# EXPLORING PRESERVICE SCIENCE TEACHERS' ELICITATIONS OF STUDENT THINKING THROUGH MICROTEACHING

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Curriculum, Instruction, and Teacher Education—Doctor of Philosophy

2020

**ABSTRACT**


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The new vision of science learning involves students figuring out how and why natural phenomena occur. Teaching to support this vision involves situating instruction in the context of a high-quality anchoring phenomenon and being responsive to students' developing ideas about how and why the phenomenon occurs. In order to be responsive to students' thinking, teachers must first elicit students' thinking. However, eliciting student' thinking can be challenging for preservice science teachers, who often have little or no prior experience learning science in ways that are in line with the new vision and have limited exposure to (and understanding of) students' alternative ways of thinking about how and why natural phenomena occur. Therefore, the purpose of this research is to explore how preservice teachers elicit student thinking about an anchoring phenomenon and how understanding of student ideas, informed by learning progressions, might support their elicitations.

We attempted to help preservice teachers learn to elicit and work with students' science ideas in a semester-long secondary science methods course at our large, midwestern university. We introduced learning progressions to provide an explicit focus on student thinking and engaged preservice teachers in rehearsals of teaching practice using the *Ambitious Science Teaching* (AST) framework. This research presents case studies of two preservice teachers engaging in cycles of planning, enacting, and reflecting on microteaching three AST-based lessons to their methods course peers. Findings indicate that both preservice teachers in this study drew on the same three characteristics to elicit student thinking. The first two characteristics are (1) ability to segment the anchoring phenomenon into distinct periods of change or action and (2) alignment between the anchoring phenomenon and the grade-level appropriate Disciplinary Core Idea(s) in the NGSS Performance Expectation. The third characteristic, "features," emerged from the two cases and are defined as substantive details that (a) illustrate changes explained by the Disciplinary Core Idea(s), (b) can be drawn from to elicit student thinking about the Disciplinary Core Idea(s), and (c) specify distinct periods of the anchoring phenomenon. Findings also indicate that both preservice teachers were attentive to student ideas from the learning progressions when planning for, eliciting student thinking during, and reflecting on their microteaching lessons. Implications of these findings for teacher education are provided.

For Kristie, Grace, and Harper.

## ACKNOWLEDGMENTS

This dissertation would not have been possible without the support of faculty advisors at Michigan State University, friends, family, and funding from the National Science Foundation. I would like to thank my advisor and dissertation chair, Dr. Alicia Alonzo, for her thoughtful guidance and continual patience over the past six years. I would also like to thank my dissertation committee, Dr. Charles (Andy) Anderson, Dr. Amelia Gotwals, and Dr. David Stroupe, for lighthearted lunch table conversations, advice, and mentorship throughout this journey. Additionally, I would like to thank my friends—Kraig Wray, May Lee, Amy Guenther, Scott Farver, Christa Haverly, and Lindsay Wexler—and my family for their unwavering support. Lastly, this dissertation is based on work supported by the National Science Foundation under Grant No. DRL-1253036. Any opinions, findings, and conclusions or recommendations expressed in this dissertation are those of the author and do not necessarily reflect the views of the National Science Foundation.

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## KEY TO ABBREVIATIONS

| | |
|---|---|
| AST | Ambitious Science Teaching |
| DCI | Disciplinary Core Idea |
| LP-C | Learning progression: Chemistry |
| LP-P | Learning progression: Physics |
| MT | Microteaching |
| NGSS | Next Generation Science Standards |
| PE | Performance Expectation |

# CHAPTER ONE: INTRODUCTION

The new vision of science learning involves students in figuring out how and why natural phenomena occur (National Research Council, 2012; Schwarz et al., 2017). Teaching to support this vision involves situating instruction in the context of a high-quality anchoring phenomenon and being responsive to students' developing ideas about how and why the phenomenon occurs (Windschitl et al., 2012, 2018). This vision of responsive science instruction is conceptualized by some researchers and teacher educators as "ambitious" science teaching (e.g., Stroupe & Gotwals, 2018), in which student thinking "plays a central role in teachers' daily work" (Stroupe & Windschitl, 2015, p. 181). Centering the substance of students' thinking involves eliciting student thinking in order to figure out what they know, so that their ideas can be leveraged as resources for future instruction. Therefore, eliciting student thinking is paramount to teaching in ways that are responsive to students' science ideas. However, this can be challenging for preservice science teachers, who often have little or no prior experience learning science in this way and limited exposure to (and understanding of) students' alternative ways of thinking about how and why natural phenomena occur. Therefore, supporting preservice science teachers' understanding of and ability to elicit student thinking about how and why natural phenomena occur is an important goal of preservice science teacher education. In a semester-long secondary science methods course at our large, midwestern university, we attempted to help preservice teachers learn to elicit and work with students' science ideas through an explicit focus on student thinking (drawing on learning progressions) alongside rehearsals of teaching practice using the *Ambitious Science Teaching* (AST) framework (Windschitl et al., 2012, 2018). This dissertation focuses on how preservice science teachers elicited student thinking about a natural phenomenon in the context of "microteaching" within this secondary science methods course.

## The New Vision of Science Learning

Learning science should be both “inspiring and meaningful” (Schwarz et al., 2017, p. 4), and teachers can support this by developing a classroom in which students engage in an “ongoing process of questioning, developing, and refining explanatory knowledge about the world” (Schwarz et al., 2017, p. 5). Teaching in this way supports students in developing a “deeper understanding of science content and an appreciation for the scientific enterprise” (Lustick, 2010, p. 508). Current visions of science learning involve students actively engaging with science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs), which is described in the *Next Generation Science Standards* (NGSS) as three-dimensional learning (NGSS Lead States, 2013). Science teaching, as enacted through this vision, involves helping students “mak[e] sense of the natural world,” which is “the fundamental goal of science and should be at the core of what happens in science classrooms” (Schwarz et al., 2017, p. 6). In this way, the purpose of science education is to help students “explain something in the real world that occurs—a phenomenon—and to *figure out* and reach consensus on how and why it works the way it does” (Reiser, Brody, Novak, Tipton, & Sutherland Adams, 2017, p. 98).

Consequently, engaging with natural phenomena represents a central component of science learning as envisioned by the NGSS (Schwarz et al., 2017). Natural phenomena are “events or processes (‘things that happen’) that are observable by the senses, or detectable by instruments” (Ambitious Science Teaching, 2014b, p. 3). Natural phenomena used to frame a unit of instruction are called anchoring phenomena. Examples of anchoring phenomena include a rising weather balloon popping at altitude (Hancock & Lee, 2018), a tanker car imploding (Tools for Ambitious Science Teaching, 2014a), or a singer shattering glass with only his voice (Tools for Ambitious Science Teaching, 2014b). Anchoring phenomena are puzzling to students (Ambitious Science Teaching, 2014); have explanations that require the synthesis of multiple NGSS performance expectations (PEs) over a series of lessons (Penuel & Bell, 2016); are rich with contextual detail; fit well to students' interests; and support multiple, compelling, lines of inquiry (Achieve et al., 2016).

In the context of a phenomenon-based framework for science instruction, the process of sense-making (Schwarz et al., 2017) in K-12 classrooms should be motivated by a driving question[1] about the anchoring phenomenon. The driving question helps focus students' attention (Erdogan & Campbell, 2008; Passmore et al., 2017), "make[s] abstract and difficult concepts more accessible" (Lustick, 2010, p. 497), and serves as the foundation for students' modeling or development of evidence-based explanations. In addition to providing an initial framing for students' thinking, the driving question serves as the basis of subsequent questions designed to elicit students' thinking and inform future instruction.

## Teaching for the New Vision of Science Learning

Teaching for the new vision for science learning is "deceptively simple" on the surface (Grossman, Hammerness, & McDonald, 2009, p. 273), yet skillfully integrating phenomena and foregrounding student thinking throughout a unit is decidedly complex work. To engage students in "figuring out" how and why natural phenomenon occur instead of simply "learning about" science, teachers need to first identify an anchoring phenomenon with which to frame a unit of instruction. Then, teachers must plan and enact instruction that is responsive to students'

[1] The language around unit-level guiding questions is inconsistent across the literature, as they are referred to as driving (Erdogan & Campbell, 2008; Passmore et al., 2017), research (Reiser, Brody, et al., 2017), focus (Lustick, 2010) or essential (Ambitious Science Teaching, 2014) questions. In this dissertation I use "driving questions" to identify unit-level guiding questions.

thinking, experiences, and needs and supports students to work collaboratively to figure out—and ultimately develop a causal explanation for—how and why the anchoring phenomenon occurs. At the core of enacting instruction that is responsive to student thinking is eliciting student thinking throughout the unit. In the sections that follow, I describe two facets of the complex work of teaching for the new vision of science learning: leveraging anchoring phenomena as contexts to support student learning and eliciting student thinking.

**Leveraging Anchoring Phenomena as Contexts to Support Student Learning**

Engaging students in figuring out how and why natural phenomena occur involves being able to identify an appropriate anchoring phenomenon. After selecting an anchoring phenomenon, a teacher needs to draw on subject matter knowledge to unpack how and why the phenomenon occurs to ensure it will allow students to engage in relevant NGSS PEs. The teacher also needs to draw on pedagogical content knowledge ([PCK]; Ball, Thames, & Phelps, 2008; Shulman, 1986) to think through how their students might reason about how and why the phenomenon occurs in order to inform a preliminary trajectory for the unit.

Throughout the unit teachers need to elicit their students' thinking about how and why the phenomenon occurs (Larkin, 2017); make sense of the ideas underlying students' thinking (Sherin & van Es, 2005); and plan future instruction based, in part, on those ideas (Coffey et al., 2011). This type of teaching is considered to be *responsive* in that it attends to the "substance of student thinking" (Hammer, Goldberg, & Fargason, 2012, p. 55) as integral to what it means to support students in figuring out the anchoring phenomenon. Eliciting student thinking is necessary to enacting instruction that is responsive to student thinking, and thus to enacting teaching that is in line with the new vision of science learning.

## Eliciting Student Thinking

Eliciting student thinking in the context of phenomena-based science instruction is the process by which teachers identify students' understandings of an anchoring phenomenon in order to ultimately "analyze students' ways of engaging with that puzzle to adapt upcoming instruction" (Windschitl et al., 2012, p. 889). Eliciting student thinking involves anticipating student responses, providing opportunities for students to share their developing thinking, and noticing student thinking about how and why the anchoring phenomenon occurs.

Anticipating student responses, as conceptualized in mathematics and science education research (e.g., Cartier, Smith, Stein, & Ross, 2013), involves anticipating how a range of students' science ideas will interact with characteristics of the phenomenon they attend to. Anticipating student responses in advance of eliciting their students' thinking may help reduce the improvisation required to clarify and respond to students' ideas in the moment (Smith et al., 2009).

Providing opportunities for students to share their developing thinking involves planning and launching elicitation tasks designed to encourage students' sensemaking. In the context of phenomena-based science instruction, teachers can elicit students' initial observations of an anchoring phenomenon; the mechanisms students use to explain how and why the phenomenon happens, both initially and as their ideas develop throughout a unit; and the language students use to express their ideas.

Responsive teaching involves building on students' underlying ideas as resources to inform instruction that supports ongoing changes in students' thinking (e.g., Levin, Hammer, & Coffey, 2009). In this process, teachers need to continually work to make sense of the student thinking that is shared; this work has been characterized in the literature through the framework of *noticing*. According to van Es and Sherin (2002) noticing involves "identifying what's important or noteworthy about a classroom situation," "making connections between the specifics of classroom interactions and the broader principles of teaching and learning they represent," and "using what one knows about the context to reason about classroom interactions" (p. 573).

In order to teach in ways that are responsive to student thinking (i.e., noticing and making instructional decisions based on the substance of student thinking), teachers must continually work to elicit student thinking throughout a unit of instruction. Therefore, eliciting student thinking serves as a key practice for teaching in ways that are in line with the new vision for science learning and represents an important focus for preservice teachers learning to teach in these ways.

## Supporting Preservice Teachers in Learning to Elicit Student Thinking

Teaching in ways that are in line with the new vision of science learning can be difficult to enact, particularly for preservice teachers. One way to support preservice teachers in learning to enact ambitious instruction is to focus on high-leverage or core teaching practices within practice-based methods courses. Eliciting is considered to be one of the core practices of teaching, which "are limited in number and represent broadly applicable instructional strategies known to foster important kinds of student engagement and learning" (Windschitl et al., 2012, p. 879). Such practices are the "activities of teaching that are essential to the work" (Ball et al., 2009, pp. 460-461) and are attainable by preservice teachers (Grossman, Hammerness, et al., 2009). Methods courses are considered to be practice-based if they focus on supporting preservice teachers in learning to enact high-leverage (or core) practices (Zeichner, 2012).

Within such a methods course, preservice teachers can engage in approximations of practice to rehearse the work of teaching in a simplified context (Grossman, 2011; Grossman, Compton, et al., 2009).

Eliciting student thinking requires teachers to know something about how students think about how and why a phenomenon occurs. Learning progressions explicitly represent trends in how students' ideas about a topic increase in sophistication from novice to more canonically correct (Gotwals & Alonzo, 2012; National Research Council, 2007; Shavelson & Kurpius, 2012) and may serve as one tool to support teachers in understanding students' thinking about phenomena. Learning progressions are typically "bordered on one end by naïve ideas about the natural world…and on the other end scientifically accepted explanations. The middle is occupied by intermediate understandings" (Furtak, 2009, p. 3). These intermediate understandings, or the "messy middle" (Gotwals & Songer, 2010, p. 277), are aspects of students' understandings that build on prior experience-based or formal classroom knowledge but are not yet considered "correct." While much of the current research on learning progressions is with in-service teachers (e.g., Covitt, Gunckel, Caplan, & Syswerda, 2018; Furtak, 2012; Furtak, Circi, & Heredia, 2018), research suggests that learning progressions may also support preservice teachers' understanding of student ideas.

Research on practice-based teacher education acknowledges the role of knowledge in high-leverage practices. However, research on practice-based teacher education has not focused on how to support preservice teachers to develop and integrate the knowledge that is "entailed by the work" of teaching (Ball & Forzani, 2009, p. 503) with their evolving skill in enacting practices. Additionally, while there exist numerous recommendations for what constitutes a "high-quality" anchoring phenomenon, little is known about how preservice teachers draw on particular characteristics of such phenomena when eliciting student thinking. Therefore, this dissertation research focuses on how preservice teachers, when supported by a learning progression, elicit student thinking about an anchoring phenomenon.

Participants in this study are undergraduate preservice science teachers enrolled in a year-long secondary science methods course at a large, midwestern university. Students enroll in this methods course, the first in a two-year sequence, in the year prior to their student teaching internship. During the fall semester, students learn about the AST framework (Windschitl et al., 2012, 2018) and engage in collaboratively planning, and individually "microteaching," phenomena-based mini-lessons to their methods course peers. In the fall 2017 semester, methods course instructors, researchers, and research assistants (the "LP team") further supported preservice science teachers in learning about and attending to student thinking by introducing and working with content-specific learning progressions in a series of eight work sessions. This research focuses on how a subset of these preservice teachers elicited student thinking during their microteaching lessons.

## Dissertation Overview

In the following chapters I situate this work in the context of recent research in science teacher education, I outline my research context and methods, I describe my findings, and I discuss the significance of this work.

Specifically, in chapter 2 I review the role of natural phenomena in teaching aligned with the new vision of science learning and discuss the importance of eliciting student thinking in science instruction that is responsive to students' ideas. Then, I discuss challenges preservice teachers face in eliciting student thinking: selecting a high-quality anchoring phenomenon, anticipating student responses about how and why the phenomenon occurs, designing and engaging students in productive elicitation tasks, and noticing student thinking. Next, I describe three potential supports for preservice teachers learning to teach in this way: practice-based frameworks for teaching, practice-based methods courses, and the use of content-specific learning progressions to support preservice teachers' understanding of—and ability to anticipate and elicit—students' science ideas.

In chapter 3 I describe my research methods, including the research context and participant selection criteria. I describe my coding schema and methods of individual and cross-case analysis.

In chapters 4 and 5 I present two sets of findings. I describe and summarize how two preservice teachers drew on characteristics of their anchoring phenomenon (in chapter 4) and their understanding of student ideas (in chapter 5) to elicit student thinking. I conclude each findings chapter with a cross-case analysis, in which I identify similarities and differences between the two preservice teachers.

In chapter 6 I connect findings from my two research questions to current literature and suggest practical recommendations for supporting preservice teachers in learning to elicit student thinking when enacting ambitious science instruction.

# CHAPTER TWO: LITERATURE REVIEW

The new vision of science learning necessitates a wholesale shift in what it means to teach science in K-12 classrooms. This vision explicitly positions students in the role of investigators figuring out how and why natural phenomena occur (Osborne & Quinn, 2017). One way teachers can engage students in this role is by developing a coherent unit of instruction around an anchoring phenomenon, eliciting students' preliminary and developing explanations of the phenomenon, designing and enacting instruction that is responsive to what is elicited in order to help students "figure out" the phenomenon, and ultimately supporting students in drawing on their developing understanding to construct a more nuanced and scientifically accurate explanation for the phenomenon (Windschitl et al., 2012, 2018). As such, eliciting student thinking is central to teaching in ways that are in line with this vision of science learning. Practice-based teacher education, particularly approximating the work of teaching through microteaching, is a promising approach for supporting preservice science teachers in learning to elicit student thinking. However, relatively little is known about how to support preservice teachers to draw both on particular characteristics of anchoring phenomena and on their understanding of student ideas to elicit student thinking, as the basis for phenomenon-based instruction.

In this chapter I first define and situate the role of natural phenomena in the new vision of science learning. Then, I discuss the importance of eliciting student thinking about how and why anchoring phenomena occur, as integral to responsively supporting students' learning in the context of phenomenon-based instruction. Next, I identify challenges in this work and describe approaches to meeting these challenges through teacher education. In particular, I propose the use of learning progressions as one potential tool to support preservice teachers' elicitations of student thinking in the context of microteaching in a practice-based methods course. I conclude with a description of my dissertation research, which focused on how preservice teachers, when introduced to a learning progression, elicit student thinking about an anchoring phenomenon during microteaching.

## Natural Phenomena and Their Role in the New Vision of Science Learning

Natural phenomena are “unusual event[s] or process[es] in the world” (Windschitl et al., 2018, p. 6) and are considered to be “central to what the [NGSS] practices are all about” (Schwarz et al., 2017, p. 15). Anchoring phenomena are natural phenomena that play an important role in teaching aligned with the new vision of science learning because they are rich in context, are complex, may spark students’ interest, and serve as something for students to actively engage in “figuring out” (Reiser, Brody, et al., 2017; Reiser, Novak, et al., 2017; Schwarz et al., 2017). Anchoring phenomena are leveraged in frameworks for “storylines” (Reiser et al., 2016), model-based inquiry (e.g., Reiser, Novak, et al., 2017), and AST (Windschitl et al., 2008, 2012) and in curricular programs such as *Carbon TIME* (Carbon: Transformations In Matter and Energy; Anderson et al., 2018) and, at the undergraduate level, *CLUE* (Chemistry, Life, the Universe, and Everything; Cooper & Klymkowsky, 2013).

Since anchoring phenomena serve a central role in the new vision of science learning, the choice of which phenomenon to “figure out” in a given unit is important. The choice of anchoring phenomenon and accompanying driving question(s) should be preliminarily informed by relevant DCIs, CCCs, and/or SEPs and/or other local curricular expectations and serve to frame the scope of instruction. Additional factors should also be considered when choosing an anchoring phenomenon and framing a unit of instruction through a driving question(s), and in the sections that follow I expand on both.

## Characteristics of High-Quality Anchoring Phenomena

The anchoring phenomenon sets the stage for the unit of instruction, and the literature describes recommendations for characteristics of anchoring phenomena that make them "high-quality." These characteristics can be binned into four primary groups: puzzlement, complexity, ability to segment, and comprehensibility. In the sections that follow, I describe each group.

### *Puzzlement*

An anchoring phenomenon should have an appropriately high degree of puzzlement in order to garner and sustain students' attention. This puzzlement serves to prime students to wonder about and begin developing causal explanations for how and why the phenomenon occurs (Windschitl et al., 2012, 2018), paving the way for students to engage in the unit.

### *Complexity*

A high-quality anchoring phenomenon should also be complex, such that its explanation requires the synthesis and application of multiple NGSS PEs over a series of lessons (Penuel & Bell, 2016). A complex anchoring phenomenon should include rich contextual details to help focus students' attention on a specific event, in a specific location, under specific conditions, (Ambitious Science Teaching, 2014). Likewise, a complex anchoring phenomenon should allow for the exploration of multiple, compelling lines of inquiry (Achieve et al., 2016), meaning that—within a given phenomenon, but guided by different driving questions—students could work through multiple NGSS PEs. This multiplicity has the potential to illustrate and engage students in the interconnectedness of science (e.g., the phenomenon of a tree growing can be leveraged to support students in figuring out DCIs related to carbon cycling, biodiversity, and/or heredity).

### *Ability to Segment*

An anchoring phenomenon should also be separable into observable and distinct "before, during, or after" segments that students can represent through explanatory models (Ambitious Science Teaching, 2014). These segments help students attend to changes that occur in an anchoring phenomenon over time and organize their observations about the anchoring phenomenon.

### *Comprehensibility*

A high-quality anchoring phenomenon should consist of "comprehensible causal underpinnings" (Windschitl et al., 2008, p. 956). The anchoring phenomenon should relate to students' interests; provide opportunities to build on their cultural, personal, and/or other everyday experiences; and align with grade level-appropriate NGSS PEs (Achieve et al., 2016; Penuel & Bell, 2016; Reiser, Novak, et al., 2017; Smith & Stein, 1998). Considering the fit of an anchoring phenomenon to students in a given classroom is especially important to ensure *all* students feel encouraged and able to engage in science learning (National Science Teachers Association, 2016, 2018).

