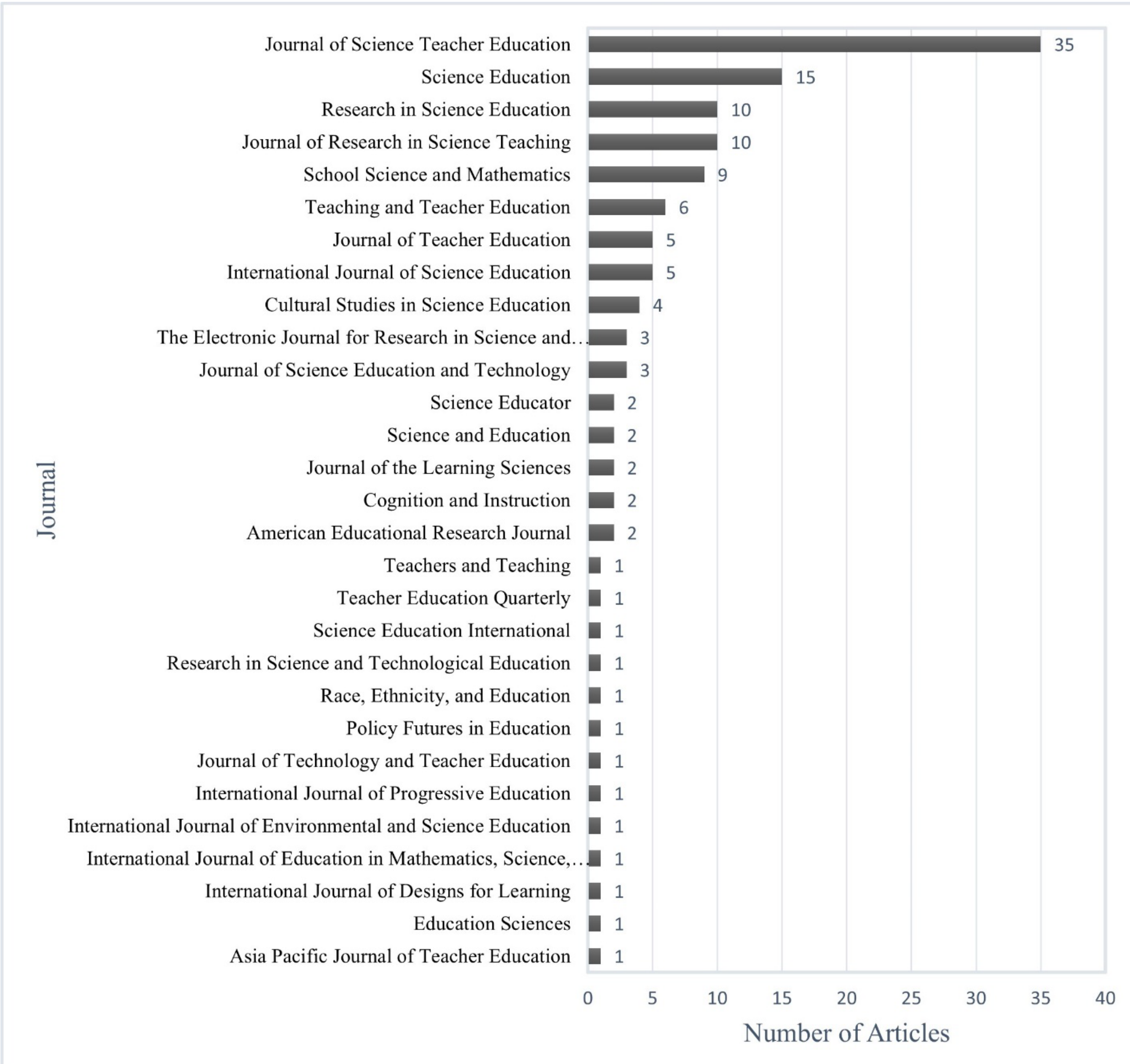

**Figure 8**

*Study Size of Selected Articles in Systematic Review*

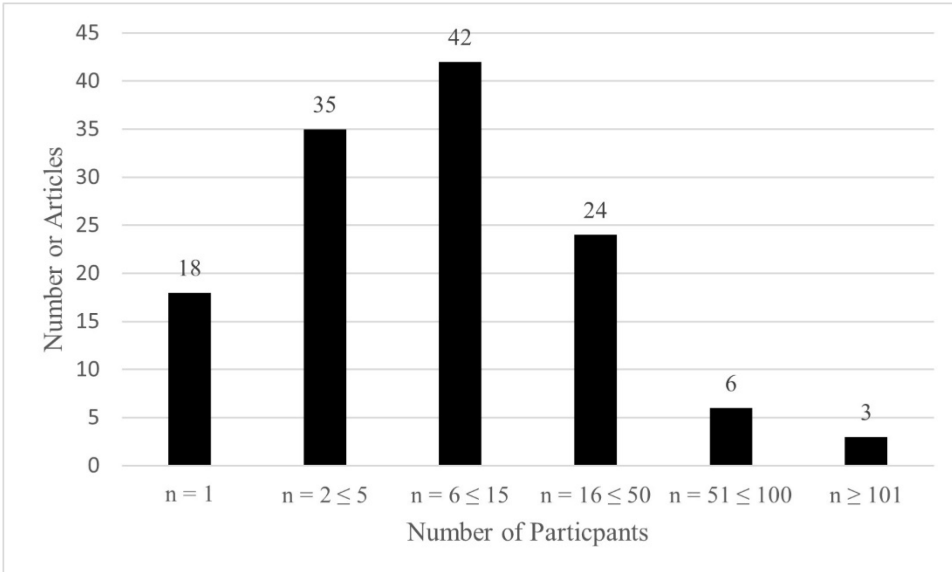


**Figure 9**

*Participant Experience in Selected Articles of Systematic Review*

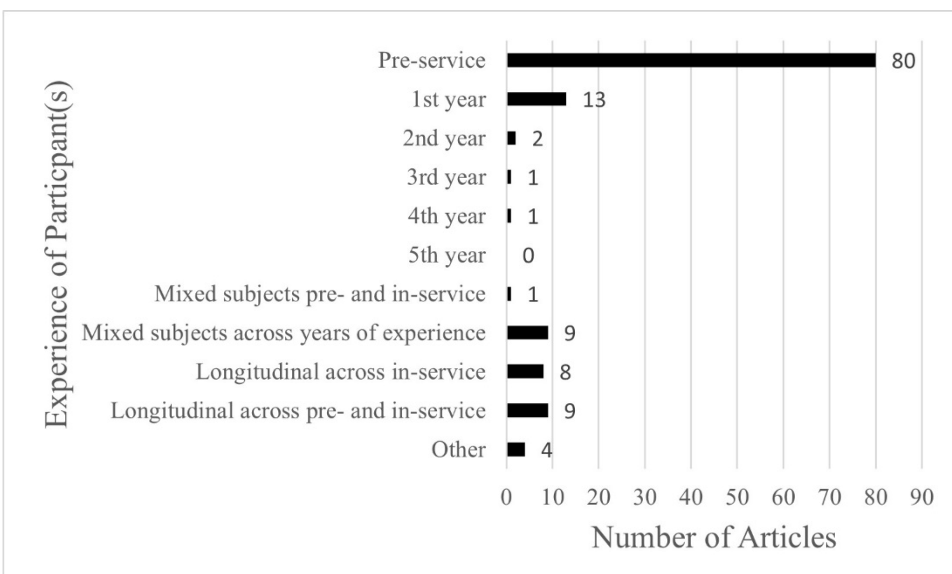

**Table 13**

*Cross Theme Comparison*

| Themes | Primary Themes | | | | | Total |
|---|---|---|---|---|---|---|
| | Theme 1 | Theme 2 | Theme 3 | Theme 4 | Theme 5 | |
| Cross-Referenced in Theme 1 | - | 13 (44) | 11 (52) | 8 (53) | 1 (8) | 33 |
| Cross-Referenced in Theme 2 | 1 (2) | - | 7 (33) | 0 (0) | 0 (0) | 8 |
| Cross-Referenced in Theme 3 | 11 (22) | 8 (28) | - | 1 (7) | 3 (23) | 23 |
| Cross-Referenced in Theme 4 | 35 (70) | 18 (62) | 8 (38) | - | 5 (38) | 55 |
| Cross-Referenced in Theme 5 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | - | 0 |
| Total Cross-Referenced Papers | 39 (78) | 23 (79) | 13 (62) | 8 (53) | 8 (62) | - |

*Note*. Percentages are listed in parentheses. Articles may be cross-referenced in multiple themes. If an article was cross-referenced in multiple subsections of a theme, it was still only tallied once for the overall theme. The right-most column represents the total number of articles cross-referenced to a theme (How many articles from other themes spread to this theme). The bottom row represents the papers in a theme cross-referenced in a different theme (How many articles referenced in this theme are from other themes). Because some articles were cross-referenced in multiple themes, the numbers are not drawn from the table to avoid double counting an article. The number of articles not cross-referenced outside of their primary theme are as follows: Theme 1 (11 articles), Theme 2 (6 articles), Theme 3 (8 articles), Theme 4 (7 articles), Theme 5 (5 articles).