## Framing a Phenomenon-Based Unit Through a Driving Question

The overarching instructional goal for phenomenon-based instruction is to support students in developing a gapless, causal explanation for how and why a high-quality anchoring phenomenon occurs. At the end of the unit, students' explanations should show evidence of improved understanding of concepts in the predetermined curricular standards (e.g., DCIs). A gapless explanation is one that weaves together multiple science ideas to fully describe *why* the event happens (Ambitious Science Teaching, 2014), and is framed by the driving question for the unit (e.g., Michaels & O'Connor, 2012). A well-crafted driving question is important because, for a rich anchoring phenomenon, "[t]here are a lot of different things one could choose to wonder about" (Reiser, Brody, et al., 2017, p. 100). In the paragraphs that follow I describe features of a well-crafted driving question designed to support students' engagement in a phenomenon-based unit.

A driving question for an anchoring phenomenon should "address a big and important idea and provide coherence in the unit" (Passmore et al., 2017, p. 133). This question should serve to "motivate, guide, and foster [students'] learning" (Lustick, 2010, p. 495); should require critical thinking; should not be answerable with a simple "yes or no" response; and should promote the development of "evidence-based causal accounts for the anchoring event" (Windschitl et al., 2018, p. 32). The driving question should be applicable to students' prior experiences, "tailored to meet the different needs and interests of a specified audience" (Lustick, 2010, p. 497), and should not be answerable via a simple Google search (Reiser, Brody, et al., 2017).

At a smaller grain size, teachers can ask pre-planned and/or spontaneous follow-up focus questions that—in concert with a unit's driving question (Michaels & O'Connor, 2012)—can help narrow students' attention on instructional objectives (Erdogan & Campbell, 2008). Such questions also help teachers to elicit their students' preliminary—and developing—thinking about how and why the phenomenon occurs. In the context of the new vision for science in schools, preparing to work with students' ideas is an important part of enacting instruction that is responsive to students (Windschitl et al., 2012, 2018).

## Eliciting Student Thinking

Teaching in ways that are in line with the new vision of science learning foregrounds student thinking about natural phenomena. In planning a unit of instruction, a teacher identifies a high-quality anchoring phenomenon, defines a driving question to frame the unit, and creates a preliminary roadmap for how to support students in figuring out how and why the phenomenon occurs. This planning process involves anticipating what students might find interesting or challenging. However, instruction should be flexible and responsive to what students *actually* know and/or wonder about the phenomenon, building on and shaping students' ideas throughout the unit (e.g., Ball & Forzani, 2011; Ball, Sleep, Boerst, & Bass, 2009). In order to have student ideas to work with, teachers must continually elicit student thinking. Eliciting student thinking involves anticipating the ways students will engage with an anchoring phenomenon, providing opportunities for students to share their developing thinking, and noticing students' science ideas to inform follow-up questions. In the sections that follow, I describe these three components of eliciting student thinking.

## Anticipating Student Responses

One way teachers prepare to elicit their students' thinking is by considering how their students will interpret and interact with the anchoring phenomenon prior to and throughout a unit of instruction. The practice of anticipating student responses (ASR) was initially conceptualized in mathematics and science education as teachers predicting how their students will interpret and respond to a given assessment, instructional task, or activity. ASR is considered to be important behind-the-scenes work for effective teaching because it can help "moderat[e] the degree of improvisation required by the teacher" during classroom instruction that is flexible and responsive to students' ideas (Cartier, Smith, Stein, & Ross, 2013, p. 28). ASR, in the context of phenomenon-based science instruction, involves teachers predicting how their students will engage with an anchoring phenomenon (in advance of and throughout a unit of instruction). Engaging in ASR about an anchoring phenomenon may encourage teachers to think critically about if and how a given phenomenon will support students' engagement in curricular goals (e.g., NGSS performance expectations), the extent to which students will find the phenomenon to be puzzling and relevant to their lives, and the range of ideas students may bring to bear when explaining how and why the phenomenon occurs. In the sections that follow, I describe the knowledge and dispositions underlying ASR, I review affordances of ASR, and I illustrate three potential ways teachers might engage in ASR in the new vision of science learning.

### *Knowledge and Dispositions Underlying ASR*

ASR can be a difficult practice, requiring a framing of students' ideas as valuable resources to inform future instruction and a robust understanding both of the content and of a multitude of ways students think about a concept. This latter domain of teacher knowledge, called PCK, was originally defined by Shulman (1986) as the "subject matter knowledge *for teaching*," including, among other things, knowledge of "the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons" (p. 9). In addition to knowledge, ASR requires the teacher to view a given task through the eyes of their students, coordinating their understanding of how students think about a concept with how students may interpret and respond to the particular task. This coordination implies flexibility in the teacher's understanding of the ways students think about a concept.

#### ***Affordances of ASR***

While some teachers implicitly engage in ASR as part of their regular teaching work (e.g., deciding on the appropriate level of difficulty when writing tasks or planning an anchoring phenomenon for a unit that will excite and engage students), researchers and teacher educators have recently made this practice more explicit because of its potential to support responsive teaching (e.g., Carpenter, Fennema, & Franke, 1996). For example, mathematics and science education researchers have foregrounded ASR to aid teachers in managing in-the-moment responses to students' ideas in discussion-based teaching (Cartier et al., 2013; Stein & Smith, 2011). These scholars posit that, after engaging in ASR, teachers are better prepared to leverage their interpretations of what students share during instruction, to monitor changes in students' thinking, and to use students' solutions and ideas about a topic to scaffold future learning.

### *ASR in the New Vision of Science Learning*

To illustrate how teachers might engage in ASR in the context of phenomenon-based science instruction, I draw on an example of an anchoring phenomenon: the Lego Man in Space YouTube video (Ho & Muhammad, 2012). In this time-lapse video, two middle school students are seen inflating a weather balloon (with helium) on an overcast late fall or early spring day. The balloon is attached to an apparatus containing a video camera facing a Lego Man who is holding a Canadian flag. The apparatus is released and rapidly gains altitude. Across the time lapse frames, the color of the sky gradually changes from blue to a mix of blue and black as the apparatus reaches the upper limits of Earth's atmosphere. The motion of the Lego Man with respect to the horizon becomes more labored and erratic as it rises through light breezes in the waning atmosphere. Suddenly, there is a pronounced popping noise, and as the camera shifts shreds of the balloon enter the frame. The Lego Man is seen falling rapidly back toward Earth as the sound of wind resistance buffets the video camera's microphone.

I see four primary ways teachers can engage in ASR in this example, and in phenomenon-based teaching more generally. First, teachers may anticipate surface-level features or mechanisms of the anchoring event that will be interesting or noteworthy to students but not immediately relevant to advancing specific content-related goals (e.g., focusing on how the Lego Man is attached to the camera or that the Lego Man is holding a flag). Second, teachers may anticipate particular clues, features, or mechanisms of the anchoring event that are interesting and relevant to advancing specific content-related goals but that students may initially not attend to and/or struggle to identify (e.g., the balloon pops at a certain point high in the atmosphere, and there are clues—sound, balloon shreds, more deliberate movements in the balloon's trajectory as evidenced by changes in shadows—that are important to notice in order to construct a gapless explanation). Third, teachers may anticipate students' understandings of relevant features of the event, which may need to be developed further (e.g., knowing that students will have an understanding of "too much pressure inside the balloon" or that "atmospheric pressure decreases as you increase in altitude" but that they may need support in coordinating these ideas when constructing an explanation for the popping of the balloon). Fourth, as the unit progresses, teachers may anticipate if and how students' developing explanations might change as a result of instruction.

### ***Summary***

The practice of ASR is often implicit in the work of teaching. In the context of phenomenon-based science teaching, one way teachers can anticipate how students will engage with the anchoring phenomenon is by drawing on their understanding of student ideas. While teachers can use this practice to prepare for instruction, enacting instruction that is responsive to students' thinking additionally involves continually figuring out what their students *actually* think about how and why the phenomenon occurs. This work involves providing opportunities for students to share their thinking, and in the section that follows, I expand on this practice.

## **Providing Opportunities for Students to Share Their Thinking**

One way teachers can provide opportunities for students to share thinking in the context of a phenomenon-based unit is through structured *elicitation tasks*. Such tasks are designed to encourage students to think about and share their initial and developing thinking about how and why the anchoring phenomenon occurs (e.g., constructing and revising initial models to explain the phenomenon; Windschitl et al., 2008, 2012, 2018). Teachers must both launch these tasks and structure opportunities for students' sensemaking.

"Launching a task" entails introducing and communicating the task to the class (Jackson et al., 2013; Kang et al., 2016). In the context of phenomenon-based science instruction, a unit typically starts with an introduction to the anchoring phenomenon. While launching the task that will elicit student thinking about the anchoring phenomenon, the teacher may highlight how it is puzzling (e.g., "I saw this on YouTube, and it made me wonder…"), outline particular goals of the task (e.g., "We're looking to figure out how this phenomenon occurs" or "Based on what you know now, I want you to further explain how…"), set expectations (e.g., "There are no incorrect answers; I just want to hear your ideas"), narrow students' attention (e.g., "Can you tell me more about what's happening at this particular point?") and/or discuss logistics (e.g., "I'd like you to work with a partner to first talk about what you noticed"). The ways the teacher launches the elicitation task impact how students engage with the task, and therefore shape what is actually elicited. For example, according to Hammer, Goldberg, and Fargason (2012), the ways the teacher launches a given task "signal[s] to students what is important and relevant," which—in the context of responsive teaching—could include students' thinking and different kinds of reasoning that they may be drawing from (e.g., cause and effect; p. 67).

After launching the task, teachers must provide opportunities for students to make sense of and share their developing understanding of how and why the anchoring phenomenon occurs. Such opportunities can be accomplished through individual (private) and partner or group (public) activities and may include writing or partner talk (as ways to help students think), as well as small group or whole-class discussions (as ways to help students share ideas). The goal of these activities is to engage students in "productive talk," which is the process by which students "explore ideas and use evidence to build and critique academic arguments" (Michaels & O'Connor, 2012, p. 1). For example, after presenting the anchoring phenomenon to the class, a teacher may ask students to first think about and write, individually, what they noticed about the phenomenon, before asking students to share and discuss their ideas with a partner or as a whole class. Later in the unit, a teacher may ask students to revise their initial explanations and may elicit students' ideas about specific connections between instructional activities and students' revised explanations for the anchoring phenomenon. In elicitation tasks such as these, there are rich opportunities for the teacher to gain an understanding of student thinking (e.g., by moving around the classroom to observe individual students' writing; by simply listening—and guiding, as necessary—the subsequent small group or whole-class discussions). When enacting elicitation tasks such as these, the teacher plays a crucial role in supporting productive talk by using "talk moves" (such as, "Can you say more about that?" or "Why do you think that? What's your evidence?) to scaffold students' engagement with these activities (Michaels & O'Connor, 2012).

Teachers can also provide opportunities for students to share their thinking by engaging students in the practice of modeling the anchoring phenomenon: "*developing* a model that embodies aspects of a theory and evidence, *evaluating* that model against empirical evidence and theory, and *revising* that model to better meet the goals of explaining and predicting" (Passmore et al., 2017, p. 117). For students, modeling is valuable because it helps them "coordinate observable features" of a given phenomenon with their hypothesis as to why "events, properties, or structures" or other unobservable features occur (Windschitl et al., 2008, p. 945). For teachers, engaging groups in developing and revising models of the anchoring phenomenon represents one way to elicit student thinking because it helps "to make ideas and contributions from students in the class public," and "provide[s] windows into students' thinking" (Passmore et al., 2017, p. 133).

**Noticing Student Thinking**

Enacting responsive instruction is more than simply providing opportunities for students to share their ideas (i.e., launching and engaging students in elicitation tasks during a unit of instruction). Rather, the process of working on and with students' ideas involves continually eliciting, making sense of, and shaping instruction based, in part, on students' developing thinking about relevant content. One way the process of making sense of student thinking has been characterized in the literature is through the framework of *noticing*. van Es and Sherin (2002) define noticing as involving "identifying what's important or noteworthy about a classroom situation," "making connections between the specifics of classroom interactions and the broader principles of teaching and learning they represent," and "using what one knows about the context to reason about classroom interactions" (p. 573). In the paragraphs that follow I unpack this framework and discuss how teachers can use what they notice to further elicit student thinking.

Students may share a range of ideas in response to a given elicitation task, and as they do "teachers must be selective in determining where to focus their attention" and be able to identify "which interactions are particularly significant" (Sherin & van Es, 2005, p. 477). In other words, what a teacher *notices* in an interaction with students is based, in part, on what they are attending to (e.g., student thinking or engagement with the lesson). A teacher's selective attention to student thinking interacts "in a dynamic manner" with their "knowledge-based reasoning," in that what "stands out to [a] teacher in any given situation" depends on the teacher's knowledge and expectations (Sherin & van Es, 2009, p. 22)—e.g., what they may have anticipated with respect to student thinking. After teachers notice a particular aspect of student thinking, they "use their knowledge of the subject matter, knowledge of how students think of the subject matter, as well as knowledge of their local context to reason about events as they unfold" (van Es & Sherin, 2002, pp. 574-575).

During this reasoning process, teachers may realize they need to know more about how students think about an elicitation task in order to move forward with instruction. One way teachers can clarify student thinking is by asking follow-up questions intended to prompt students to further explicate their thinking. These follow-up questions may provide substantive information from which to further work on students' emerging science ideas.

**Summary**

Eliciting students' ideas involves anticipating students' responses, providing opportunities for students to share their thinking, and noticing student thinking. To an extent, teachers can draw on knowledge of typical students' ideas to anticipate how their students will interact with the anchoring phenomenon. However, to be responsive to their students' actual thinking, teachers need to provide opportunities for students to make sense of and share their developing thinking; these opportunities to elicit student thinking arise through launching and engaging students in elicitation tasks throughout a unit of instruction. After eliciting students' thinking, teachers need to notice their students' ideas and reason about these ideas to inform follow-up questions, as well as future instruction. Especially for preservice teachers, these components are challenging to enact.

## Challenges Preservice Teachers Face in Eliciting Student Thinking

Teaching in ways that are aligned with the new vision of science learning requires a wide range of skills, deep science knowledge, and a disposition to teach in ways that foreground student thinking. Focusing just on the key practice of eliciting student thinking, preservice teachers face challenges in: (a) selecting a high-quality phenomenon in which to anchor a unit of instruction; (b) anticipating student responses related to the anchoring phenomenon and driving question; (c) designing and engaging students in productive elicitation tasks; and (d) noticing student thinking.

### Selecting a High-Quality Anchoring Phenomenon.

When selecting a phenomenon and driving question with which to anchor a unit of instruction, teachers bridge their understanding of the phenomenon (based on their subject matter knowledge) with relevant standards (e.g., NGSS) and curricula. Without much prior experience learning or teaching through phenomena or working with students, it can be difficult for preservice teachers to identify and select phenomena that are aligned with standards and/or local curricula, have "enough" puzzlement, and are sufficiently complex yet comprehensible to students. Without much prior experience working with students, choosing a phenomenon that is interesting and accessible to their students, while also providing opportunities to engage students in and elicit their ideas about the corresponding DCI(s), can be difficult for preservice teachers.

### Anticipating Student Responses

Anticipating student responses requires knowledge of typical student ideas. Methods courses and field placements both serve as possible sites for preservice teachers to develop knowledge of both what ideas students hold about particular topics and what to do with that information in order to further support student learning (i.e., PCK). However, without much prior experience in the field, developing an understanding of student thinking can be difficult, since teaching experience (Brown et al., 2013; Cochran et al., 1991; van Driel et al., 2014) is considered to be both a prerequisite and potentially a means through which teachers develop their PCK.

**Designing and Engaging Students in Productive Elicitation Tasks**

Responsive teaching involves eliciting students' thinking in ways that can inform subsequent instruction, but the ways that preservice teachers elicit student thinking vary, and some elicitation tasks are more productive than others. Larkin (2017) found preservice teachers' elicitation tasks could be categorized into three types: *resource*, *reasoning*, and *evaluation*. Some elicitation tasks involve "tak[ing] stock of [students'] cognitive and cultural resources" (p. 439). These elicitation tasks are open-ended and inform preservice teachers of the ideas—positioned as *resources*—that students bring into the classroom. Other tasks elicit students' model-based *reasoning* or attention to particular features of an anchoring phenomenon, which entail eliciting "student ideas specifically for model building and explanation" (p. 439). These elicitation tasks focus on encouraging students to share more details about their initial and developing models and explanations of the phenomenon in an effort to support students' sense-making and metacognition. Lastly, some tasks do not elicit students' cultural or cognitive resources, nor do they press students to engage in further reasoning. Instead, these *evaluative* elicitation tasks are designed to measure "the conceptual distance between existing and desired outcomes" (p. 439). Other researchers have identified a similarly evaluative approach to elicitation across a multitude of contexts, as both in-service (e.g., Erdogan & Campbell, 2008; Kazemi & Stipek, 2009) and preservice teachers often "[fail] to recognize any need to elicit student thinking beyond the specific answer for which they were searching" (McNew-Birren & van den Kieboom, 2017, p. 84). Thus, while some elicitation tasks support teachers in discovering their students' ideas (as *resources*) or push students to further explicate and make sense of their own thinking (*reasoning*), other elicitation tasks serve to compare students' ideas to the correct answer (*evaluate*).

### Noticing Student Thinking

Developing the ability to notice and interpret student thinking is a key aspect of responsive teaching, but noticing does necessarily come naturally and thus is a skill to be learned (Rodgers, 2002). Studies have shown that teachers more readily attend to teacher actions (e.g., pedagogy) than to the substance of student thinking (Sherin & van Es, 2005), and preservice teachers, in particular, struggle to perceive and interpret students' errors (e.g., Stahnke et al., 2016). Additionally, preservice teachers need "opportunities to learn to focus on and interpret essential interactions in teaching" (Benedict-Chambers, 2016, p. 39) and support in learning "how to see" nuance in student thinking (Johnson & Cotterman, 2017, p. 412).

## Supporting Preservice Teachers in Learning to Elicit Student Thinking

A few key supports exist that may help preservice teachers in learning to teach in ways that are responsive to student thinking, which begins by learning to elicit student thinking. In the sections that follow, I identify potential supports for preservice teachers learning to elicit student thinking: practice-based frameworks for teaching, practice-based methods courses, and learning progressions.

### Practice-Based Frameworks for Teaching

Eliciting student thinking is widely regarded as one of a small set of high-leverage teaching practices, which are defined as the "activities of teaching that are essential to the work" and are "most likely to equip beginners with capabilities for the fundamental elements of the professional work and that are unlikely to be learned on one's own through experience" (Ball et al., 2009, pp. 460-461). High-leverage practices are those that are used frequently, support student learning, and have "significant power for teachers' effectiveness with pupils" (p. 461). These teaching practices "represent descriptions of the professional practice of advanced and expert teachers" (McNew-Birren & van den Kieboom, 2017, p. 77) yet are attainable by novice educators (Grossman, Hammerness, et al., 2009).

Eliciting student thinking is a key component of the AST teaching framework, which is one approach that is consistent with supporting the new vision of science learning. The AST framework draws on a few core (or high-leverage) practices that "represent broadly applicable instructional strategies known to foster important kinds of student engagement and learning" (Windschitl et al., 2012, p. 879). This framework uses model-based inquiry (through the enactment of core teaching practices) to support students in "figuring out" how and why a phenomenon occurs and to "*develop defensible explanations of the way the natural world works*" (Windschitl et al., 2008, p. 955). The four core teaching practices in AST are: Planning for engagement with important science ideas, Eliciting students' ideas to adapt instruction, Supporting ongoing changes in thinking or helping students make sense of material activity, and

Pressing students for evidence-based explanations. These four practices are designed to build on one another in a coherent system of teaching (Windschitl et al., 2012). While eliciting student thinking is positioned as a stand-alone core practice early in a unit (in order to help inform the direction of the unit), student thinking should continually inform instruction throughout the unit. Therefore, eliciting student thinking is implied within the practices of supporting ongoing changes and pressing for evidence-based explanations.

Teacher education that focuses on high-leverage practices, such as the four core practices in AST, requires new forms of pedagogy. Grossman and colleagues have described practice-based teacher education as entailing pedagogies of practice, in which teacher educators represent, decompose, and support preservice teachers' approximations of specific aspects of teaching practice (Grossman, Compton, et al., 2009) in an effort to purposefully position the work of K-12 teachers at the heart of teacher education (Grossman, 2011). This practice-based approach to teacher education is designed to better support preservice teachers in developing their understanding of educational theory alongside "practical strategies for teaching" (Grossman, Hammerness, et al., 2009, p. 275) in ways that are accessible to novice teachers (Grossman, 2011). One way to enact pedagogies of practice is through practice-based methods courses.

**Practice-Based Methods Courses**

A teacher education course is considered to be practice-based if it includes a "systematic focus on developing teacher candidates' abilities to successfully enact high-leverage practices" (Zeichner, 2012, p. 378), such as eliciting student thinking, and supports preservice teachers in learning to "integrate these distinct practices together in the form of lessons" (p. 379). For this dissertation, I consider practice-based methods courses to be those that incorporate representations of practice, draw from pedagogical frameworks that decompose the work of teaching (e.g., AST), and engage students in approximations of practice to rehearse the work of teaching in a simplified context (Grossman, 2011; Grossman, Compton, et al., 2009).

Microteaching in a practice-based teaching methods course is one way to engage preservice teachers in an approximation of practice through the creation of a "simplified" teaching context in which the class size and instructional duration are reduced, and the overall complexities of teaching are constrained (Macleod, 1987). Microteaching provides preservice teachers opportunities to "rehearse instructional strategies," "decompose the complexities of teaching into smaller pieces, and practice them in more controlled settings in brief spurts of time" (Stroupe & Gotwals, 2018, p. 297). One instantiation of this approximation of teaching involves preservice teachers enacting one or more high-leverage or core instructional practices (e.g., eliciting student thinking) with their methods course peers (acting as students) which affords preservice teachers an opportunity to "engage in practice that is related, but not identical, to the work of practicing professionals" (Grossman, 2011, p. 2840). Teaching a microteaching lesson affords a preservice teacher the opportunity to struggle with the inherent uncertainty of working with students (e.g., Labaree, 2000); participating in a microteaching lesson as a "student" (of a peer teacher) allows a preservice teacher to experience instruction from the perspective of his or her future audience. In the AST framework, specifically, three of the four core practices offer opportunities for microteaching, each aligning with a core instructional practice: 1) Eliciting student thinking, 2) Supporting ongoing changes in student thinking, and 3) Pressing for evidence-based explanations (Windschitl et al., 2012).

A full AST-based unit of instruction in a K-12 teaching context involves planning and enacting one or more lessons for each core practice (in order to continually work on and with the substance of student thinking). While microteaching brief and somewhat disconnected lessons to peers curtails the extent to which preservice teachers can experience working on and with student thinking over time (compared to what happens in a "real" classroom with "real" students), microteaching represents a context in which preservice teachers can begin to learn the complex work of teaching, even if there are limitations on its authenticity.

**Learning progressions**

While microteaching represents one way to support preservice teachers' skill in enacting high-leverage practices in a simplified context, practice-based teacher education programs must also consider how to support preservice teachers' development of the "knowledge that counts for practice" or is "entailed by the work" of teaching (Ball & Forzani, 2009, p. 503). Learning progressions may serve as a support for developing an understanding of the ideas students may hold, as knowledge available to draw from when anticipating, eliciting, and noticing student thinking (Gotwals & Birmingham, 2015).

Learning progressions represent an ordered portrayal of how students' ideas may increase in sophistication with instruction (National Research Council, 2007). Learning progressions are structured with lower and upper anchors, spanning from the naïve ideas about a particular topic that students may bring with them to the classroom to those widely accepted in the scientific community (Furtak, 2009). Research with inservice teachers (e.g., Covitt, Gunckel, Caplan, & Syswerda, 2018; Furtak, 2012; Furtak, Circi, & Heredia, 2018) suggests that these tools may support preservice teachers' understanding of student ideas. As representations of how students' ideas about a given concept may increase in sophistication, learning progressions explicate a range of students' ideas that can be difficult for preservice teachers to generate entirely on their own. Historically, learning progressions have been framed within literature on formative assessment, which is the process by which teachers "elicit and interpret evidence of students' learning needs in order to respond with appropriate instructional supports" (Alonzo, 2018, p. 104). This literature has shown learning progressions have potential for influencing teachers' ability to make sense of (Yin et al., 2014) and make inferences about (e.g., Furtak, 2012; Furtak et al., 2014) student thinking related to the ideas represented in a learning progression.

The ideas represented in any given learning progression are not explicitly connected to a specific phenomenon. For example, Alonzo and Steedle's (2009) learning progression explicates a range of ideas students may hold about the relationship between the force(s) acting on an object and the resulting motion of the object. If a preservice teacher connects the ideas represented in a learning progression (e.g., students' ideas about the relationship between force and motion) to an anchoring phenomenon (e.g., the trajectory of a kicked football, motion of an object within a decelerating vehicle), he or she may be better able to anticipate how students will interact with the phenomenon and respond to questions and tasks designed to elicit their thinking.

Learning progressions make visible particular aspects of practitioners' knowledge (in this case, knowledge of student ideas), but because all representations are inherently incomplete, it is important to consider what student ideas learning progressions "enable novices to see and learn and what they leave opaque" (Grossman, 2011, p. 2838). While a content-appropriate learning progression may indeed help focus a preservice teacher's attention by providing an initial lens through which to plan for and elicit particular ideas, a study by von Aufschnaiter and Alonzo (2018) showed learning progressions may unnecessarily narrow preservice teachers' attention to *just* the ideas represented on the learning progression and hinder their ability to consider relevant ideas *not* represented on the learning progression. To date, most studies of teachers' use of learning progressions have focused on in-service teachers (e.g., Covitt, Gunckel, Caplan, & Syswerda, 2018; Furtak, 2012; Furtak, Circi, & Heredia, 2018); therefore, further research is needed to identify if and how learning progressions support preservice teachers.

## Summary

Teaching in ways that are aligned with the new vision of science learning involves supporting students in "figuring out" how and why natural phenomena occur (e.g., Osborne & Quinn, 2017; Reiser et al., 2016; Schwarz et al., 2017), which requires teachers to elicit students' thinking throughout a unit of instruction. Practice-based teacher education, organized around high-leverage practices, can be used to support preservice teachers in learning complex practices such as eliciting student thinking. In particular, some practice-based methods courses offer preservice teachers opportunities to engage in microteaching as an opportunity to practice integrating practices, such as eliciting student thinking, into lessons. Within such a practice-based methods course, learning progressions may support preservice teachers' understanding of students' ideas and their ability to anticipate students' thinking, design and engage students in productive elicitation tasks, and notice students' thinking about how and why an anchoring phenomenon occurs. Better understanding *how* preservice teachers elicit student thinking about an anchoring phenomenon and how tools—such as learning progressions—might support their elicitations may help teacher educators support preservice teachers' development as responsive educators. Therefore, the questions that guide my research are as follows:

1. How do preservice teachers draw on characteristics of an anchoring phenomenon to elicit student thinking?

2. How do preservice teachers, when informed by a learning progression, draw on their understanding of student ideas to elicit student thinking?

# CHAPTER THREE: METHODS

This study is part of a larger project that explored the use of learning progressions in a university-based, senior-level secondary science methods course. In this dissertation, I seek to better understand how preservice teachers—when supported with learning progressions—elicit student thinking about an anchoring phenomenon.

In order to answer my research questions, I conducted a qualitative multiple case study. According to Merriam and Tisdell (2016), a case study is defined as "an in-depth description and analysis of a bounded system" (p. 37). A multiple case study calls for the identification of and synthesis across cases *of*, which serve as the unit of analysis (e.g., Yin, 2009). The primary goal of this type of research is to identify and report overarching themes across cases, in addition to descriptions of the cases themselves; therefore, this methodology is well-suited for my research questions. In the sections that follow, I provide contextual information about the research setting, describe the participants and data sources, and outline my research methods and analysis.

## Context

Participants in this study were enrolled in a year-long, AST-based, senior-level (undergraduate) secondary science methods course. In this methods course, instructors grouped 3-4 secondary science preservice teachers with the same content area major to form four microteaching groups. Each microteaching group was assigned one NGSS PE (NGSS Lead States, 2013) to use in three short cycles of planning for, enacting, and reflecting on microteaching lessons. Additionally, each group worked with a learning progression that was selected—and sometimes adapted—to align, as closely as possible, with the DCI(s) in their assigned NGSS PE (see Table 3-1). In the sections that follow, I describe the microteaching cycles and the workshop-based learning progression supports that were used in this study.

Table 3-1:
*NGSS PE and Learning Progression for Each Microteaching Group*

| Group | Topic | NGSS Performance Expectation | Selected/Adapted Learning Progression |
|---|---|---|---|
| Biology | Carbon cycling | **HS-LS2-5:** Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. | Matter and energy in carbon-transforming processes (Parker et al., 2015) |
| Chemistry | Chemical energy | **HS-PS1-4:** Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. | Matter and energy in carbon-transforming processes (Carbon TIME, n.d.) |
| Physics I | Force and motion | **HS-PS2-1:** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. | Force & motion (Alonzo & Steedle, 2009) |
| Physics II | Momentum | **HS-PS-2:** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. | Momentum (Alonzo et al., 2017) |

## Microteaching Cycles

Each of the three microteaching cycles aligned with one of the three AST enactment practices, and each microteaching cycle involved preservice teachers planning for the relevant AST practice, enacting the practice with a group of their methods course peers taking on the role of students, and reflecting on the lesson. Each planning phase was supported by a specific AST tool (see Appendix A: AST Tools for Planning and Reflecting), which also included a post-lesson reflection section called the *Rapid Survey of Student Thinking*. The first microteaching cycle aligned with the Eliciting student thinking practice, the second cycle aligned with the Supporting ongoing changes in student thinking practice, and the third and final cycle aligned with the Pressing for evidence-based explanations practice. In addition to collaboratively working through the AST planning and reflection tools for each microteaching lesson, preservice teachers individually planned for and reflected on their lessons (see Appendix B: Methods Course Assignments). In the sections that follow I describe the three phases of the microteaching cycles (planning, enacting, and reflecting), highlighting preservice teachers' work around elicitation of student thinking.

### *Planning*

Prior to the first microteaching cycle, each group worked through the AST collaborative tool *Planning for engagement with important science ideas* to plan the "big picture" for a unit of instruction (see Appendix A-1). Using this tool, each group identified an anchoring phenomenon connected to their assigned NGSS PE, developed a gapless explanation as to how and why the phenomenon occurred, and defined student success for the unit. Then, prior to each microteaching lesson, each group completed the associated AST tool to anticipate student ideas and script specific talk moves and/or questions they would use to engage their students in the specific practice for that lesson. In order to plan their first microteaching lesson (MT1), each group completed the AST collaborative tool *Eliciting students' ideas and adapting instruction* (see Appendix A-2). This tool is designed to support teachers in developing a series of questions to ask students about *what* is represented in their chosen anchoring phenomenon and *how* and *why* the anchoring phenomenon occurs. In order to plan their second microteaching lesson (MT2), each group completed the AST collaborative tool *Supporting ongoing changes in student thinking* to plan instruction about one or more key ideas related to explaining their anchoring phenomenon (see Appendix A-3). Each group used the AST collaborative tool *Pressing students to construct evidence-based explanations* to plan their third microteaching lesson (MT3; see Appendix A-4). Additionally, each preservice teacher individually wrote a lesson plan designed to enact the practice-based goals for each microteaching (see Appendix B-1).

Even though only the practice for MT1 has an explicit focus on elicitation, practices for MT2 and MT3 also require teachers to elicit students' thinking. The MT2 planning tool scaffolds teachers to design an instructional activity, including questions and prompts intended to support students in making connections between the instructional activity and the anchoring phenomenon. The MT3 planning tool is designed to support teachers in preparing to press for students' evidence-based explanations, including developing prompts to probe students' reasoning about their explanations and final revisions to their initial model.

### *Enacting*

Each preservice teacher used his or her lesson plan to microteach a 20-minute lesson to a small group of peers who acted as "students" during the microteaching lessons.[2] Even though only MT1 had an explicit focus on elicitation (i.e., preservice teachers presented the anchoring phenomenon and elicited their students' initial ideas about how and why the phenomenon

[2] These "students" (from different content area groups within the methods course) remained together across all three microteaching cycles, so that they experienced a coherent sequence of AST-based microteaching lessons (from each "teacher") in each of the content areas.

occurred), preservice teachers elicited their students' ideas in the other two microteaching lessons as well. In MT2, preservice teachers drew on what they elicited in the first microteaching lesson to support changes in their students' thinking. In MT3, preservice teachers pressed students to use what they know and learned to develop an explanation for the anchoring phenomenon and/or complete a summative assessment.

### *Reflecting*

After each microteaching lesson, preservice teachers were tasked to identify the student ideas that surfaced during their microteaching and add these to the *Rapid Survey of Student Thinking* section at the end of the AST planning tool for each enactment practice. Preservice teachers then discussed these ideas in content areas groups during a methods class work session and collected their ideas on a shared Google document. Lastly, each preservice teacher individually completed a *Reflection on Teaching* report (see Appendix B-2) in which she or he outlined the "story of what happened" in the lesson, identified "lessons learned" (drawing on the *Rapid Survey of Student Thinking*), and listed implications for future instruction.

## Learning Progressions and Associated Supports

Researchers and course instructors (the "LP team") designed eight work sessions around content-specific learning progressions in order to support preservice teachers' understanding of and ability to work with student ideas. In the sections that follow, I describe the two learning progressions relevant for this study and each work session.[3]

[3] As described below, this study focuses on preservice teachers from the Chemistry and Physics I groups; therefore, only these two learning progressions are presented in detail.

### *Learning Progressions*

Each content-area group worked with a learning progression that was selected—and sometimes adapted by members of the LP team—to align, as closely as possible, with the DCI(s) in their assigned NGSS PE (see Appendix C). The four learning progressions were developed through the work of two separate research groups. The carbon cycling and chemical energy learning progressions (for the chemistry biology and chemistry groups, respectively) were based on different *Carbon TIME* learning progressions that focused on tracing matter and energy through carbon-transforming processes (Carbon TIME, n.d.; Parker et al., 2015). The force and motion (Alonzo & Steedle, 2009) and momentum (Alonzo et al., 2017) learning progressions were developed by some members of the research group involved in the present study. The learning progressions developed in each group differ in important ways. In the paragraphs that follow, I summarize these differences and describe the learning progressions involved in this study.

The *Carbon TIME* learning progressions differ from the physics learning progressions in (a) what is progressing (b) breadth, and (c) grain size (e.g., Alonzo, 2012). The *Carbon TIME* learning progressions describe the progression of students' reasoning to explain phenomena holistically, from force-dynamic reasoning (e.g., Talmy, 1988) to scientific, model-based reasoning (Gunckel et al., 2009; Mohan et al., 2009). Also, both *Carbon TIME* learning progressions are designed to cover many years of instruction; as such, the "distance" between levels is relatively large. In contrast, the physics learning progressions focus more narrowly on students' ideas about a single concept and are grounded in literature on students' alternative conceptions. Both physics learning progressions are designed to cover a relatively short unit of instruction; as such, the distance between levels is relatively small.

The chemistry group's NGSS PE includes two DCIs: (a) PS1.A (Structure and Properties of Matter): A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart and (b) PS1.B (Chemical Reactions): Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. Therefore, the chemistry group worked with a learning progression related to students' understanding of chemical energy (see Appendix C-1; Carbon TIME, n.d.). This learning progression features four levels, ranging from students' conceptualization of energy as "needs" for an event (illustrating a force-dynamic reasoning; e.g., air and wood are needed for a fire) to a sophisticated attention to bond energies across reactants and products. Ideas in the "messy middle" (Gotwals & Songer, 2010, p. 277) include an interchangeability between energy and matter, separate conservation of energy and matter (linked through chemical energy), as well as an incomplete understanding of energy required for or released during the breaking and formation of chemical bonds.

One physics group's NGSS PE includes one DCI (PS2.A: Forces and Motion), which states that Newton's second law accurately predicts changes in the motion of macroscopic objects. Therefore, this physics group worked with a learning progression related to students' understanding of the relationship between force and motion (see Appendix C-2; Alonzo & Steedle, 2009). This learning progression utilizes four levels to depict a progression from naïve to scientifically correct understandings. At the lowest level, students view forces as properties of objects, rather than as interactions between objects and, thus, do not identify a consistent relationship between force and motion. At the highest level, students identify the net force acting on an object as proportional to the object's acceleration. Intermediate understandings include the notion that force is carried with a moving object (Buridan's notion of an impetus conception, as cited in Halloun & Hestenes, 1985), in which students treat force similar to the way physicists would define momentum rather than as a measure of the interaction between two objects.

### ***Work Sessions***

To support preservice teachers' understanding of and ability to work with student ideas, members of the LP team led eight work sessions ranging in duration from 45 to 110 minutes (*M* = 86.88, *SD* = 22.35) during the methods class (see Appendix D for Work Session Materials). In the paragraphs that follow, I describe these work sessions.

In the first work session (prior to MT1), the LP team introduced content-area groups to selected student responses to assessment items aligned with their assigned learning progressions (see Appendices D-1 and D-2). With guidance from a LP team member, each group of preservice teachers characterized and clustered similar student responses together and identified key features of student thinking across clusters of responses. They then ordered clusters in terms of increasing sophistication of student thinking and recorded the main ideas present in each cluster on a "features sheet," resulting in a representation of student ideas that was almost identical to the respective learning progression (see Appendix D-3).

In the second work session (also prior to MT1), the LP team engaged each group of preservice teachers in an activity designed to practice (a) using the features sheet (i.e., the learning progression) to interpret student ideas and (b) identifying questions that could be used to support interpretations of student ideas. During this work session, preservice teachers were provided with sample student responses and asked to identify (a) if and how the response aligned with the ideas present in the features sheet, (b) what was confusing or unclear about the student's response, and (c) what potential questions they might ask to clarify the student's thinking (see Appendices D-4 and D-5).

The third work session focused on debriefing the MT1 lessons, with the LP team helping each content group to focus attention on student ideas that surfaced during MT1 (see Appendix D-6). During this work session each group recorded and categorized student ideas in the *Rapid Survey of Student Thinking*.

The LP team continued to support preservice teachers' understanding of and ability to work with student ideas after the first microteaching cycle by working with each group to consider how the learning progression can support student learning. During the fourth work session, each group was introduced to the actual learning progression and prompted to identify gaps between levels of the learning progression to describe how student thinking changes from one level to the next (higher) level (see Appendix D-7). Then each group worked to develop potential instructional "next steps" to support students in moving from thinking consistent with one level of the learning progression to thinking consistent with the next level (see Appendix D-8).

After MT2 the LP team again worked with each group to debrief their lesson, this time in two separate work sessions. During the fifth work session (the first of two post-MT2 work sessions), preservice teachers were each prompted to share a short video recording from their MT2 lesson and a lingering question or problem of practice based on their lesson. Each group followed a video discussion protocol (see Appendix D-9). During the sixth work session (the second of the post-MT2 work sessions), the LP team again supported each group in recording and categorizing student ideas in the *Rapid Survey of Student Thinking* (see Appendix D-10).

Prior to MT3, the LP team led a seventh work session designed to support the preservice teachers in considering how to use the learning progression to assess student learning in MT3. During this work session, preservice teachers considered how students with ideas consistent with each level of the learning progression might respond to assessment items. The session started with items provided by the LP team (see Appendices D-11 and D-12), but groups also discussed assessment items they were planning for MT3. Following MT3, the LP team facilitated an eighth work session, during which each group debriefed their MT3 lesson, examined student responses to their assessment items, and shared a short video recording from their MT3 lesson. As with MT1 and MT2, each group recorded and categorized student ideas from MT3 in the *Rapid Survey of Student Thinking*.

## Participants

Participants (14 total) in the larger research project were science content area majors (e.g., biological science, chemistry, physics) enrolled in the first semester of a year-long, senior-level secondary science methods course at a large midwestern university in the United States. These preservice teachers were pursuing teaching certification within a content area major and minor[4] and planned to complete their content area coursework by the end of the academic year (prior to beginning their year-long student teaching internship).

At the beginning of the semester, researchers provided the preservice teachers with an overview of the larger research project and described opportunities to participate in data collection for the project. All 14 preservice teachers consented to the collection of course assignments and video recordings of their in-class work (e.g., participation in group debriefs

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[4] Students pursuing a "comprehensive major" (majors requiring 50 or more credits; e.g., physical science) were not required to complete a content area minor.

after microteaching), and all but one preservice teacher (from the momentum group) allowed recordings of their microteaching lessons. In addition, 10 preservice teachers agreed to participate in an individual semi-structured interview after each microteaching cycle.

## Data Sources

The data sources I draw on in this dissertation are a subset of those collected as part of a larger research project. For each microteaching cycle, the written data sources for the larger project are preservice teachers' completed AST-based tools (*Planning for engagement with important science ideas, Eliciting students' ideas and adapting instruction*, *Supporting ongoing changes in student thinking,* and *Pressing students to construct evidence-based explanations*) and methods course assignments designed to support their planning for, enacting of, and reflecting on each microteaching lesson (microteaching lesson plans and reflections on teaching reports, which included student ideas from the *Rapid Survey of Student Thinking* section of the AST planning tools). Audio and video data sources for the larger project are recordings of (a) learning progression-based work sessions, (b) preservice teachers' microteaching lessons, and (c) semi-structured interviews with participants after each microteaching lesson. During each post-microteaching interview, preservice teachers were prompted to discuss: (a) their goals and plan for the lesson, (b) ideas that students shared during the lesson, and (c) reflections on selected portions of their lesson through video-stimulated recall using pre-selected clips of their lesson (see Appendix E for each Post-microteaching Interview Protocol). Each interviewer selected the clips to highlight instances of (a) student thinking that was potentially related to "features" from the learning progression and (b) teacher questions and/or responses potentially indicating attention (or inattention) to features.

For this study my primary data sources are the preservice teachers' lesson plans (see Appendix B-1), transcripts of their microteaching lessons, and transcripts of their post-microteaching interviews (see Appendix E). The lesson plans highlight key ideas from the preservice teachers' AST planning tool(s) and provide insight into their goals for the lesson. In particular, Part I of the lesson plan ("Information about the Lesson") provides details about each preservice teacher's anchoring phenomenon and their goals for student success. Part III of the lesson plan ("Classroom Activities") outlines a step-by-step sequence of activities (e.g., elicitation tasks) planned for the lesson. Part V of the lesson plan ("Assessment") provides details about the assessment task and expectations for what an "ideal response" to the task might entail. The preservice teachers enacted their plans to elicit student thinking in the microteaching lessons. The transcripts of these lessons provided information about the questions and prompts the preservice teachers used to elicit student thinking, as well as how their students responded and any follow-up questions the preservice teachers may have asked to clarify student thinking. The post-microteaching interviews focused on the lesson as a whole (not specifically on elicitation of student ideas) but, given the larger project's focus on student thinking, the interviews provided information about how preservice teachers were thinking about eliciting and interpreting student thinking. Drawing from these varied sources of data allowed me to triangulate across multiple sources when answering my research questions.

## Research Methods and Analysis

The purpose of my research is to learn about how preservice teachers draw on characteristics of the anchoring phenomenon and their understanding of student ideas (when supported by a learning progression) to elicit student thinking in the context of a secondary science methods course. In this section I explain the process by which I selected cases for this study, and I describe two phases of analysis: one focused on individual cases and one synthesizing substantive findings across cases.