# Appendix B

**Case Study Data Sources**

CO: MGSM – Class observation Middle Grades Science Methods
CO: IDM I – Class observation Interdisciplinary Methods I
CO: IDM II – Class observation Interdisciplinary Methods II
OBS - Observation
INT – Interview
J INT – Joint interview

**Table 14**

*Case study data sources*

| AY 2017-2018 | AY 2018-2019 | AY 2019-2020 | AY 2020-2021 |
|---|---|---|---|
| CO: MGSM 8/31 | INT 10/18 | J INT 10/7 | J INT 1/27 |
| CO: MGSM 9/5 | OBS 11/9 | OBS 10/18 | J INT 2/24 |
| CO: MGSM 9/7 | OBS 2/13 | OBS 10/22 | J INT 3/24 |
| CO: MGSM 9/12 | OBS 2/15 | INT 10/22 | J INT 5/12 |
| CO: MGSM 9/14 | INT 2/16 | J INT 11/4 | JOURNALS |
| CO: MGSM 9/19 | INT 5/2 | OBS 11/5 | |
| CO: IDM I 9/21 | | OBS 11/7 | |
| CO: MGSM 9/21 | | J INT 12/2 | |
| CO: MGSM 9/26 | | J INT 2/24 | |
| CO: MGSM 9/28 | | SELF CASE STUDY | |
| INT 10/2 | | EMAIL | |
| CO: MGSM 10/3 | | | |
| CO: IDM I 10/5 | | | |
| CO: MGSM 10/5 | | | |
| CO: MGSM 10/10 | | | |
| CO: MGSM 10/12 | | | |
| CO: MGSM 10/17 | | | |
| CO: IDM I 10/19 | | | |
| CO: MGSM 10/24 | | | |
| CO: IDM I 10/26 | | | |
| CO: MGSM 10/26 | | | |
| CO: MGSM 10/31 | | | |

| | |
|---|---|
| CO: MGSM | 11/2 |
| CO: MGSM | 11/14 |
| CO: IDM I | 11/16 |
| CO: MGSM | 11/16 |
| CO: MGSM | 11/21 |
| CO: IDM II | 1/30 |
| CO: IDM II | 2/7 |
| OBS | 2/13 |
| OBS | 2/14 |
| CO: IDM II | 2/14 |
| OBS | 2/15 |
| INT | 2/15 |
| CO: IDM II | 2/21 |
| OBS | 2/23 |
| OBS | 2/26 |
| OBS | 2/27 |
| INT | 2/27 |
| CO: IDM II | 3/7 |
| OBS | 3/19 |
| OBS | 3/20 |
| OBS | 3/22 |
| INT | 3/22 |
| CO: IDM II | 4/25 |
| Coursework in MGSM, IDM I, & IDM II | |

# Appendix C

**Case Study Interview Protocols**

***Baseline Interview***

What are some of the experiences that led you to teaching?

I understand that these drew you to teaching, but I also want to know how you think they have prepared you to be a teacher?

Any thoughts they would like to share about any of your education classes?

What do you feel like you need to learn to be more prepared as a science teacher?

What should be the goal of K-12 science?

What should be the goal of middle school science teaching?

Describe your ideal learning environment? What will it look like? What types of activities will the
students do?

What is your goal for your students by the end of the year?

What experiences do you have that have provided you with skills that will prepare you for the work of classroom teaching (tutoring etc.)?

***Stimulated Recall Interview***

1) I am going to start with a purposefully vague and open-ended question: Is there anything you noticed during the lessons I observed?

2) From the three lessons we recorded, were there any particularly interesting moments you would like to comment on? **Pause**(e.g., Maybe something made you excited, left you uneasy, or left you thinking well after the lesson).

3) Here is a quick clip, as you watch it please pause (tag) it anytime you see something interesting or something that you want to know more about. Then we will discuss it a little bit.

4) Here is a quick clip, as you watch it please pause (tag) it anytime you see something interesting or something that you want to know more about. Then we will discuss it a little bit.

5) **Have a conversation across videos asking PST. This will change based upon the chosen videos but will be related to responsiveness over a larger time scale and the goals of the PST.

*Possible Follow-up Questions (Anticipated/potential questions)*

Video Discussion:

a. Why did you pause the video here?

b. What stands out to you here?

c. What do you notice?

d. Can you help me understand what you might have been thinking in this moment? Why did you respond (or not respond) the way you did?

e. Optional: What is something else that you *could* have done?

**If they miss a particular moment.

I found this moment interesting, what do you notice? Does anything stand out to you? What can you tell me about student thinking? What were you thinking in this moment?

**Types of questions asked when comparing the moments**

1) Do you see these moments differently? If so, how?

2) How are these moments related?

3) What are differences and similarities in the students' thinking?

4) What claims can you make about student understanding?

5) What about students understanding do you still not know?

6) Where there any differences in the way you respond?

***Post Observation Interview***

Is there anything you noticed during the lessons I observed?

Were there any particularly interesting moments you would like to comment on?

What do you think about these (key moments selected from RTOP notes) moments?

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