**Case Selection**

While the complete data set for the larger research project illustrates a range of preservice teachers' microteaching enactments (e.g., variations in their preparation to enact the lessons, attention to student ideas, and reflections on their practice) across multiple content areas, for this study I include two participants who represent strong cases of "what's possible" with respect to my research questions. To select my participants, I first identified preservice teachers who participated in all aspects of the data collection and thus provided a full dataset to analyze. Next, I reviewed each group's learning progression and AST collaborative tool *Planning for engagement with important science ideas* to identify content groups that exhibited strong alignment between their DCI, learning progression, and anchoring phenomenon. Both the physics I (force and motion) and chemistry group's choice of anchoring phenomenon clearly had potential to engage students in the DCI(s) in their respective NGSS PEs and also provided a context in which ideas from their respective learning progressions could surface. Additionally, the physics I and chemistry learning progressions were developed by two separate research groups and differed in terms of what is progressing, breadth, and grain size, as described above. Therefore, I focused on these two groups of preservice teachers as potential candidates for my study.

In order to identify cases of "what's possible" in the context of this study, I further narrowed the available participants based on the extent to which ideas related to their respective learning progressions surfaced during their units (from their MT1 transcripts) and their attention to student thinking (from their post-MT1 interview transcripts). Through this process, it was clear that both Seth (from the force and motion group) and Will (from the chemistry group) were strong candidates to include in this study. I reviewed the remaining data (across MT2 and MT3) for these two preservice teachers and found that, while they were both thoughtful and reflective about how they elicited student thinking, they varied in 1) how they drew on characteristics of their anchoring phenomenon and 2) how they drew on their understanding of student ideas to elicit student thinking. Therefore, I focused my analysis on these two preservice teachers.

### Phase I: Coding

After determining which cases to include in this study, I started by identifying what I am calling "interaction threads" within the transcripts of microteaching lessons. Next, I coded all primary data sources in order to "attribute meaning" to the data for analysis (Saldana, 2016, p. 4). I describe both processes in the sections below.

#### *Identifying Interaction Threads*

To disaggregate the transcribed microteaching lesson data and focus on preservice teachers' elicitations, I identified instances in which the preservice teacher enacted an elicitation task (i.e., asked students to develop a model or explanation, encouraged students to think about and share their ideas) and segmented the data into "interaction threads" based on elicitation tasks. An interaction thread is a fairly large unit of analysis that captures an elicitation sequence associated with a single elicitation task. Each thread began with the preservice teacher launching an elicitation task (e.g., "I want you to think about, what did you see going on in that demonstration?") and included all student responses and any follow-up questions or responses from the preservice teacher related to the task (e.g., "Can you tell me what this arrow represents on your model?"). Subsequent interaction threads began with the launching of a new elicitation task.

***Coding***

To capture relevant aspects of each data source and help "facilitate comparison" (Maxwell, 2013, p. 107) across the data, I coded each starting with a priori codes informed by the literature and modified and/or added to these a priori codes based on emergent themes from the data. Three organizational categories for codes were: (a) characteristics of the phenomenon and driving question, (b) talk and teacher moves, and (c) learning progressions. In the paragraphs that follow, I describe each of these three coding categories. The first and second coding categories correspond to research question 1, while the second and third categories correspond to research question 2.

The codes that correspond to the characteristics of anchoring phenomena were developed based on the literature for what constitutes a "high-quality" anchoring phenomenon and driving questions (see Chapter 2) and were refined based on emergent themes in the data. These codes are represented in Tables 3-2 and 3-3 below. During my analysis, it became apparent that some of these characteristics were more helpful than others in identifying and parsing substantive differences between the preservice teachers' anchoring phenomena. All codes describing characteristics of high-quality anchoring phenomena and driving questions were applied to the data and are included in Tables 3-2 and 3-3, but the codes that allowed me to identify substantive differences in the data—indicated in bold in the table—are: (a) features, (b) segments,

Table 3-2:
*Codes: Characteristics of the Phenomenon*

| Code | Sub-codes | Description |
|---|---|---|
| *Dynamicity* | Low | The anchoring phenomenon does not illustrate change over time (it is "static") |
| | Medium | The anchoring phenomenon illustrates change over time |
| | High | The anchoring phenomenon illustrates significant change over time (it is "dynamic") |
| ***Features*** | Cosmetic | Details of the anchoring phenomenon that are not necessary to draw from when developing an explanation of the anchoring phenomenon |
| | Substantive | Details of the anchoring phenomenon that can be drawn from when developing an explanation of the anchoring phenomenon |
| ***Segments*** | Before & after | The anchoring phenomenon can be parsed into two distinct periods of change or action. |
| | Before, during, & after | The anchoring phenomenon can be parsed into three distinct periods of change or action. |
| ***Breadth of content required*** | | Explaining how and why the anchoring phenomenon occurs requires students to draw from and synthesize a range of content understandings. |
| *Breadth of exploration possible* | | The anchoring phenomenon can support the exploration of other driving questions (in support of other NGSS PEs) |
| ***Delivery format*** | Picture(s) | The anchoring phenomenon is presented using a picture or pictures |
| | Video | The anchoring phenomenon is presented using video |
| | Demonstration | The anchoring phenomenon is presented using a "live" demonstration |
| ***Connectedness*** | Disconnected | The anchoring phenomenon is unrelatable to students' interests and provides limited or no opportunities to build on students' cultural, personal, and/or everyday experiences |
| | Moderately Connected | The anchoring phenomenon is relatable to students' interests and provides opportunities to build on students' cultural, personal, and/or everyday experiences |
| | Highly connected | The anchoring phenomenon is highly relatable to students' interests and provides strong opportunities to build on students' cultural, personal, and/or everyday experiences |

Table 3-2 (cont'd)

| | | |
|---|---|---|
| ***Alignment*** | No alignment | The anchoring phenomenon is not aligned with nor explained by grade level-appropriate DCI(s) |
| | Partial alignment | The anchoring phenomenon is partially aligned with and explained by grade level-appropriate DCI(s) |
| | Full alignment | The anchoring phenomenon is fully aligned with and explained by the grade level-appropriate DCI(s) |

Table 3-3:
*Codes: Driving Questions*

| Code | Sub-codes | Description |
|---|---|---|
| *Clarity* | Lacking | The driving question is multi-focused and/or unclear |
| | Adequate | The driving question is adequately focused |
| | High | The driving question is narrowly focused and clear |
| *Alignment/Connectedness to phenomenon* | Disconnected | The driving question is disconnected to the anchoring phenomenon (it does not represent a logical question to explore) |
| | Peripherally connected | The driving question is somewhat connected to the anchoring phenomenon |
| | Adequately connected | The driving question follows naturally from the anchoring phenomenon and represents a logical question to explore |
| ***Type*** | Explanatory | The driving question prompts students to explain how and why the anchoring phenomenon occurs |
| | Predictive | The driving question prompts students predict future occurrences (based on the anchoring phenomenon) |

(c) breadth of content required, (d) delivery format, (e) connectedness, (f) alignment, and (g) driving question—type. The codes in Tables 3-2 and 3-3 were primarily applied to lesson plans (holistically) and to interaction threads in transcripts of microteaching lessons in which the preservice teacher drew on a particular characteristic, but they were also applied to lines of text within the post-microteaching interviews.

Table 3-4:
*Codes for Microteaching Lessons: Talk and Teacher Moves*

| Code | Description |
| --- | --- |
| *Eliciting Observations* | Preservice teacher elicits students' observations of the phenomenon or activity |
| *Eliciting Mechanism* | Preservice teacher elicits a mechanism of the phenomenon or activity |
| *Eliciting Predictions* | Preservice teacher elicits predictions of what will happen in the phenomenon or activity |
| *Eliciting Lingering Questions* | Preservice teacher elicits students' lingering questions about the phenomenon or activity |
| *Focus/seed* | Preservice teacher directs students to consider a particular idea (including content knowledge) |
| *Ask for more responses* | Preservice teacher elicits more responses from students |
| *Press* | Preservice teacher presses students for reasoning or an explanation |
| *Clarify SS thinking* | Preservice teacher clarifies students' thinking |
| *Restate/revoice* | Preservice teacher restates or revoices a students' claim |

Table 3-5:
*Codes for Written Documents: Talk and Teacher Moves*

| Code | Description |
| --- | --- |
| *Goal* | Preservice teacher describes the goal for a lesson or activity |
| *Anticipating* | Preservice teacher anticipates student thinking |
| *Planning* | Preservice teacher describes planning for a lesson or activity |
| *Reviewing or interpreting SS response* | Preservice teacher reviews or interprets a student's response |

The codes that correspond to preservice teachers' talk and teacher moves when eliciting students' ideas were iteratively developed based on both the literature (e.g., launching the task, engaging students in productive talk; see Chapter 2) and emergent themes from the data. This group of codes was applied to the lesson plans, interaction threads in transcripts of the microteaching lessons, and transcripts of the post-microteaching interviews. These codes were helpful in identifying differences in (a) *what* the preservice teacher was eliciting (or planned to elicit), (b) *how* the preservice teacher went about eliciting (or planned to elicit), and (c) how the preservice teacher responded to student thinking that was elicited (e.g., asking for clarification). Tables 3-4 and 3-5 present codes that were applied to interaction threads in the transcripts of

Table 3-6:
*Codes: Learning Progressions*

| Content area | Code | Abbreviated description of key student ideas |
|---|---|---|
| Physics | LP-P:4 | Force is proportional to acceleration; net force may not be in the direction of motion |
| | LP-P:3 | Force is proportional to speed or velocity; net force is in the direction of motion |
| | LP-P:3a | For an object in motion, the net force causing motion is carried with the moving object |
| | LP-P:2 | Force is associated with motion |
| | LP-P:2a | For an object in motion, there is only a force in the direction of motion |
| | LP-P:1 | Conflating force and motion; if no motion it is because a (net) force is opposing motion |
| | LP-P:LP-related content | Ideas related to force and/or motion but are not explicitly represented in the LP-C. |
| Chemistry | LP-C:4 | Breaking chemical bonds requires energy; making chemical bonds releases energy |
| | LP-C:3 | Breaking bonds releases energy; making bonds requires energy |
| | LP-C:2 | Energy and matter are separate and have no relationship; matter turns into energy |
| | LP-C:1 | Subject has needs (e.g., material or action) |
| | LP-C:LP-related content | Ideas related to energy but are not explicitly represented in the LP-C. |

microteaching lessons and to lesson plans and transcripts of post-microteaching interviews, respectively.

The codes that correspond to ideas in the learning progression were developed based on each group's learning progression (see Table 3-6). As described above, each learning progression includes levels indicative of the sophistication of students' ideas. Codes within this category identified the learning progression and level (e.g., LP-P: 3, corresponding to level 3 of the force and motion learning progression). This category of codes applied to the lesson plans (to identify planned elicitations of student ideas aligned to the learning progression), to lines of text within interaction threads in transcripts of the microteaching lessons (to identify questions asked by the preservice teacher and/or student responses aligned with the learning progression), and to lines of text within transcripts of the post-microteaching interviews (to identify the preservice teachers' reflections about student ideas aligned to the learning progression).

## Phase II: Individual Case and Cross-Case Analyses

I conducted both individual and cross-case analyses in order to identify and synthesize patterns across the dataset for each of my two research questions. In the sub-sections that follow, I describe each type of analysis.

### *Individual Case Analysis*

In order to identify if and how each preservice teacher drew on characteristics of their respective anchoring phenomena to elicit student thinking (my first research question), I analyzed coded segments of the pre-service teachers' lesson plans, coded interaction threads in transcripts of their microteaching lessons, and coded segments of their post-microteaching interviews. Specifically, I sought to identify instances in which the *Characteristics of the phenomenon* codes co-occurred with the *Talk and teacher moves* codes for each teacher's planning, enacting, and reflecting on MT1, MT2, and MT3. Based on the co-occurrence of *Characteristics* and *Talk* codes within the interaction threads, I wrote, and rewrote, memos describing how each preservice teacher drew on characteristics of the anchoring phenomenon to elicit student thinking in each elicitation task for a given microteaching lesson.

Through the process of writing these memos, I identified themes in preservice teachers' elicitation in each interaction thread. Looking across preservice teachers' moves to *focus/seed, ask for more responses, press,* and *clarify*, I described how preservice teachers drew on *Characteristics* to elicit student thinking (e.g., the preservice teacher scaffolded students' attention to X by focusing students on one or more characteristics of the anchoring phenomenon). Next, I drew on the associated coded lesson plans and post-microteaching interview transcripts to add detail to the memos as evidence for the emergent themes. I repeated this process for each microteaching cycle.

I iteratively drew on these memos to write detailed descriptions of how each preservice teacher drew on characteristics of the anchoring phenomenon to elicit student thinking in each microteaching lesson. While writing these descriptions, I repeatedly referenced the original data to ensure accuracy in my portrayals.

In order to identify if and how each preservice teacher drew on their understanding of student ideas to elicit student thinking (my second research question), I again analyzed coded segments of the pre-service teachers' lesson plans, coded interaction threads in transcripts of their microteaching lessons, and coded segments of their post-microteaching interviews. In this process, I started with the coded lines of text within interaction threads in the transcripts of the preservice teachers' microteaching lessons in order to focus my attention on the elicitation tasks and associated student responses and teacher follow-up responses. I examined how these elements of each interaction thread aligned with specific levels of the preservice teachers' respective learning progressions. To answer my second research question, I identified co-occurrences of the *Learning progressions* and *Talk and teacher moves* codes for each teacher's MT1, MT2, and MT3 lessons. Next, I highlighted instances in which the preservice teacher explicitly planned for (or retrospectively indicated that he anticipated) student ideas from his learning progression, based on the coded lesson plans and transcripts of post-microteaching interviews. I wrote and rewrote memos describing if and how each preservice teacher drew on his understanding of student ideas to elicit student thinking in each microteaching lesson. As for my first research question, I used the resulting memos to write detailed descriptions of each preservice teacher's planning for, eliciting student thinking during, and reflecting on each microteaching lesson.

### *Cross-Case Analysis*

To synthesize the data and find patterns across cases for each research question, I read, and re-read, findings for the individual cases—referring to full data sources as necessary. Throughout this process, I wrote memos to record "analytic thinking about [the] data" (Maxwell, 2013, p. 105) and sought to identify similarities and differences in how each preservice teacher drew on (a) characteristics of his anchoring phenomenon and (b) his understanding of student ideas to elicit student thinking. In these memos I recorded details about how the cases were alike and how they were different. From these memos I wrote, and rewrote, cross-case comparative summaries to distill how both preservice teachers drew on characteristics of their respective anchoring phenomena and their understanding of student ideas to elicit student thinking. I present these cross-case analyses at the end of the findings for each research question.

# CHAPTER FOUR: DRAWING ON CHARACTERISTICS OF AN ANCHORING PHENOMENON TO ELICIT STUDENT THINKING

In this first of two findings chapters, I describe how Seth and Will drew on characteristics of the anchoring phenomenon to elicit student thinking across three microteaching lessons (MT1: eliciting student thinking, MT2: supporting ongoing changes in student thinking, and MT3: pressing for evidence-based explanations). For each preservice teacher, I first describe the anchoring phenomenon in terms of three characteristics: alignment with the DCI(s), segments, and features. Next, I describe how each preservice teacher explicitly drew on these characteristics of the anchoring phenomena to elicit their students' thinking across MT1, MT2, and MT3. The sections within the description of each microteaching lesson are based on one or more interaction threads (the launching of an elicitation task and all student and preservice teacher follow-up responses related to the task). These sections present themes about *how* each preservice teacher drew on one or more characteristics of the anchoring phenomenon to elicit student thinking. I also describe variations in how each preservice teacher drew on characteristics of his anchoring phenomenon across the sequence of three microteaching lessons. I conclude this chapter with a summary of similarities and differences in how Seth and Will drew on characteristics of their respective anchoring phenomena to elicit student thinking.

## Characteristics of Anchoring Phenomena

Both Seth and Will's anchoring phenomena were "high-quality" with respect to literature on characteristics of anchoring phenomenon. To elicit student thinking, both primarily drew on two of these characteristics—segments and alignment with the DCI(s)—as well as an additional characteristic (features) that emerged from the data. The segments characteristic represents the ability to parse an anchoring phenomenon into distinct periods of change or action, and the alignment with the DCI(s) characteristic represents the extent to which the anchoring phenomenon is aligned with and explained by the DCI(s) in the grade-level appropriate NGSS PE. The features characteristic emerged from the data as a way to identify details of the anchoring phenomenon that can be drawn from when developing an explanation for the anchoring phenomenon (i.e., *substantive details*).

## Case 1: Seth

### Seth's Anchoring Phenomenon

The physics group's NGSS PE is HS-PS2-1, which indicates that students will analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. This PE includes one DCI (PS2.A: Forces and Motion), which states that Newton's second law accurately predicts changes in the motion of macroscopic objects. The physics group chose to show a slow-motion video of a football being kicked as the anchoring phenomenon for their unit. This video starts with a football at rest and clearly shows the interaction between the kicker's foot and the football; this interaction causes the football to accelerate off of a tee and continue moving out of the (narrow) frame of the video. This anchoring phenomenon has potential for strong alignment with the DCI, is able to be divided into distinct segments, and includes substantive features. In the paragraphs that follow, I expand on these characteristics.

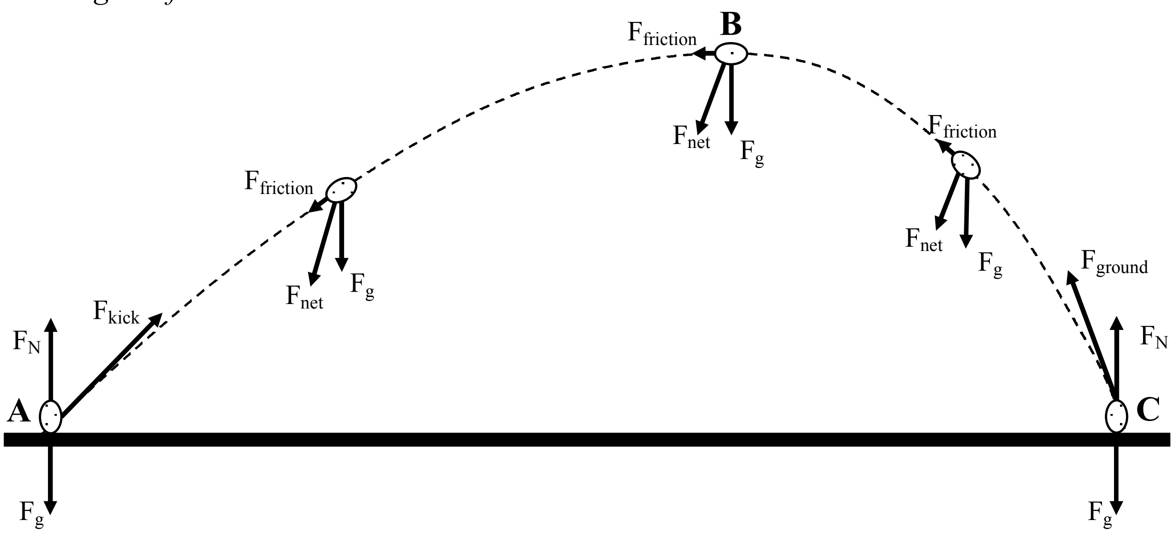
An explanation for the changes of the football's motion across its trajectory requires understanding the relationship between net force and acceleration highlighted in the NGSS PE. To provide an explanation, the trajectory can be divided into segments according to the motion of and net force acting on the football: before the kick, during the kick, and after the kick. The after the kick segment can be further subdivided into four segments: when the football is moving up, falling down, impacting the ground, and ultimately at rest on the ground. These different motion and net force pairs are important features of the anchoring phenomenon that can support students' engagement with the DCI. In particular, two segments of the trajectory involve no net force acting on the football (and thus no acceleration[5]); four segments of the trajectory involve net force acting on the football (and thus acceleration). In the paragraphs that follow, I provide an explanation for the trajectory of the football, highlighting the relationship between net force and motion within segments of the trajectory.

There are two segments of the trajectory in which there is no net force acting on the football (and therefore, no acceleration). First, there is no net force when the football is initially at rest on the tee: the force of gravity $F_g$, acting in the "down" direction, is balanced by the normal force $F_N$, acting in the "up" direction, resulting in no net force on the football. Second, there is no net force on the football when it is again at rest on the ground (after its flight through the air). Because there is no net force in either of these segments, there is no acceleration, so the football remains at rest.

There are four segments of the trajectory in which a net force is acting on the football, causing the football to speed up, slow down, and/or change direction (i.e., accelerate; see Figure 4-1). First, at point A, in addition to the force of gravity and the normal force acting on the football, the kicker's foot exerts a force on the football ($F_{kick}$). The football accelerates in the direction of the net force (i.e., speeds up in the direction of $F_{kick}$) while the kicker's foot is in

[5] Acceleration is defined as the rate of change of velocity. Because velocity is a vector quantity, having both magnitude—or size—and direction, a change in velocity (i.e., an acceleration) can occur by changing speed and/or changing direction.

Figure 4-1:
*Force Diagram for a Kicked Football*




contact with the football. Second, after the kick (between points A and B), air resistance (a frictional force; $F_{friction}$) acts in the direction opposite to the football's instantaneous velocity, and the force of gravity ($F_g$) continues to act in the "down" direction. The resulting net force ($F_{net}$) causes the football both to slow down and to change direction (an acceleration). The football changes speed because a component of the net force is parallel to the football's instantaneous velocity. The football changes direction (to follow a curved trajectory) because a component of the net force is perpendicular to the direction of the football's instantaneous velocity. At the highest point along its trajectory (point B), the net force has caused the football's vertical velocity to be instantaneously zero. At that point the football is traveling horizontally; immediately after this point it begins to fall back toward the ground. Third, between points B and C, the net force causes the football to accelerate back toward Earth because a component of the net force is parallel to the football's instantaneous velocity. Fourth, at point C, the football impacts the ground. At this point, the force of gravity and the normal force again act on the football, but the impact provides an unbalanced net force, $F_{ground}$, in the direction opposite to the football's instantaneous motion. This net force causes the football to decelerate and come to rest.

As is evident above, the explanation for the trajectory of a slow-motion video of a football being kicked aligns with the DCI, is divisible into distinct segments based on different force-motion pairings, and has relevant features (e.g., changes in speed along the path) that are explained by and can serve to support students' engagement with the DCI. In the sections that follow, I describe how Seth explicitly drew on these characteristics to elicit his students' ideas across the three microteaching lessons.

## Microteaching 1

During MT1, Seth used a predictive modeling task to elicit his students' ideas about the force(s) acting on the football throughout its trajectory. In order to specifically elicit students' ideas about force (i.e., ideas connected to the physics group's DCI), Seth focused students' attention on specific segments of the anchoring phenomenon, elevated particularly relevant observations, and scaffolded students' attention to segments and connections to the DCI as they developed their initial model. In the sections that follow, I describe how these moves supported Seth in eliciting his students' ideas during MT1.

### *Focusing on Segments*

After showing the anchoring phenomenon video to his students, Seth elicited their initial observations "when [the football] was just staying there in place" (before it was kicked) and after it was kicked. This move to focus students' attention on before and after segments of the anchoring phenomenon provided him an opportunity to elicit their ideas about these segments, including observations that the motion of the football is different in different segments. In response to his prompt, both Hank and Jen offered observations about the motion of the football. Hank shared that before the kick the football “wasn’t moving,” and Jen offered that after the kick “it started moving.” Hank also noted that “the ball kind of went up when it was kicked.” Hank also shared an observation that was not about the motion of the football, noting that “After the kicker kicked the ball he kind of like flew off the ground a little bit. As his leg came through.” Even though these observations do not directly tap students’ ideas about the DCI, Seth was able to elicit descriptions of the motion in different segments of the trajectory. As noted above, the DCI is central to explaining the motion in the different segments.

***Elevating Relevant Observations***

While Hank’s observation about the motion of the kicker was salient to the students, it was not as relevant to Seth’s learning goal as observations about the motion of the football (a feature of the anchoring phenomenon). Therefore, as a transition to the predictive modeling task, Seth elevated Hank’s other observation that “the ball kind of went up” after the kick and elicited students’ experience-based understandings of the path of the kicked football by asking, “Where do you think the ball is going to go after he kicked it?” In response, Jen offered that “the ball will come up and then eventually it’s going to hit its highest point and then come back down.” Seth acknowledged her idea was “interesting” and asked, “Why do you think that? Some sort of life experience? Jen replied, “Yeah just because I watch football and it’s not like, you kick it and eventually it’ll make its way back down. It’s not like a balloon that will stay in the air.” Seth’s move to elevate Hank’s observation about the motion of the football (instead of focusing on the motion of the kicker) and elicit students' ideas about the shape of the football's path served as a segue to elicit their explanations for *why* the football follows such a trajectory.

### ***Scaffolding Students' Attention to Segments and Connections to the DCI***

In order to elicit his students' explanations for why the football follows the predicted path, Seth asked his students to collaboratively develop a model of the football's trajectory "from being kicked until a point where you see fit to stop drawing the model. So maybe at the end of what you think the path is." In this predictive modeling task, Seth planned to focus students' attention on the DCI by asking them to include "the forces acting on the [foot]ball at every point [they] think is important" (Seth, MT1 lesson plan). During MT1, Seth explicitly prompted his students to "represent at every point [they] think a force on the ball is changing" and to "draw what [they] think those forces are," thus providing opportunities to elicit students' ideas about what forces are acting and about how those affect the motion of the football across the predicted path.

Seth's explicit move to connect the football's path (motion) to force supported his ability to elicit ideas connected to the DCI, since without this explicit focusing students may or may not have attended to forces along the path. According to Seth's post-MT1 interview, he anticipated that students' ideas about if and how forces acted on the kicked football would surface while they were developing their initial models, and, indeed, relevant ideas did surface during MT1. For example, during his post-MT1 interview Seth talked about how his students knew "the ball moved from the force of the kick" and that gravity causes the ball to follow a parabolic path. He also talked about his students' indication that gravity first began acting at the top of the football's trajectory (point B in Figure 4-1), which Seth recognized as being a "partial idea" for "how forces would cause motion." Seth contrasted this to ideas shared in his colleagues' microteaching lessons, noting that "every student basically had different ideas of when the forces were acting on the ball at what moments and what kind of forces were there." Seth reflected that where and how students drew forces acting along the kicked football's path served as "some indication where they're at," and he felt the predictive models showed "exactly where their thinking is" with respect to the DCI.

**Microteaching 2**

According to Seth's post MT1 interview, he and the physics group planned to "branch out" and support students in developing a "deeper understanding of Newton's second law" in MT2. Seth's plan for MT2 focused on exploring students' ideas related to the DCI by focusing students' attention on particular features of the anchoring phenomenon (e.g., where the football moves the fastest, the force of gravity acting throughout the path), defining and differentiating velocity and acceleration, and investigating the relationship between force and motion through an in-class activity that involved pushing a chair in the hallway. While the primary purpose of MT2 is to support ongoing changes in student thinking, during MT2 Seth elicited students' ideas in two ways: focusing his students' attention on particular features within specific segments of the anchoring phenomenon and scaffolding connections to the DCI through a model revision task (to elicit connections between "new knowledge" of the DCI from MT2 and their initial predictive model from MT1). In the sections that follow I describe how these moves supported Seth in eliciting his students' ideas during MT2.

### *Focusing Students' Attention on Particular Features Within Segments*

To re-center his students on the anchoring phenomenon and elicit their ideas about a relevant feature (the changing speed of the football), Seth began MT2 by asking them to consider a lingering question from MT1, "When is the ball moving the fastest in your model?" This feature is relevant to the explanation of the anchoring phenomenon because the net force acting on the football throughout its trajectory changes the football's velocity. In response Hank replied, "Probably when they kick it, right? When they first kick it." Seth restated Hank's idea and pressed him for an explanation, asking, "Why do you think that is?" Pam offered that the football is moving fastest when they kick it "because that's when the force is first applied." In this exchange, Seth's move to focus students' attention on the motion of the football along its path allowed him to elicit their ideas about a relevant feature of the anchoring phenomenon (the changing speed of the football at a particular point on its path) and a brief explanation that illustrates at least a surface-level engagement with the DCI (connecting force from the kick to the ball moving its fastest and, thus, perhaps the ball speeding up or slowing down—i.e., acceleration).

Building on the students' ideas about the location of the football's maximum speed, Seth next asked, "Why does the speed change" along the path? Seth further scaffolded students to draw on their ideas about motion and forces present in their initial model: "So if it's the fastest right after the kick is applied, what slows it down? Maybe one of these other forces that you guys put on the list [from MT1]? What do you think would be slowing it down?" Almost simultaneously, Jen offered "Gravity," and Hank said, "The ground." Seth pressed on Hank's response to further elicit the students' ideas about the motion of the ball along the path, asking "…so if the ground slows it down, does that mean it would move at the same speed through the entire path?” In response, Jen merged her idea with Hank’s, offering that both gravity and the ground have a role in changing the speed of the ball along the path. Seth’s move to focus students’ attention on how the speed of the football changes at various points along the path supported him in eliciting students’ ideas about relevant forces: gravity (a substantive feature of the anchoring phenomenon that shapes the path of the kicked football throughout its path) and the force from the ground (an important feature at the end of the path).

### *Scaffolding Connections to the DCI*

After engaging his students in an activity to investigate the relationship between force and motion, Seth concluded MT2 by engaging students in a model revision task (using their predictive model from MT1) in order to elicit connections between the MT2 activity and explanations of the anchoring phenomenon. To launch the model revision task, Seth instructed his students to “use [their] new knowledge [about the relationship between force and motion] and bring it back to the model of the football…[to] see if there’s any changes you want to make to your model.” During their model revision, Seth’s students partitioned the path of the kicked football into distinct segments, discussing the forces acting on the ball before, during, and after the kick (e.g., “pre-kick, no forces, because there’s no acceleration;” “it’s accelerating…while the foot’s on it;” “the ground also puts a force on it, because it stops”). They also talked about the ball going “up” and “down,” and the acceleration of the ball at various points on its path.

Through this task Seth was able to elicit students’ developing understandings of if and how forces change the motion of the football in each segment of their model. Seth was “surprised” that his students’ revised model did not include any forces acting on the ball during the “pre-kick” segment (when the ball is at rest), “Because in their first models, they had forces acting on the ball before it was kicked" (Seth, post-MT2 interview). In this instance, Seth's students may have been confusing zero net force acting on the motionless football with no forces acting on the football at all. Seth later positioned their "pre-kick, no forces" idea as being reasonable, saying that "it makes sense that they wouldn't understand that the net force being zero means no acceleration" because "we didn't really address net force [during MT2]."

## Microteaching 3

In order to elicit his students' ideas about (a) the force(s) acting on the football throughout its trajectory and (b) how force(s) change the motion of the football, Seth engaged his students in revising their predictive models during MT3. Two themes emerged in how Seth elicited his students' ideas. First, he focused students' attention on particular features of the anchoring phenomenon using explicit questioning and a model comparison activity. Second, when students were revising their initial model, he scaffolded their attention to segments of the trajectory, connections to the DCI, and features of the anchoring phenomenon. In the sections that follow I describe these two themes.

### *Focusing Students' Attention on Particular Features Within Segments*

Seth began MT3 by eliciting his students' ideas about two important features of the anchoring phenomenon: the speed of the kicked football and forces acting on the football. In the paragraphs that follow I describe how Seth's moves to elevate these features supported him in eliciting his students' thinking about ideas related to the DCI.

**Speed of the Kicked Football.** Similar to MT2, Seth began MT3 by focusing his students' attention on and eliciting their thinking about the speed of the kicked football along its path. This allowed Seth to confirm his students' thinking about the football's motion after the kick. However, in MT3 he leveraged a student's subsequent response to highlight the directionality of force(s) acting on a moving object, which is an important idea in the DCI relating to the concept of *net* force. After asking, "When does the ball move the fastest?" Seth reminded his students that they previously thought the football would move fastest "right after the force from the kick is applied." Pam agreed and suggested the football is fastest at the beginning because "everything has friction, some force, so like maybe like the air has some friction to it," which causes the football to slow down along its path. Seth reworked Pam's ideas about friction into a statement to highlight the its directionality, offering, "So the air could be providing a force opposite to the direction of motion of the ball, perhaps."

In this interaction, Seth's move to again focus students' attention on the motion of the football along its path supported his ability to confirm their ideas about where the speed of the ball is maximum as well as elicit Pam's idea about friction as a potential mechanism to explain why the ball changes speed along the path. Seth's decision to then build on Pam's idea by highlighting the directionality of force with respect to an object's motion (i.e., forces may or may not be in the direction of the object's motion) provided a segue to focus students' attention on and to elicit their ideas about another relevant detail of the anchoring phenomenon: forces acting on the football.

**Forces Acting on the Football.** Following his focus on the speed of the kicked football, Seth elevated particular forces acting on the football in two subsequent elicitation tasks. In the first Seth focused his students' attention on the force of gravity, asking if the anchoring phenomenon would "happen the same way on the moon." Seth's goal was to focus students' attention on and elicit their ideas about gravity (i.e., "one of the variables") as a mechanism that shapes the path and motion of the kicked football (Seth, post-MT3 interview). In response, Jen noted that "the moon has different gravity" than Earth, and Hank followed that the football would travel both farther and higher on the moon. Hank also added that, on the moon, "you don't have the friction"; Seth agreed and highlighted for the students how Hank brought the two ideas (gravity and friction) together in his explanation. Seth's move to focus on and elicit students' ideas about an important feature of the anchoring phenomenon (the force of gravity) paved the way for students to consider the role of gravity in their explanatory model in the next task.

In the second elicitation task, Seth further focused his students' attention on and elicited their ideas about forces acting on the football through a model comparison activity, in which students compared their model to one from another microteaching group. While the comparison model was similar to Seth's students' model in many ways (e.g., the general shape of the path and what was included as important points along the path), it also featured important differences (related to gravity, friction, and the normal force) that Seth hoped his students would notice, discuss, and improve on in their final model. In their model Seth's students indicated that the force of gravity only starts acting at the highest point in the football's trajectory, but they noticed the comparison model showed the force of gravity acting on the football at all points along the trajectory. Seth's students noticed that the comparison model did not include friction and that what they called the upward "force from the ground" on their model was labeled "normal force" on the comparison model. Seth's move to highlight how and when the forces of gravity, friction, and the normal force act on the football in the model comparison task supported him in eliciting his students' thinking about these forces in their final model.

### *Scaffolding Students' Attention to Segments, Connections to the DCI, and Features*

Following the model comparison activity, Seth asked his students to collaboratively develop a final model of the football's trajectory. In order to elicit their explanations for why the football follows the predicted path, Seth scaffolded consideration of segments of the trajectory by prompting his students to include "all the points that you deem important" during their model revisions. Later, Seth also focused his students' attention on net force (as a mechanism to understand how the motion of the football changes as it progresses along the path) by reminding them about the relationship between net force and acceleration (i.e., the DCI) and highlighting relevant features of the trajectory (e.g., changes in speed of and forces acting on the football).

As the group began drawing their model, students talked about relevant forces and the resulting accelerations at play along the trajectory. During the ensuing discussion, members of the group added arrows indicating forces acting on the ball at multiple points in their model. Pam suggested that "all [the points] have…gravity" and Jen added, "there was the force like, friction in the air," noting that "friction is going to be pushing against [the football]." Pam also recalled that the original model "had the force from the kick" and then questioned whether or not the group wanted to add "any of the accelerations, or anything." Pam shared that the group was confused about "how to draw the arrow" for each acceleration, later asking "if it has multiple forces, there has to be multiple forms of acceleration?" In response, Seth prompted his students to recall that a "net force on an object…would induce an acceleration" (i.e., the big idea from his MT2 lesson and the DCI) and highlighted how gravity—an important feature of this anchoring phenomenon—puts “a force on the ball at every point.” While it was apparent that Seth’s students knew the general shape of the trajectory and agreed with Seth’s statement that “the ball moved the fastest immediately after it was kicked,” they struggled to represent how multiple forces (friction, gravity) could simultaneously act on the football to explain its trajectory.

By scaffolding students’ attention to specific features of the phenomenon (e.g., the speed of the football and forces acting on the football) through explicit questioning and engaging students in the model comparison activity, Seth felt he was able to “gauge where the class was at” (Seth, post-MT3 interview). During his post-MT3 reflection Seth described that he was interested in identifying if students believed “forces can be acting opposite to the direction of an object’s travel.” Based on their revised model, Seth noted how his students “had the forces drawn…pretty well” but struggled to connect a net force in the direction opposite to an object’s motion with an acceleration in the direction of the net force (i.e., opposite to the object’s motion). Seth acknowledged that he was “trying to help them” through his questions linking net force and acceleration (i.e., making an explicit connection to the DCI) but figured “if we had actually done the simulation” in another microteaching lesson, “they probably would have gotten that.”

**Summary**

Each microteaching lesson focuses on a single, specific teaching practice (e.g., supporting ongoing changes in student thinking), but because eliciting student thinking is a key feature of responsive teaching, it is intended to be present in all of the microteaching lessons (i.e., eliciting is an explicit practice in MT1 and MT3 and an implicit practice in MT2). Across all three of Seth’s microteaching lessons he drew on three characteristics of the anchoring phenomenon (features, segments, and alignment with the DCI) to elicit students' ideas about the DCI. However, across MT1, MT2, and MT3, the ways he drew on these characteristics to elicit student thinking varied. In the paragraphs that follow, I summarize how he drew on each characteristic and describe variations in how he drew on these characteristics across his microteaching lessons.

In MT1 Seth built on the three characteristics of the anchoring phenomenon to prepare his students for and engage them in developing an initial model. Seth first elicited his students' observations within distinct segments of the anchoring phenomenon and then elevated specific observations of relevant features (within these segments) that supported their engagement with the DCI. Finally, Seth scaffolded students' attention to segments and connections to the DCI when launching the initial (predictive) modeling task of the trajectory of the football. In these elicitations, Seth provided opportunities for students to share their observations and scaffolded their preliminary explanations for the anchoring phenomenon.

To start MT2 Seth focused his students' attention on particular features within later segments of the football's predicted trajectory. Then, compared to the initial modeling task in MT1, the model revision task at the end of MT2 was more explicitly focused on the DCI in the NGSS PE, in which he asked students to "use [their] new knowledge [about the relationship between force and motion] and bring it back to the model of the football…[to] see if there's any changes you want to make to your model." According to his post-MT2 interview, Seth was "confused" by some of the what his students included in their initial model related to how forces were acting on the football at various points along the trajectory. Seth's move to have students connect the results of the activity (about the DCI) to their model revision represents a targeted way to clarify how his students thought the forces acting along the trajectory affected the motion of the football and simultaneously scaffold students' explanations of the anchoring phenomenon.

Seth began MT3 by again focusing his students' attention on particular features of the anchoring phenomenon (e.g., the change in speed of the football and the force of gravity acting throughout its path), and then scaffolded his students' attention to all three characteristics (segments, features, and alignment with the DCI) when engaging students in their final modeling task.

Although Seth drew from the same characteristics across all three microteaching lessons, the ways he drew from these characteristics to elicit student thinking varied. One difference occurred in how Seth drew on segments and features in MT1 as compared to in MT2 and MT3. In MT1 Seth focused his students' attention on the motion of the football as visible in the slow-motion video (before and during segments), while in MT2 and MT3 he focused their attention on the motion of the football along its predicted path after what was visible in the video (the after segments). In addition, in MT1 Seth focused his students' attention on the feature of changes in motion, while in MT2 and MT3 he focused their attention more specifically on the feature of changes in speed. Another difference was in how Seth drew on multiple characteristics to elicit student thinking through modeling. Across the three microteaching lessons, Seth drew on the alignment with the DCI by directing students to include in their models force (in MT1), what they learned about force and motion (in MT2), and how net force causes acceleration (in MT3). However, to help elicit students' ideas about these concepts in the DCI, he drew on the two other characteristics differently across his lessons. In MT2, Seth did not use any additional characteristics, relying solely on alignment with the DCI to elicit student thinking. In MT1 and MT3, Seth additionally drew on the characteristic of segments, focusing his students' attention on force in particular segments. In MT3, he also focused students' attention on features (i.e., the speed of the football after it was kicked) to elicit their model revisions, thus drawing on all three characteristics of the anchoring phenomenon.

## Case 2: Will

### Will's Anchoring Phenomenon

The chemistry group's NGSS PE was HS-PS1-4, which states that students will develop a model to illustrate the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. This PE includes two DCIs: (a) PS1.A (Structure and Properties of Matter): A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart and (b) PS1.B (Chemical Reactions): Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. The chemistry group chose to support students' engagement with the DCIs by investigating chemical bonds in the combustion of a gummy bear, as food is "pertinent" to students' lives and represents "accessible manifestations of the concept of energy stored in chemical bonds" (Chemistry group Big Idea Planning Tool, p. 1).

For MT1, one member of the chemistry group (Hank) demonstrated the combustion of a gummy bear in front of the entire methods class. To begin, Hank introduced the "really cool reaction" and prompted students to focus on the gummy bear, "which [is] going to be changing" (MT1 chemistry phenomenon video). Slowly, he began heating a white powder ("some stuff that we'll talk about in a little bit") in the bottom of the test tube using a blow torch. As he heated the test tube, the white powder changed into a clear liquid. When there was no white solid remaining, Hank inserted a single red gummy bear into the test tube. It immediately began reacting, and smoke, flames, and loud crackling noises were emitted from the test tube. At the conclusion of the reaction, smoke lingered in the classroom, and a black residue remained inside the warm test tube. This anchoring phenomenon has potential for strong alignment with the DCIs (i.e., the reaction can be explained by changes in total bond energy from reactants to products); it is divisible into before, during, and after segments; and it has features connecting the anchoring phenomenon to the DCIs. In the paragraphs that follow, I expand on these characteristics.

The combustion of the gummy bear can be described by the following balanced equation:

$$C_{22}H_{12}O_{11} + 12O_2 \rightarrow 12CO_2 + 11H_2O \text{ (+5,466 kJ)}$$

An explanation for the combustion of the gummy bear draws on changes in total bond energy as atoms in the reactants rearrange to form products during the reaction. In particular, the role of energy (from the blow torch and released as part of the change in bond energies across reactants and products of the reaction) represents a feature of the anchoring phenomenon that can support students' engagement with the DCIs. Additionally, the reaction can be partitioned into distinct before (reactants), during, and after (products) segments. In the demonstration, potassium chlorate ($KCLO_4$; a white powder at room temperature) in the test tube is slowly heated, causing it to decompose into potassium chloride ($KCl$; a clear liquid) and oxygen ($O_2$; an invisible gas). When the gummy bear (table sugar or sucrose, $C_{12}H_{22}O_{11}$) is placed into the test tube, heat energy (from the warm oxygen gas) allows the breaking of "high-energy" bonds between carbon atoms and between carbon and hydrogen atoms in the sucrose molecules. As bonds in the reactants are broken, and atoms begin to rearrange, bonds form in the products of gaseous carbon dioxide ($CO_2$) and water ($H_2O$). Because the bonds in the resulting products are lower in energy than those in the reactants, the reaction results in a dramatic release of energy (5,466 kJ/mol) to the surroundings (in the form of heat, light, and sound).

As is evident above, the explanation for the combustion of a gummy bear aligns with the DCIs, is divisible into distinct segments based on changes from reactants to products in the reaction, and has relevant features to support students' engagement in the DCIs. In the sections that follow I describe how Will drew on these characteristics of the anchoring phenomenon to elicit his students' ideas across all three microteaching lessons.

## Microteaching 1

In MT1, Will engaged students in developing an initial explanation for what happened to the gummy bear in order to elicit their ideas about changes in both matter and energy during the reaction. In order to elicit students' ideas about changes in bond energy, specifically (i.e., the DCIs), Will focused students' attention on particular features within segments of the reaction, elevated relevant observations of reactants and products in the reaction, and explicitly directed students to consider changes at the molecular level. In the sections that follow, I describe how these moves supported Will in eliciting his students' ideas during MT1.

### *Focusing Students' Attention on Particular Features Within Segments*

After observing the anchoring phenomenon "live," Will planned to elicit his students' initial observations by focusing their attention on specific features of the reaction, asking, "What did you see? What did you hear? …what did you smell?" According to Will's MT1 lesson plan, he anticipated that students might attend to relevant features such as the "light, heat, sound, and smoke created by the reaction" and "the gas bubbles that were shown as the $KClO_4$ melted." During MT1, Will's students shared observations about the change in color of the gummy bear; the heat and light produced throughout the reaction; and other sights, sounds, and smells of the reaction. These observations are important because they ultimately provide clues to draw from when developing an explanation for how and why the reaction occurs.

Will further reframed his students' attention to substantive changes in the reaction by organizing their observations into reactants and products. Will summarized the reactants as "the gummy bear, the white chemical, the heat from the torch that Hank used" and elicited their observations of the products present at the conclusion of the reaction. In response, his students identified light, smoke, and gas, and Ann noticed "something left in the bottom" of the test tube. Will's move to organize students' observations into reactants and products supported their attention to changes in both matter and energy throughout the reaction.

### *Elevating Relevant Observations*

Ann's observation about "something left in the bottom" of the test tube was certainly an obvious remnant of the chemical reaction, but—compared to other observations about energy—it was not as relevant to Will's learning goal. Additionally, Will viewed the presence of the black solid as potentially a "distraction" to the "main idea" about chemical reactions, and he felt this particular detail could have been challenging to work with because, for a surface-level explanation of the combustion reaction "there's not any sort of leeway for this mysterious black solid to be leftover." This is because the material products for complete combustion of any fuel include only gaseous $CO_2$ and $H_2O$; the "black solid" is a result of incomplete combustion, which occurs when there is not enough oxygen to react with the fuel. Therefore, to elicit his students' understanding of the role of energy in the reaction, Will elevated their other observations about products of the reaction. Will prompted his students to think about "where the heat and light came from" and to identify "the source of the heat and light" in the reaction. Will's students offered ideas about "bonds breaking," "energy being given off from the gummy bear…in the form of light," and that "the flame…caused for the transfer of energy" as part of a chemical reaction. Will's move to focus students' attention on heat and light served to elicit their ideas about energy (i.e., ideas related to the DCIs) and supported him in further eliciting an explanation for the anchoring phenomenon.

### *Attending to Changes at the Molecular Level*

Will prompted his students to develop "an explanation for why did the gummy bear disappear" by asking them to think about "What really happened to the gummy bear?" and to "talk about what we can't see - the molecules." Will's students drew from their observations of before, during, and after segments of the anchoring phenomenon to develop an initial explanation for what happened to the gummy bear. When developing their explanation, Will's students discussed what was "initially there" and that "the bonds were converted," "giving off energy" at the conclusion of the reaction. While Will's students did not discuss specific material products of the reaction, they did discuss, at length, types of bonds (e.g., "high-energy bonds") present in the reactants and their role in explaining how the energy in the candy is "transferred into the form of heat and light" (when high-energy bonds break during the reaction).

Will's explicit move to specifically prompt his students to attend to the molecular level when developing their explanation for the anchoring phenomenon supported his students to consider changes in chemical bonds during the reaction. During his post-MT1 interview, Will reflected on how his students engaged in the lesson at a high level and attended to unobservable features of the reaction at the microscopic level: they developed “a molecular model” and indicated that “bonds in the model that [will] break somehow and release energy.” However, he noted that some students’ ideas about how energy is involved in bonding (e.g., Ann’s statement that “breaking bonds equals give off energy,” or Dawn’s summary that “the candy was converted into the light that we saw, as well as the heat”) represented “alternative conception[s]” and provided a “teachable thing to move forward with.”

**Microteaching 2**

During MT2 Will did not explicitly draw on any characteristics of the anchoring phenomenon to elicit his students’ thinking. Instead, Will spent the vast majority of MT2 teaching his students about chemical bonding. However, features of the gummy reaction did surface in his lesson. For example, Will elevated his students’ observations of the combustion reaction from MT1 (e.g., the light and smoke produced during the reaction, that a “chemical reaction [took] place”) to introduce the primary activity for MT2, an online simulation designed to illustrate how energy is involved in chemical bonds. Additionally, during a follow-up discussion about the results of the activity, Dawn made a connection back to a specific detail of the anchoring phenomenon. Will had asked, “How is energy involved in the formation of a bond?” In response, Dawn posited that “heat was involved in changing the state of the gummy bear, so it would probably be involved in changing the bonds? So it would require energy to break the bonds?” Will responded to the latter of Dawn’s questions but did not respond to the former (which was connected to the anchoring phenomenon). Despite intending to conclude

MT2 by asking students to make connections between the activity and the gummy bear reaction (Will MT2 lesson plan), Will ran out of time and did not follow up on Dawn's connection to the anchoring phenomenon.

### Microteaching 3

During MT3 Will again adopted a teaching stance, heavily guiding his students to revise their initial explanation for the gummy bear reaction by providing a before, during, and after framework. To specifically elicit their ideas about energy in the reaction (i.e., the DCIs), Will again focused their attention on features present within distinct segments of the anchoring phenomenon that he then leveraged to scaffold connections to the DCIs. In the sections that follow, I describe how these moves supported Will in eliciting his students' ideas.

#### *Focusing Students' Attention on Particular Features Within Segments*

Early in MT3 Will began eliciting his students' recollections of features of the gummy bear combustion reaction that they had included in their initial explanation from MT1 by prompting them to "identify what our reactants and products are." Will's students identified glucose as a reactant, recalled the chemical in the test tube, and remembered how heat was applied to the test tube at the beginning of the reaction. Will further scaffolded students to recall $CO_2$ and $H_2O$, specifically, as products of the reaction. The reactants and products, as features of the anchoring phenomenon, were important to highlight because they represent what is changing across the reaction and provide clues to draw from when developing an explanation for how and why the reaction occurs.

### *Scaffolding Connections to the DCIs*

After Will highlighted relevant features of the reaction, he drew on differences between reactants and products to focus students' attention on the role of energy in the reaction and encourage connections to the DCIs. Will elicited his students' ideas about "bonds breaking and forming" by reminding them "if we're starting with $O_2$ and we're getting $H_2O$ through some sort of rearrangements, what has to happen for $O_2$ to become $H_2O$?" In response, Will's students shared ideas about how energy is involved in bonding. Ann recalled that "it requires energy to make a bond, because I remember it seems opposite to me," and later continued, "when bonds break it releases energy." Dawn helped correct Ann's statement about energy being released when bonds break by offering that "glucose"—a reactant present in the gummy bear—"isn't going to just break" (without some addition of energy). Will further reminded Ann of the online activity from MT2, which showed "it requires energy to break that bond." During his post-MT3 interview, Will reflected that he ultimately did not have enough time during MT3 to engage his students in developing a full, revised explanation for the combustion reaction. However, through his continual work focusing students' attention on particular features within distinct segments of the reaction, Will was able to elicit his students' developing ideas about how energy is involved in the formation of a chemical bond.

## Summary

As mentioned above, each microteaching lesson focuses on a specific AST practice, but the practice of eliciting student teaching is intended throughout all three microteaching lessons. Will drew on three specific characteristics of the anchoring phenomenon (features, segments, and alignment with the DCIs) to elicit student thinking and scaffold their developing explanations during MT1 and MT3. During MT2 Will prioritized "teaching about" content in favor of "learning about" his students' thinking and, as such, did not draw on any particular characteristics of the gummy bear reaction to elicit his students' developing thinking in that lesson. Although Will drew on the same three characteristics of the anchoring phenomenon in MT1 and MT3 and drew on two of these characteristics similarly across the two lessons, he drew on the third characteristic differently across the two lessons. In the paragraphs that follow, I summarize how he drew on each characteristic in each lesson and describe these similarities and differences.

During MT1 Will focused his students' attention on particular features of the chemical reaction, which he organized into reactants and products—i.e., segments of the reaction. He then elevated and built on relevant observations of the reaction to further focus his students' attention on energy in the reaction (i.e., the DCIs). Finally, Will scaffolded his students' developing explanations by directing them to attend to changes at the molecular level when developing an initial explanation for the reaction, during which they discussed changes in bond energy throughout the reaction (i.e., they made the connection between the reaction and the DCIs).

In MT3 Will adopted a "teach about" stance, yet he drew on characteristics of the anchoring phenomenon to elicit his students' ideas about bond energy in the gummy bear chemical reaction. As in MT1, Will again focused his students' attention on particular features within segments of the anchoring phenomenon (e.g., what is present at the beginning and end of the reaction) but in MT3 he heavily scaffolded students to connect their developing explanation for "What happened to the gummy bear?" back to the DCIs (changes in bond energy). Even though Will ran out of time to have his students formally revise their initial explanation for the gummy bear reaction, throughout MT3, Will was able to successfully elicit students' ideas related to changes to chemical bonds in a reaction.

In Will's MT1 and MT3 lessons he similarly drew on the segmenting of the anchoring phenomenon into reactants and products and did so to focus students' attention on and elicit their ideas about particular features of the reaction within these segments. However, Will drew on the alignment between the gummy bear phenomenon and the DCIs differently in the two lessons. In MT1 Will asked students to attend to the molecular level when developing their initial explanation for the gummy bear reaction, from which they discussed and he highlighted ideas about chemical bonding and changes in bond energy (i.e., the DCIs). While Will did answer one student's question about which types of bonds in the reactants were considered "high-energy," he did not explicitly direct students to attend to changes in energy in the reaction during MT1. In contrast, during MT3 Will explicitly scaffolded connections to and elicited students' ideas about how bond energy changes in a chemical reaction.

## Comparison Between Seth and Will

Both Seth and Will drew on three primary characteristics of their respective anchoring phenomena—features, segments, and alignment to the DCI(s)—when eliciting student thinking. Although the teachers integrated features and segments to elicit student thinking in similar ways, their elicitations drew on different types of connections to their respective DCI(s). I discuss this similarity and this difference in the sections below.

**Features and Segments**

Across their respective microteaching lessons, both Seth and Will tended to elicit students' ideas about important features of their respective phenomena within distinct segments of the phenomenon. The presence of features seemed to help both Seth and Will define segments of the anchoring phenomena in which to elicit students' ideas about their respective DCI(s).

Seth's slow-motion video of a football being kicked included "before, during, and after" segments, each containing a primary feature that is explained by the DCI. Before the kick the football is at rest, and there is no net force, so there is no acceleration. In this segment, the feature is the constant motion (the football is at rest) and no net force, which can be drawn from when developing an explanation based on the DCI. During the kick the net force provided by the kicker's foot causes an acceleration in the direction of motion (the ball speeds up). In this segment, the feature is the force of the kick and the change in motion, which is in the same direction as the force of the kick. After the kick the foot is no longer in contact with the football, and the ball proceeds upward and out of the frame. However, instead of simply focusing on the football within the frame of the video, Seth's primary elicitation task was for his students to predict the subsequent path of the kicked football and to explain the path based on the forces acting on the football at various points (e.g., as the kicked football is moving upwards after the video). Unlike what was visible in the video (in which the net force from the foot was acting in the direction of the change in motion of the football), having his students draw the predicted trajectory on the way up allowed Seth to elicit his students' ideas about how a net force that is *not* acting in the same direction of motion changes the football's motion, thus allowing for a deeper engagement with the DCI.

Seth used these segments to elicit student ideas in MT2 and MT3. During these lessons he focused students' attention on the changing speed of the football—a feature of the anchoring phenomenon that connects to the concept of acceleration and, thus, the DCI—by asking, "When is the ball moving fastest in your model?" Seth's move to highlight the changing speed also drew on the ability to consider the predicted trajectory in segments of different force-motion pairs (and in this example, the constant force of gravity slows the ball as it travels upward, so the ball is moving fastest immediately after the kick). By extending the task beyond what was visible in the video, Seth drew in additional segments—consisting of features explained by the DCI—that supported his ability to elicit students' ideas about the DCI.

Similarly, Will's gummy bear demonstration could also be considered in terms of "before, during, and after" segments, which were defined by features: a hot, liquefied white powder and gummy bear (before the reaction); heat, light, and smoke (during the reaction); and smoke and heat (after the reaction). The heat, light, and smoke during the reaction can be explained by the rearranging of atoms in reactant molecules to form products with bond energies lower than those in the reactants (i.e., the DCIs).

During MT1 and MT3, Will elicited students' ideas about relevant features of the reaction (e.g., the heat and light produced throughout the reaction), which he subsequently reframed into reactants and products (i.e., segments) of the reaction, and then focused their attention to explaining changes within these segments. By drawing on specific features of the reaction as a way to focus students' attention on changes within segments of the reaction, Will was able to successfully elicit students' ideas about the DCIs.

### Connections to the DCI(s)

Both Seth and Will were successful in eliciting students' thinking about ideas in their respective NGSS PEs across their microteaching lessons. However, they differed in the extent to which they explicitly scaffolded connections to the DCI(s) during elicitation tasks.

Across all three microteaching lessons, Seth consistently scaffolded students in making connections to the DCI. For example, when launching the initial modeling task during his MT1 lesson, Seth scaffolded an explicit connection to force in the DCI by asking his students to "try to represent at every point you think a force on the ball is changing. I want you guys to draw what you think those forces are." Similarly, in both MT2 and MT3, Seth also scaffolded explicit connections to force (and, later, acceleration) when eliciting subsequent revisions to his students' initial model.

In contrast, Will became more focused on scaffolding connections to the DCIs over the course of his microteaching lessons. For example, during MT1 Will never explicitly asked students to attend to chemical bonding or energy in the reaction (the equivalents of "force" for the chemistry group's DCIs). Instead, Will asked his students to "talk about what we can't see—the molecules" as they developed an initial explanation for the combustion of the gummy bear, yet his students, who he claims engaged "at the college-student level" (Will, post-MT1 interview), responded by attending to changes in bond energy and, therefore, the DCIs. By his MT3 lesson, however, Will was more explicit in eliciting his students' thinking about ideas in the DCIs. During this lesson he scaffolded students to consider how differences in reactants and products could be explained by changes in chemical bonds (and, by extension, changes in energy).

# CHAPTER FIVE: DRAWING ON UNDERSTANDING OF STUDENT IDEAS TO ELICIT STUDENT THINKING

In this second findings chapter, I describe how each preservice teacher drew on his understanding of student ideas to elicit student thinking across three microteaching lessons, paying particular attention to the teachers' understanding of ideas represented in their respective learning progressions. For each preservice teacher, I first provide a brief overview of his microteaching lessons. Next, I describe his planning for, eliciting student thinking during, and reflecting on each lesson. I conclude this chapter with a comparative summary about how Seth and Will drew on their understanding of student ideas to elicit student thinking.

## Brief Overview of Seth's Microteaching Lessons

Seth's physics group planned to support their students' engagement with the DCI by designing their unit of instruction around the anchoring phenomenon of a slow-motion video of a football being kicked. This video clearly showed a kicker's foot striking a football, causing it to accelerate off the tee and into the air. During MT1 Seth planned to prompt his students to predict and develop a preliminary explanation for the trajectory of the kicked football by creating an initial model of the event. Seth planned to support his students' developing understanding of relevant ideas by engaging them in a series of activities related to Newton's 1$^{st}$ and 2$^{nd}$ Laws during MT2 and pressing them to revise their initial model during MT3. He also planned to engage his students in a written summative assessment at the end of MT3. At the conclusion of the unit, Seth hoped his students would understand the relationship between force, mass, and acceleration and be able to "describe how forces can affect motion in macroscopic objects" to explain the path of the kicked football (Seth, MT1 lesson plan). In the sections that follow, I use evidence from Seth's planning for, enacting, and reflecting on MT1, MT2, and MT3 to describe how he drew from his developing understanding of student ideas to elicit his students' thinking about the anchoring phenomenon across the three microteaching lessons.

## Microteaching 1

The purpose of MT1 is to introduce students to the anchoring phenomenon for the unit and to elicit their initial explanation for how and why the anchoring phenomenon occurs. When planning for and enacting MT1, Seth anticipated some student ideas, including some in the LP-P. In his post-MT1 interview, Seth was reflective about decisions he made while eliciting student thinking during the lesson. In the sections that follow, I describe how Seth drew on his understanding of student ideas while planning for, eliciting student thinking during, and reflecting on MT1.

### Planning for MT1

For MT1 Seth planned to focus his students' attention on and elicit their ideas about how forces shape the trajectory of the kicked football. According to his post-MT1 interview, Seth anticipated his students may not have a "complete understanding" of how gravity acts on the ball and also may think the force from the kick would be carried along with the moving football (i.e., the impetus idea on the LP-P). Seth planned to encourage his students to "think about [the video] in terms of forces" (Seth, post-MT1 interview), which provided an initial framing to support students' engagement with the anchoring phenomenon in alignment with the DCI. Following this prompt, Seth planned to elicit his students' ideas about which forces act on the football at "important" points in its trajectory by having them draw a predictive model of the football's path and prompting them to include “the forces acting on the [foot]ball at every point you think is important” (Seth, MT1 lesson plan). Seth’s decision to engage students in this predictive modeling task allowed him to elicit student ideas related to the DCI (some of which are also represented in the LP-P).

**Eliciting Student Thinking During MT1**

Seth’s plan to engage his students in the predictive modeling task was successful in eliciting their thinking about what forces are acting on the football throughout its trajectory and how those forces change the motion of the football. During his post-MT1 interview, Seth talked about how he anticipated the two aforementioned “alternative ideas” from the LP-P would surface during MT1 and how he attempted to verify one of these ideas during the lesson.

First, Seth anticipated that his students may or may not have a “complete understanding” of how gravity acts on the ball, and he was prepared for students to indicate that “gravity started at a certain moment” along the ball’s predicted path. This idea is consistent with LP-P:2, motion is associated with applied force, and surfaced when students were developing their predictive model. During this predictive modeling task Seth’s students discussed the motion of the kicked football as it neared, and passed, the highest point in the trajectory, and they posited that gravity began acting at the top of the trajectory might explain why the football began to fall back toward Earth. While discussing how to include the force of gravity on their model, Jen said, “Like when it starts to come back down. I’ll just put like, from here maybe?” (pointing to the top of the trajectory). Hank replied, “Yeah, that’s where I’d say gravity starts.” According to his post-MT1 interview, Seth noticed that Hank and Jen indicated the force of gravity begins acting at the top of the football’s trajectory and attempted to verify the group’s thinking about gravity by asking, “So…from that model, you guys think that gravity starts right when the [foot]ball reaches its highest point, that’s when gravity starts to act on the [foot]ball?” Jen agreed and justified their model, saying, “Yeah, because that’s when it starts to go down,” and at the same time Jen said, “‘cause it stops.”

Second, Seth anticipated the impetus idea from the LP-P would surface in his students’ initial model. When launching this predictive modeling task, Seth prompted his students to "represent every point you think a force on the ball is changing …draw what you think the forces are. So for example, at the beginning when he kicks the [foot]ball, what do you think the forces are on the [foot]ball?" Students sometimes think that a force is acting on the football in the direction of motion and, for the football traveling up from the ground, identify this force as the force of the kick; therefore, prompting students to represent the forces acting on the football has the potential to elicit the idea that a force is carried along with the football (i.e., the impetus idea). During his post-MT1 interview, Seth noted that his students did not draw “the force of the kick following the [foot]ball” on their initial model, which he interpreted as meaning they thought “the force from the kick acted once and then didn’t continue to act.”

**Reflecting on in-the-Moment Decisions About Eliciting Student Thinking in MT1**

During his post-MT1 interview, Seth reflected on two decisions he made during MT1 with respect to ideas he anticipated eliciting in the lesson. One decision was about his attention to slight differences in how students responded to his verification question about when in its trajectory gravity started acting on the football; another was about his choice to *not* follow up on the impetus idea that was not present in his students’ initial model. In the paragraphs below, I describe Seth’s reflections about each.

Seth was reflective about his attention to slight differences in students' responses in the moment of instruction. As mentioned above, Seth anticipated that his students might think gravity started acting at the top of the football's trajectory. During the lesson, his students appeared to express this idea in their initial model, and when Seth tried to verify this interpretation, Jen and Hank responded "Yeah, 'cause that's when it starts to go down" and "'cause it stops," respectively. In the moment, Seth followed Jen's idea. However, when reviewing the video recording of this exchange during his post-MT1 interview, Seth reflected about the importance of attending to "slight wording differences" when students share their understandings, as they may be evident of different ideas. He reflected that Hank's statement "'cause it stops" could indicate "that's when…the upward motion stops and the downward motion starts" (simply describing the motion of the football), or he "could mean that's where the force from the kick stops acting on it" (representing an idea consistent with the impetus conception from the LP-P).

Seth was also reflective about his decision to not follow up on the impetus idea that was not present in his students' initial model. As mentioned above, Seth anticipated that the impetus idea would surface while students were developing their initial models, but because his students did not draw "the force of the kick following the [foot]ball" he assumed his students (correctly) thought "the force from the kick acted once and then didn't continue to act." However, during his post-MT1 interview, Seth reflected that just because his students did not explicitly draw a force connected to the football in their initial model, that didn't necessarily mean that they did not have impetus-related ideas. Seth went on to say that he "should've pressed on that more" during MT1 as he "was a little surprised that they didn't draw the force from the kick continuously."

## Microteaching 2

The MT2 lesson is intended to support ongoing changes in student thinking, and eliciting student thinking is an implicit part of this work. Seth showed sensitivity to student ideas—including some in the LP-P—when planning for, eliciting student thinking during, and reflecting on his MT2 lesson. Specifically, Seth drew on his understanding of two ideas in the LP-P to plan MT2 with his physics group. Then, while enacting instruction during MT2, Seth asked his students a question designed to specifically elicit their thinking about one of those ideas. Later, during his post-MT2 interview, Seth illustrated sensitivity to the ideas he elicited during MT2 as he reflected on his own teaching moves. In the sections that follow, I describe how Seth drew on his understanding of student ideas across each of these phases of the MT2 cycle.

### Planning for MT2

Seth drew on his understanding of two ideas in the LP-P to plan MT2 with his physics group: (a) impetus and (b) velocity as proportional to the applied net force. According to his post-MT2 interview, Seth and his physics group used the LP-P to interpret their students' initial models (from MT1) and plan MT2 to either "strip away the idea of impetus" or "show a student how force is related to acceleration." Seth discussed how he was unsure if his students "had the idea of impetus or not," as according their initial model, it wasn't clear "if they were aware that there could be no force and the object could still be moving in a certain direction." From his colleagues' students' initial models, it was clear that they held the impetus idea, so Seth "just assumed [his] students did as well." However, instead of designing a lesson to "draw out impetus-related ideas," Seth and the rest of his physics group planned to address another idea on the LP-P: that the velocity of an object is proportional to the net force acting on the object. Seth and his physics group planned to teach their students about the difference between velocity and acceleration before engaging them in an activity to help figure out "whether force is directly proportional to velocity or acceleration" (ideas consistent with LP-P:3 and LP-P:4, respectively). After the activity Seth then planned to engage his students in a discussion (to help them make sense of the results of the activity), during which he anticipated his students may identify velocity as being proportional to force. Additionally, Seth planned to leave time for his students to revise their initial model of the anchoring phenomenon, which he hoped would include "force, velocity, and acceleration vectors clearly drawn."

**Eliciting Student Thinking During MT2**

In addition to drawing on the LP-P to plan MT2, during the lesson Seth asked a question he hoped would elicit ideas in the LP-P consistent with level 3 (velocity is proportional to force) and level 4 (acceleration is proportional to net force). Seth planned to elicit these two ideas by prompting his students to discuss the "mystery factor" in the force and mass equation (i.e. Newton's 2$^{nd}$ Law: the acceleration of a macroscopic object is directly proportional to the net force acting on the object and inversely proportional to its mass).

According to his post-MT2 interview, Seth anticipated and hoped that students would identify force as being proportional to velocity (instead of acceleration) as they discussed the results of the activity because "it makes a little bit of intuitive sense that if you push something, it moves. So force equals motion, and velocity is something of motion." In response to Seth's prompt, Jen posited that the mystery factor might be velocity "because we talked about [the] speed, velocity" in each activity. Seth noticed Jen's idea, positioned it as "reasonable," and responded with further instruction about the relationship between force and acceleration (during which he made explicit connections back to the results of the activity).

**Reflecting on in-the-Moment Decisions About Eliciting Student Thinking in MT2**

Seth illustrated sensitivity to student ideas during his post-MT2 interview by reflecting on his tendency to inaccurately revoice students' responses while eliciting their thinking "into what [he] understood of it, instead of what they said." One exchange at the beginning of his MT2 lesson was particularly salient for Seth. To begin the lesson, Seth elevated two of his students' lingering questions from MT1 that were "related to acceleration": "When does the [foot]ball move the fastest?" and "Why does the speed change?" In response to the first question, Hank said, "Probably when they kick it." Seth replied, "So, after you kick it, it will be going the fastest." During his post-MT2 interview, Seth reflected that he "reworded [Hank's statement] in the way that [he understood] the concept. But they perhaps don't understand it in that way." Seth went on to explain that his students may have thought, "'When it's kicked' could mean, like, during the entire time, the [foot]ball is in contact the foot. Or, it could mean … what I thought I meant in the moment, which is right after. So, after they separate." During his post-MT2 interview, Seth acknowledged that he was thinking "in the moment of the kick as, like, an instantaneous impulse," but—upon reflection—he recognized students may not think about it in the same way and was conscious that his rewording of Hank's statement could have inadvertently shifted his intended meaning.

## Microteaching 3

The purpose of MT3 is to press students to develop an evidence-based explanation for how and why the anchoring phenomenon occurs. Seth again drew on his understanding of student ideas when planning for, eliciting student thinking during, and reflecting on his MT3 lesson. In particular, Seth drew on his understanding of his students' ideas to plan and enact three elicitation tasks in MT3: one to engage students in the lesson initially, one to provide evidence of changes in their thinking about the anchoring phenomenon, and one culminating activity to assess his students' ability to apply their knowledge to new scenarios. In the sections that follow, I describe how Seth drew on his understanding of student ideas across each of these phases of the MT3 cycle.

### Planning for MT3

Based on his post-MT3 interview, Seth was "ready for" the impetus idea (from the LP-P) and anticipated his students would not yet fully understand that "force is directly proportional to acceleration [and] force is directly proportional to mass." He did, however, expect his students to "understand that gravity acts on all earthly objects in the same way," that the "gravitational acceleration is constant," and that "friction is a force that opposes the direction of motion of the object." For MT3 Seth planned three tasks designed to elicit his students' ideas about the relationship between force and motion. First, Seth planned to revisit a question from MT1 about the speed of the kicked football. Second, Seth planned to "work with students to finalize each moment on the model" (Seth, MT3 lesson plan) by having them compare and contrast their initial model with a model from another group. Third, Seth planned to administer a written summative assessment to "see how well you can apply your knowledge to some new problems"

(Seth, MT3 lesson plan). Seth's decision to engage his students in these three elicitation tasks allowed him to elicit student ideas related to the DCI and, especially in the written assessment, to elicit specific ideas from the LP-P.

### Eliciting Student Thinking During MT3

During MT3 Seth enacted three separate elicitation tasks designed to allow his students to show what they know about ideas in the DCI. In the sections that follow I describe how Seth drew on his understanding of student ideas to enact each task.

#### *Revisiting a Question from MT1*

Seth began MT3 by eliciting his students' thinking about when the kicked football was moving fastest along its trajectory (a student's question from the MT1 lesson). According to his post-MT3 interview, Seth figured that a "good explanation of why the [foot]ball is the fastest right after the force is applied would show that they understand that it would be slowing down due to air resistance…[and] that gravity would be acting on it," but that in the event his students didn't share a "really good explanation," he would use their answer to "gauge where the class was at" on the LP-P.

#### *Model Revision*

Across all three MT lessons, Seth engaged his students in modeling the anchoring phenomenon as a way to elicit their ideas about how force shapes the motion of the kicked football. During MT3 Seth asked his students to compare and contrast their model with another model (which served to elevate ideas that Seth anticipated his students would understand by the start of MT3) and build on substantive differences between the two models to construct a final model of the anchoring phenomenon. Seth expected his students would have a sense for how friction and gravity "fit together" in the context of their anchoring phenomenon, but he also anticipated students might have ideas consistent with the impetus conception on the LP-P. In the event he noticed students were incorporating impetus-related ideas into their model revisions, Seth planned to confirm those ideas by asking, "Is force X attached to object Y?" (Seth, MT3 lesson plan).

In his post-MT3 interview, Seth described two things he had noticed about his students' thinking during the model revision task. First, Seth noticed that his students did not represent ideas consistent with the impetus conception, and he confirmed this interpretation by asking questions about forces acting at individual points along the trajectory. Second, Seth noticed that his students were struggling to reconcile the ideas of net force and acceleration for the interaction between the ground and the football at the end of the trajectory. Specifically, Seth noticed his students' model had the force from the ground "drawn in the wrong direction." The students had drawn the force from the ground acting "straight up" instead of at an angle opposite to the direction of the football's instantaneous velocity at that point (see Figure 4-1). As drawn, this force would not result in the football accelerating in the direction his students indicated on their revised model.

### *Written Assessment*

Seth concluded MT3 by having students complete a four-item summative assessment task, each item of which had the potential to elicit ideas related to the LP-P and DCI. According to Seth's post-MT3 interview, his physics group chose to include this written assessment because they "really wanted to see if [their students] could apply these concepts [from the MT lessons] and they weren't just memorizing the path of the football." During this interview, Seth indicated that his physics group figured their students "were around a three range" on the LP-P. In order to assess "the difference between a three and a four," his group developed four questions, with "each problem…designed to get at specific concept" from the LP-P. "So if they got number one wrong, then they're missing this chunk. If they got number two wrong, they're missing this chunk." In the paragraphs that follow I describe the four questions, Seth's "ideal" answer for each, Seth's reflections on how students at different levels of the LP-P might respond to each question, and Seth's interpretations of student responses to some of these questions.

The first written assessment question was about a horizontal force acting on an object moving in the horizontal plane:

> Q1: Mike is driving down a flat road in his 2016 Mustang and there is a constant force on the car (from the badass 3.7-liter engine). Mike notes his car is going faster and faster. Is this possible? Or has he broken the laws of physics? Explain.

In his MT3 lesson plan, Seth indicated that an "ideal" answer would be, "Yes, this is possible. Since force is directly proportional to acceleration, and the badass engine is applying a constant force to the car, the car will be constantly accelerating, or getting faster and faster." Such a response is clearly connected to the DCI and is consistent with LP-P:4. During his post-MT3 interview, Seth talked through how students with ideas consistent with other levels of the LP-P might respond to this question. Seth reflected that "level one students might be able to guess at the right answer," noting that they "can be all over the place." Level two students "would definitely say constant force means constant velocity." Level three students "might be a little confused," or they might say, "No, it's not possible, because constant force equals constant velocity. Or they might know that wait, cars can accelerate. So of course it is possible." He went on to say that the level three response is "sort of what we intended to get from that question is, do they know that F=m*a, rather than F=m*v" (i.e., one "chunk" that is different between LP-P:3 and LP-P:4).

The second written assessment question was about how a constant force (from gravity) explains zero velocity at the top of an object's trajectory:

> Q2: Patrick throws a D20 (a dice [sic] with 20 sides) straight up into the air. When it reaches the highest point in the path, why is the velocity of the die zero? (Neglecting air resistance).

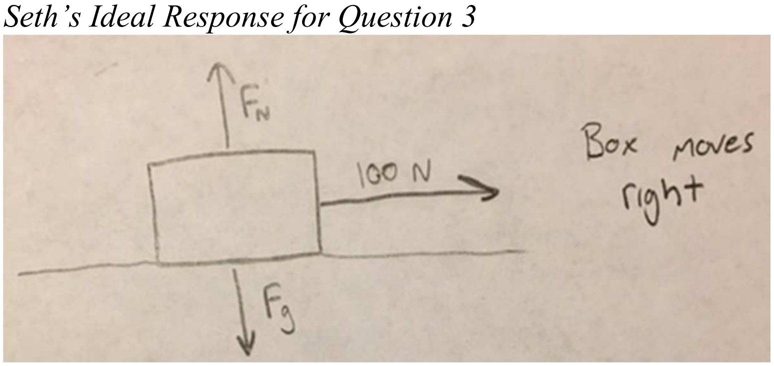
According to his MT3 lesson plan, Seth's "ideal" answer would be, "Initially the die accelerates due to the force from Patrick's hand, but the force of gravity constantly decelerates it to zero at the highest point in the path." This response is connected to the DCI and is consistent with LP-P:4 in that it shows an understanding of a net force causing an acceleration. In this case, net force and acceleration are opposite to the direction of motion, which decreases the velocity until it momentarily reaches zero at the highest point in the path. During his post-MT3 interview, the interviewer confirmed that the intent of this question was to see if students thought impetus was involved by asking if it was "specifically designed to see if they think that there's an up-force on that object still?" Seth agreed with the interviewer's hunch but did not expand further.

Similar to Q1, the third written assessment question also prompted students to consider a constant force acting in the horizontal direction:

> Q3: Draw a force diagram for a box being pushed to the right across a frictionless floor with a force of 100 N. State which direction the box is moving.

Seth's ideal response for question 3 is shown in Figure 5-1. According to his post-MT3 interview, Seth's group included this question "to find whether or not [students] would recognize the normal force. And also just to see their skill with drawing force diagrams." The first goal is connected to the DCI and to LP-P:3. The normal force, along with gravity, creates a net force of zero, which accounts for the box remaining stationary (i.e., zero acceleration) in the vertical direction. The second goal is not explicitly included in the DCI or LP-P but is important for students' ability to express related ideas in ways consistent with physics conventions. In addition, depicting the box moving in the direction of the force is consistent with LP-P:2 (and, thus, an idea that is a precursor to the DCI). Students may have understandings of the relationship between force and motion at higher levels of the LP-P, but the question does not seem designed to elicit these higher level understandings.

Figure 5-1:
*Seth's Ideal Response for Question 3*

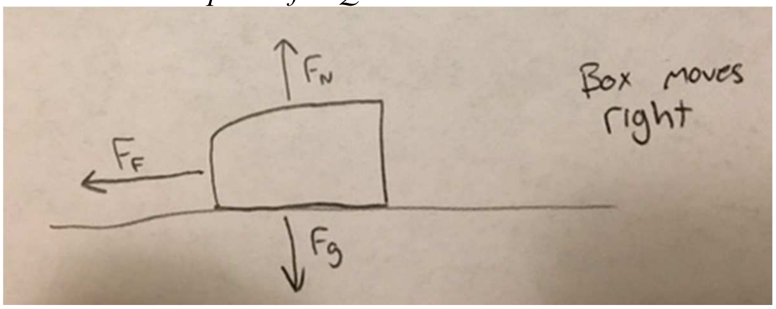


Seth's last written assessment question asked students to consider the scenario in Q3 after the box is no longer being pushed to the right:

> Q4: Draw a force diagram for a box that was pushed to the right along a floor at 100 N, but is no longer being pushed. State which direction the box is moving.

Seth's ideal response for question 4 is shown in Figure 5-2. During his post-MT3 interview, he expanded on this ideal response, adding that it "would have the normal force and the force of friction, but [students] would recognize that the box is still moving to the right. It hasn't stopped yet." He added that his physics group was hoping students would not simply draw the same model for both questions 3 and 4 (i.e., they would not include a force acting to the right). While he did not expand on this point during his post-MT3 interview, one way to distinguish between responses consistent with LP-P:3 and those consistent with LP-P:4 is that a student with ideas consistent with LP-P:3 would think there needs to be a force acting in direction of motion and therefore might include a force acting to the right. A student with ideas consistent with LP-P:4 would know that a) an object can be moving without a net force acting in the direction of motion and b) an object can be moving with a net force acting in the direction opposite of motion (e.g., friction), so they would recognize that the box could still be moving to the right, even with no force to the right—or even a force to the left.

Figure 5-2:
*Seth's Ideal Response for Question 4*




During his post-MT3 interview, Seth readily classified some of his students' responses to questions 2-4 with respect to ideas in the LP-P. For example, when reflecting on Jen's response to the second question, Seth said:

> Jen said that was because an equal and opposite force is acting on the die. So, that sort of shows that she's carrying with her the impetus idea, and she even drew a little diagram that showed the normal force acting on the rock or die with gravity at the same time. So she's sort of in that two-three range where she knows that forces balancing out would cause, could cause an object's velocity to be zero. So she's sort of thinking net force being zero means the velocity is zero, which isn't quite there, so that was pretty telling.

When reviewing his students' responses to the third and fourth questions, Seth classified their responses as consistent with ideas from level 2 to level 4 on the LP-P. He noted:

> [Jen] doesn't have the normal force on either of the diagrams she drew, so that's a clear indication [of a level 2]… Pam and Hank I would say are good examples of a three and a four, and the difference there is just basically the normal force. They both recognize friction. They both recognize the force of gravity acting constantly on the object that's being pushed. But, Pam doesn't have the normal force opposing gravity on either of her models. So, yeah. So those were, I'd say they're [level] two three four [on the LP-P], across the three of them.

**Reflecting on Preparing to Elicit Student Thinking in MT3**

During his post-MT3 interview, Seth reflected that he was generally satisfied with his elicitations during MT3; however, according to his post-MT3 reflection on teaching report, Seth felt he could have been more prepared to address students' "alternative ideas that came up" during the modeling task in his lesson. Specifically, Seth reflected on how he responded to his students' ideas about the direction of the force from the ground acting on the football. During the lesson Seth noticed his students were confused about the direction of the net force acting on and the resulting acceleration of the football. In his written reflection, Seth lamented that he struggled to "come up with a question to help them better explain" how the net force is related to the resulting acceleration of the football, and he felt that preparing for more "out of the box" responses in the future would be helpful.

## Summary

As is evident in the descriptions above, Seth drew on his understanding of student ideas to elicit student thinking across MT1, MT2, and MT3. Across all three lessons, Seth was sensitive to student ideas and was thoughtfully reflective about his moves to elicit student thinking. In particular, two ideas from the LP-P were salient to Seth: impetus and the notion that velocity is proportional to the applied net force. According to his post-MT interviews, Seth anticipated his students would hold ideas consistent with the impetus conception and was prepared to verify this idea (in the modeling tasks, specifically), if it surfaced. Seth also planned his MT2 lesson to specifically address the LP-P:3 idea that the velocity of an object is proportional to the net force acting on the object; he planned an elicitation task designed to specifically target this idea.

In addition to being sensitive to ideas from the LP-P, Seth was also reflective about decisions he made with respect to eliciting (and subsequently working with) student ideas in all three microteaching lessons. In his post-MT1 interview, Seth reflected on his attention to slight wording differences in students' responses to his questions, lamenting that small differences in the ways students express their thinking could provide evidence of substantive differences in their thinking that he might miss. Seth also reflected on his decision not to explicitly ask students about whether they thought the force from the kick was carried along with the football; he felt that not probing to see if his students held the impetus idea was a misstep. Seth was similarly reflective about his elicitations in MT2, noting that his tendency to inaccurately revoice students' responses could unintentionally change the meaning of the responses, which, again, could inadvertently gloss over substantive differences in students' thinking. During his post-MT3 interview, Seth reflected on his ability to prepare for and respond to students' "out of the box" responses that surfaced during the lesson.

**Brief Overview of Will's Microteaching Lessons**

Will's chemistry group planned to support their students' engagement with the DCIs by using the rapid combustion of a gummy bear as their anchoring phenomenon. During MT1 Will planned to elicit his students' initial ideas about the reaction by prompting his students to develop a preliminary explanation for "What happened to the gummy bear?" During MT2 Will planned to support his students' understanding of how energy is involved in chemical bonding through an online activity. Will hoped his students would be able to apply what they learned about the energy involved in breaking and forming chemical bonds in MT2 to improve their initial explanation for the combustion of the gummy bear reaction in MT3. In the sections that follow, I use evidence from Will's planning for, enacting, and reflecting on MT1, MT2, and MT3 to describe how Will drew from his developing understanding of student ideas to elicit his students' thinking about the anchoring phenomenon across the three microteaching lessons.

## Microteaching 1

Will did not anticipate that his students would engage in MT1 with much sophistication, but he was nonetheless attentive to a range of student ideas when planning for and enacting MT1. Later, during his post-MT1 interview, Will was reflective about decisions he made while eliciting student thinking in the lesson, and he discussed potential changes to how he elicited, based on differences in students' thinking and their attention to changes at the molecular level. In the sections that follow, I describe how Will drew on his understanding of student ideas while planning for, eliciting student thinking during, and reflecting on MT1.

### Planning for MT1

According to his post-MT1 interview, Will planned to focus students' attention on particular features of the reaction in order to elicit their ideas about "bond energies of the reactants versus the products" in their preliminary explanation for "What really happened to the gummy bear?" Will anticipated his students would "probably identify that the bear reacts with the chemical in some way," but—in terms of students' understanding of how energy is involved in chemical bonding—he and the chemistry group "weren't expecting much."

For MT1 Will planned to focus his students' attention on energy in the reaction (e.g., first asking "What's being produced in the reaction?" followed by "Where did the heat and the light come from?"; Will, MT1 lesson plan). This series of questions had the potential to repeatedly narrow his students' attention to the DCIs. After eliciting his students' initial observations and ideas about energy in the reaction, Will planned to engage students in developing an initial written explanation for the reaction, which would allow him to elicit student ideas related to the DCIs (some of which are also represented in the LP-C).

**Eliciting Student Thinking During MT1**

As mentioned above, Will anticipated that his students would identify a reaction between the bear and the chemical, but he was not expecting them to understand much about how energy is involved in chemical bonding. However, during the lesson Will noticed that his students not only identified a reaction between the gummy bear and the chemical, they also engaged “more at the college-student level of thinking” and readily attended to chemical bonds breaking and forming in the reaction (Will, post-MT1 interview). Although his students engaged in the lesson at “a higher skill level, or proficiency than an average high school student might,” (Will, post-MT1 interview) Will elicited two student ideas that were particularly salient to him. During his post-MT1 interview, he reflected on the parts of the lesson when these ideas were discussed.

First, Will reflected on a discussion in which he noticed important differences in students’ thinking. In the first part of this discussion, Will launched the question and highlighted important ideas from Ann.

> **Will:** …thinking about the light, and also the heat that was produced by it, where do you think that the heat and the light came from? If I ask you, what was the source of the heat and the light?
> **Ann**: “Bonds maybe breaking? Or just like energy being given off from the gummy bear reacting with the chemical?”
> **Will**: Ok, we'll do bonds breaking, and then you said, bonds breaking, Ann, and maybe...
> **Ann**: I guess like from the gummy bear reacting with the chemical, like energy was being released in the form of light?
> **Will**: A chemical reaction, ok.

During the second part of this discussion, Will was confused by—and asked multiple follow-up questions to clarify—Dawn’s thinking.

> **Dawn**: I would say from the flame? That caused for the transfer of the energy?
> **Will**: Ok. The flame, are you talking about from the blow torch? Or…
> **Dawn**: Well, all together, as, like the system that's transferred.
> **Will**: Ok. So do you think, Dawn, that the light that we saw inside of the test tube, was that from a flame also? Is that what you were saying?
> **Dawn**: Yeah, that's what I mean.

> **Will**: Yeah, I think that's a pretty good assertion, or a hypothesis about that. Because I can tell you, like, when the gummy bear gets added, there actually is flame. Maybe that makes sense because what did we smell after the reaction happened? You said it smelled like a campfire. Some people were saying it smelled like marshmallows? So if we follow our nose, so to speak, that might say, oh there was a fire happening inside of that test tube.

Compared to Ann's statements, Dawn's were less clearly connected to chemical bonding and, in the moment, Will had difficulty making sense of what she meant. Will attempted to clarify Dawn's thinking and tried to connect her idea about the flame to the blow torch, but her reply further confused Will. He again attempted to clarify her thinking by offering a connection to a different observation from the demonstration (the light inside the test tube) but—according to his post-MT1 interview—Will was still confused by Dawn's thinking. So, he tried to "salvage something out of it" and "communicate an idea that I wanted them to know, which was that the gummy bear was burning."

Second, Will reflected on how readily his students attended to energy in chemical bonds when developing their explanation for the final elicitation task: "What really happened to the gummy bear?" During his post-MT1 interview, Will talked about how quickly his students "came up with a molecular model," in which they described the energy released during the reaction as originating from bonds breaking in the reactants. Will later recognized this idea as an "alternative conception" (consistent with LP-C:3) that the chemistry group had talked about when planning their lesson.

### Reflecting on in-the-Moment Decisions About Eliciting Student Thinking in MT1

During his post-MT1 interview, Will reflected on two decisions he made during MT1 relating to the discussion about "the source of the heat and the light" and how he launched the final elicitation task, respectively. In the paragraphs below, I describe Will's reflections about student responses.

First, Will was reflective about his inability to clarify and interpret Dawn's statement about "the system that's transferred" during the lesson. In his post-MT1 interview, Will acknowledged that—in the moment—he did not know how to make sense of what Dawn meant and that, after unsuccessfully attempting to clarify her thinking, he chose to follow up with a "leading question" in hopes that she would agree and the lesson could proceed. Will further reflected that, while he did not think the first two work sessions influenced his lesson plan, he felt that "in that moment [his] mind was sort of falling back to" work with the learning progression in one of those two sessions. He reported thinking during the lesson, "like, 'Oh, it was the friction of the person that strikes the match,' like the super-surface level" idea (i.e., LP-C:1, in which "concern is for the needs of the subject or the event, to start it or sustain it") that he was "very much trying to make…fit."

Second, Will was reflective about how he would need to launch the final elicitation task (to develop an initial explanation for the anchoring phenomenon) when working with high school students, as compared to his peers in microteaching. During MT1 Will did not explicitly direct his students to think about chemical bonds in their explanations, yet they did. According to his post-MT1 interview, Will reflected that—in the future—not all students may engage with the phenomenon similarly and that and he may need to more explicitly scaffold students "towards a molecular level understanding of things" in order to eventually elicit their ideas about how energy is involved in chemical bonding.

## Microteaching 2

Will designed MT2 to support ongoing changes in student thinking about how energy is involved in a chemical bond and showed sensitivity to student ideas—including one from the LP-C—when planning for, eliciting student thinking during, and reflecting on his MT2 lesson. Specifically, Will drew on his interpretation of his students' thinking about energy released and absorbed in a reaction in MT1 to select an activity and an analogy designed to support his students in better understanding this concept. During his post-MT2 interview, Will reflected on his planning, his teaching moves, and the impact of both on his ability to elicit students' thinking. In the sections that follow, I describe how Will drew on his understanding of student ideas across each of these phases of the MT2 cycle.

### Planning for MT2

Will's planning for MT2 was based on his students being "pretty solidly in level 3" (on the LP-C) during MT1 (Will, post-MT2 interview). Collectively, the chemistry group identified the idea of "breaking bonds releases energy, and making them requires energy" (i.e., LP-C:3) as one of the "biggest alternative ideas and conceptions, in terms of thinking of chemical bonding," and they chose to address this idea during MT2 (Will, post-MT2 interview). In order to support his students in better understanding how energy is involved in a chemical bond, Will planned to engage them in an online activity designed to illustrate how breaking chemical bonds requires energy and making chemical bonds releases energy (i.e., evidence to support LP-C:4 and refute LP-C:3). Additionally, Will planned to elicit students' ideas about an analogy: "A chemical bond is like a container of energy, you put energy into the bond, and then energy gets released when the bond is broken" (Will, MT2 lesson plan). Will anticipated that his students would either agree or disagree with this analogy and that he would use the results to inform his next instructional steps. If his students agreed with the prompt, providing evidence of thinking consistent with LP-C:3, Will indicated that he would then need to “dismantle that” idea. However, if they disagreed, that would mean his students were “further along than [he] thought”—i.e., that they correctly understood that breaking chemical bonds requires energy and that energy is released as chemical bonds form.

**Eliciting Student Thinking During MT2**

Will spent the majority of MT2 supporting students in learning about how energy is involved in chemical bonding through the online activity. After his students worked through part of the activity, Will asked them to evaluate the aforementioned analogy. In response, Ann disagreed, saying “I guess like a bond occurs between two things, and when I think of a container, I don’t know, it’s like one thing to me. Just like dumping, or filling.” Will replied, “Yeah, so it’s a little hard to picture. And that’s ok because I didn’t necessarily say that’s a right analogy. But it’s one a lot of people think of sometimes.” Will then moved on, directing his students to complete the rest of the online activity.

**Reflecting on in-the-Moment Decisions About Eliciting Student Thinking in MT2**

Although Will did discuss student ideas during his post-MT2 interview, he primarily focused on teaching moves that impacted how he was able to elicit student thinking. Specifically, Will reflected on how he presented the container analogy to his students and also about how, due to the limited time available for microteaching, he felt rushed to wrap up his lesson and was unable to elicit students' thinking about if and how the activity connected to the anchoring phenomenon.

Will reflected about whether his students understood what he was trying to illustrate through the container analogy. According to his post-MT2 interview, Will's expectations for students' responses were "pretty straightforward": he thought they would either agree or disagree and justify their thinking based on their understanding of how energy is involved in chemical bonding. However, he acknowledged that Ann's response was unexpected and recalled thinking, "All right, well, [Ann] doesn't agree with the analogy, but not because she understands that breaking bonds actually requires energy. No, it's actually that she just really can't grasp the analogy the way that I presented it." He further recalled that, "in the moment" he "grabbed onto" Ann's statement about disagreeing with the analogy and that he didn't "know what to do with" what she shared, so he directed students to get back to their activity. However, he reflected that if he could do it over again, he would "really want to be able to have Dawn share her thoughts" too, instead of simply moving on with the lesson.

During his post-MT2 interview Will also talked about how he felt rushed to wrap up his lesson and that, consequently, he was unable to elicit connections between the activity and the anchoring phenomenon. Will discussed that he was interested in hearing students' ideas as they progressed through the online activity and that he wanted to provide time for them to make sense of the activities through a model revision task at the end of the lesson. However, the online activity took longer than he planned, and Will ran out of time. Instead of further eliciting if and how students were "mak[ing] connections between chemical bonds and chemical reactions that take place" through the model revision task, he ended MT2 by quickly summarizing the container analogy for his students.

## Microteaching 3

Will planned to engage his students in a model revision task during MT3 to elicit changes in their explanation for the gummy bear reaction. Will drew on his understanding of student ideas to provide a “framework” with which to guide their model revisions and—as he had for MT2—reflected on his planning, his teaching moves, and the impact of both on his ability to elicit students’ thinking during his post-MT3 interview. In the sections that follow, I describe how Will drew on his understanding of student ideas across each of these phases of the MT3 cycle.

### Planning for MT3

According to his MT3 lesson plan, Will planned to engage his students in a model revision task so their model would be “up to date with the activities we have done in the unit.” He hoped they would include a “discussion on what reactants and products there are in the reaction, the changing energies of these reaction components, and the appropriate addressing of the bonds in the products being overall lower in energy than the bonds in the reactants” in their revised model. According to his post-MT3 interview, Will anticipated his students would be able to look at their initial model and identify places where it did and did not “match up with what we’ve learned” through the unit. Specifically, he hoped Ann would recognize that her idea of “the bond break[ing] leads to energy, or releases energy” (i.e., consistent with LP-C:3) is “not true” based on what they learned during MT2.

### Eliciting Student Thinking During MT3

Will began the lesson by having his students review their initial model from MT1, prompting them to "walk me through what you remember, what was going on here." Ann shared how the "high energy bonds" in glucose "produce energy," and Dawn added that they had indicated breaking bonds releases energy and "the making of bonds requires energy." Will transitioned to the next task by prompting them to "make a before, during, and after model of the reaction we saw." Will reminded his students about the reactants and products of the reaction and focused their attention on bonds by asking, "What do we know about what bonds are, and how energy relates to them?" Ann and Dawn shared ideas about electrons, covalent bonding, bonds being "used." With further scaffolding from Will, Ann connected the changes from reactants to products to changes in chemical bonds. Will further directed his students to "think about the energy of [bonds breaking and forming]" and asked, "When we form a bond, is energy released or taken in?" Discussion ensued:

> **Ann**: I always have to think about this.
> **Will**: That's ok, because it's a tricky thing.
> **Ann**: When bonds…
> **Dawn**: Breaking bonds…doesn't it require energy to make a bond?
> **Ann**: Yeah, it requires energy to make a bond, because I remember it seems opposite to me.
> **Dawn**: It's releasing energy.
> **Ann**: When you break it I think of water like spilling, like releasing.
> **Dawn**: Yeah.

Will paused, noting "That is backwards, but it's really interesting." Will directed his students to consider the results of the online activity in MT2, and more discussion followed:

> **Ann**: Wait, so it requires energy to break a bond.
> **Will**: Yes.
> **Ann**: Like karate.
> **Dawn**: To make one, oh yeah.
> **Ann**: Because if you think of this being like a board, it's not going to break on its own.
> **Dawn**: That's true.

**Ann**: That makes 100% sense. Ok. So requires, then when bonds break, I was right then, so when bonds break it releases energy.
**Will**: No, you just said it.
**Ann**: Ahhh!
**Will**: You just said that you have to add energy to break the bond.
**Ann**: Breaking the bond. Adding, releases.
**Dawn**: Because like this glucose isn't going to just break.

As Will neared the end of his allotted time for the lesson, he quickly summarized the big ideas about how energy is involved in chemical bonding, and concluded by asking students to write "What is it about bonds breaking, how is energy related, bonds forming?"

### Reflecting on Planning and in-the-Moment Decisions About Eliciting Student Thinking in MT3

During his post-MT3 interview, Will reflected on how the lack of "structure" in his MT3 lesson plan and his students' lingering "bonds breaking kind of idea" led to challenges in the lesson related to eliciting student thinking. Will noted that the chemistry group acknowledged the idea of breaking bonds requiring energy, and forming bonds releasing energy, as being "counterintuitive, difficult to grasp, and a key core thing," but they were not expecting to spend much time during MT3 addressing this idea. However, when it surfaced in Will's lesson, he followed the "tangent" and spent time addressing this alternative conception by "leading [his students] in the direction he wanted them to go in." Will's decisions to help "set some things straight" (Will, post-MT3 interview) caused him to feel pressed for time at the end of the lesson, and he was unable to elicit students' thinking through the summative model revision task he had planned. As a result, he found what students were able to revise on their model to be "relatively undetailed," which he lamented was because "some of the time was spent doing other things unexpectedly" during MT3.

## Summary

Will drew on his understanding of student ideas to elicit student thinking across MT1, MT2, and MT3. Across all three lessons, Will was attentive to the ideas his students shared but, especially for MT2 and MT3, he reflected about how limited time and decisions he made during the lessons impacted what he was able to elicit about students' thinking.

Will was attentive to ideas from his learning progression. For example, the common student idea of breaking bonds releasing energy and making bonds requiring energy (i.e., LP-C:3) was prevalent across all three of his microteaching lessons, and—according to his post-MT interviews—Will anticipated his students would think about bonding in this way. Will was also attentive to other ideas from the LP-C. For example, Will reflected that, in MT1, he tried to make Ann's idea of "the flame" causing "the transfer of the energy" fit the "super surface level" idea of LP-C:1. Will was also reflective about decisions he made with respect to planning and eliciting student ideas in MT2 and MT3. In the post-MT interviews for each of these lessons, Will reflected on his time management, expressing that his relatively unstructured lesson plans hindered his ability to elicit connections between the online activity and the anchoring phenomenon (in MT2), as well as to develop a final explanation for the reaction (in MT3).

## Comparison Across Seth and Will

Across all three microteaching lessons, both Seth and Will drew on their understanding of student ideas to elicit student thinking. Both teachers anticipated that at least one idea from their respective learning progressions would surface in their lessons, and while both were reflective about decisions they made with respect to eliciting student thinking, they reflected on different aspects of their elicitation practice. In the paragraphs that follow, I expand on these two comparisons.

According to their post-MT interviews, both Seth and Will anticipated LP-related ideas that would surface during their lessons and planned specific ways to elicit those ideas. For Seth, the impetus idea and the idea that velocity is proportional to the applied net force (LP-P:3) were particularly salient. Seth reflected that he was prepared to verify the impetus idea if it surfaced during the modeling tasks in MT1, MT2, and MT3. Seth planned an elicitation task during MT2 designed to specifically target the idea that velocity is proportional to net force. Similarly, Will anticipated the student idea of breaking bonds releasing energy, and making bonds requiring energy (i.e., LP-C:3), which was prevalent across all three of Will's microteaching lessons. For his MT2 lesson, Will planned to elicit students' ideas about this idea through their analysis of an analogy.

Both Seth and Will were reflective about decisions they made related to eliciting student thinking, but they reflected on different aspects of this practice: Seth's reflections were about how he interpreted and followed up on students' ideas, while Will's reflections were about planning to elicit student thinking. Across his three post-MT interviews, Seth reflected on his attentiveness to slight wording differences in his students' responses, his revoicing of student ideas, and—in one instance—his decision not to explicitly confirm a particular idea (impetus) he anticipated would surface in the lesson. In contrast, during his post-MT1 interview Will reflected on how, in the future, would need to more explicitly direct students to attend to energy (and changes in energy) when developing their initial explanation for the reaction (but did not need to during MT1 because his students engaged at the "college level"). During his post-MT2 and MT3 interviews, Will reflected on his planning and time management. Specifically, Will felt his relatively unstructured lesson plans hindered his ability to elicit connections between the online activity and the anchoring phenomenon (for MT2) and to develop a final explanation for the reaction (for MT3).

## CHAPTER SIX: DISCUSSION

Teaching in ways that are in line with the new vision of science learning involves situating instruction in the context of a high-quality anchoring phenomenon, eliciting students' preliminary and developing explanations for how and why the anchoring phenomenon occurs, and then noticing and reasoning about the student ideas that surface in order to inform future instruction. Such teaching is responsive to student thinking in that it attends to the substance of students' science ideas (Hammer et al., 2012). In order to make informed instructional decisions to "work on and with" student thinking (Stroupe & Windschitl, 2015, p. 181) teachers must first elicit their students' ideas by providing opportunities for students to think about and share their developing understandings. Therefore, the practice of eliciting student thinking is central for responsive teaching, and supporting preservice teachers in learning to enact this practice represents a key way to encourage their development as responsive teachers (Lampert et al., 2013).

The purpose of this research was to investigate how preservice teachers drew on characteristics of anchoring phenomena and their knowledge of student ideas, when informed by a learning progression, to elicit student thinking in the context of microteaching within a practice-based methods course. In the sections that follow I connect findings from my two cases to recent literature on anchoring phenomenon and learning progressions. Next, I bring together my two research questions to discuss how features of the preservice teachers' anchoring phenomena were connected to student ideas in their learning progressions. I conclude by discussing practical recommendations for teacher educators, limitations of this work, and possible directions for future research.

## Drawing on Characteristics of an Anchoring Phenomenon to Elicit Student Thinking

The new vision of science learning involves students "figuring out" how and why anchoring phenomena occur. The choice of anchoring phenomenon for a unit of instruction is paramount, and current literature describes characteristics of "high-quality" anchoring phenomena. Arguably, both Seth's and Will's anchoring phenomena were high-quality with respect to these characteristics, and both Seth and Will represent successful cases of "what's possible" when eliciting student thinking. However, when eliciting student thinking in their microteaching lessons, both Seth and Will primarily drew on a subset of the characteristics of high-quality anchoring phenomena: alignment to the DCI(s), segments, and features. These three characteristics may be important to prioritize for the purpose of supporting preservice teachers in learning to elicit, and—by extension—engage in responsive teaching.

Two of these characteristics are reflected in the literature, and the third emerged from the data as a refinement of a characteristic already described in the literature. First, according to the literature, breaking an anchoring phenomenon into distinct "before, during, and after" segments helps students notice change over time, and these segments can serve as a preliminary framework with which students can organize their observations (Ambitious Science Teaching, 2014). Second, part of what makes an anchoring phenomenon comprehensible to students is its alignment with grade level-appropriate performance expectations (i.e., NGSS PEs; Achieve et al., 2016; Reiser, Novak, et al., 2017). Third, the presence of rich contextual details to help focus students' attention on a specific event, in a specific location, under specific conditions, is part of what makes an anchoring phenomenon complex (Ambitious Science Teaching, 2014). When coding the data, I found it useful to differentiate between substantive details, as those related to an explanation based on the DCI(s), and details that are cosmetic. This differentiation represents a refinement of the recommendation that the phenomenon includes rich contextual details. My analysis revealed that Seth and Will drew on substantive details to define segments in which to elicit student thinking. Therefore, I define “features” of high-quality anchoring phenomena as substantive details that (a) illustrate changes explained by the DCI(s) in the NGSS PE, (b) can be drawn from to elicit student thinking about the DCI(s), and (c) specify distinct periods of the anchoring phenomenon.

Structuring elicitation tasks based on features supported Seth and Will in successfully eliciting students’ ideas about the DCI(s) in their respective NGSS PEs. For example, the trajectory of the kicked football in Seth’s anchoring phenomenon is broadly explained by the relationship between force and motion as described by the DCI in his NGSS PE (i.e., Newton’s second law of motion). Drawing on specific features of the football’s trajectory allowed Seth to elicit students’ thinking about different force-motion pairs and defined segments of the trajectory: during the kick the net force is in the same direction as the change in motion, and after the kick (as the football travels up) the football is moving in a direction opposite that of the net force. Similarly, the energy released during Will’s gummy bear combustion reaction is broadly explained by changes in bond energies from reactants to products. However, focusing students’ attention on features of the reaction (i.e., the heat and light released during the reaction) defined before, during, and after segments and allowed Will to elicit students’ ideas about how energy changes throughout the reaction. While the aforementioned groups of characteristics of high-quality anchoring phenomena may serve to bolster students’ engagement and are important to consider when choosing an anchoring phenomenon, the findings of this research suggest that encouraging preservice teachers to consider and draw on this refined features characteristic, in addition to segments and alignment with the DCI(s), may support their developing ability to elicit student thinking.

## Drawing on Understanding of Student Ideas to Elicit Student Thinking

In addition to situating a unit of instruction in the context of figuring out a high-quality anchoring phenomenon, teaching in the new vision of science teaching and learning foregrounds the role of student thinking. As such, eliciting student thinking is central to this vision of science teaching and learning. Current literature suggests learning progressions may help both in-service and preservice teachers attend to student ideas, but sometimes not in ways that are in line with responsive teaching. For example, Furtak, Circi, and Heredia (2018) found that learning progression-based professional development supported in-service teachers in developing formative assessment tasks around the central idea in the learning progression. However, prior work by Furtak (2012) suggested that some teachers positioned the ideas in the learning progression as “misconceptions to be ‘squashed’” (p. 1181), which is similar to how teachers in another study interpreted their students’ science ideas (Covitt et al., 2018). In the context of pre-service teacher education, von Aufschnaiter and Alonzo (2018) found that learning progressions may narrow preservice teachers’ attention to *just* the ideas represented on the learning progression and hinder their ability to consider relevant ideas that are *not* represented on the learning progression.

The findings from the present study somewhat echo those reported in literature about both in-service and preservice contexts. Across all three microteaching lessons, both Seth and Will drew on their understanding of student ideas to elicit student thinking. Similar to teachers in the Furtak et al. (2018) study, both Seth and Will designed and enacted elicitation tasks centered around identifying students' thinking consistent with specific levels of their respective learning progressions. For example, during MT2 Seth attempted to elicit students' ideas related to LP-P:3 or LP-P:4 by asking his students about what force is proportional to. Will used an analogy designed to elicit LP-C:3 or LP-C:4 responses based on students' understanding of how energy is involved in chemical bonding.

The only other study conducted to-date in a preservice context (von Aufschnaiter & Alonzo, 2018) focused on the practice of interpreting student thinking. My study adds evidence of the potential of learning progressions to support preservice teachers in a second practice: eliciting student thinking. However, also similar to von Aufschnaiter and Alonzo (2018), the learning progression may have constrained Will's interpretations of student thinking to focus on ideas in the learning progression. During his post-MT1 interview, Will discussed trying to make Ann's idea of "the flame" causing "the transfer of the energy" fit the "super surface level" idea of LP-C:1 during the lesson. Thus, attention to ideas in his learning progression may have limited his ability to attend to other ideas. Seth also attended to ideas from the learning progression in his interpretations of student thinking; however, in contrast to Will and to the teachers in von Aufschnaiter and Alonzo's study, Seth was also attentive to the language students used to express their thinking. For example, Seth reflected that he felt prepared for students to share impetus-related ideas from the LP-P in their model in MT1 (and subsequent revisions in MT2 and MT3). However, he also reflected on his tendency to inaccurately revoice students' responses while eliciting their thinking "into what [he] understood of it, instead of what they said."

**Drawing on Characteristics and Ideas in a Learning Progression to Elicit Student Thinking**

Seth and Will repeatedly demonstrated skill in eliciting student thinking and showed sensitivity to student ideas across their microteaching lessons. They also both leveraged their understanding of student thinking to draw on features of their respective anchoring phenomena; these features allowed both teachers to elicit ideas in their respective learning progressions. For example, Seth's anchoring phenomenon can be broadly explained using Newton's second law of motion. Specifically, explaining the change in motion of the football, as illustrated in the slow-motion video, draws on only one net force-motion pair, in which the net force from the kick is in the same direction as the change in motion of the football. Seth focused students' attention on the speed of the football after the kick in order to elicit students' ideas about the relationship between force and motion when the net force is not in the same direction as the change in motion. Some students may think that a (net) force cannot act in the direction opposite to the direction of motion (LP-P:2 or LP-P:3) and might indicate the force of gravity does not begin acting until the football has reached the top of its trajectory. Other students with ideas consistent with the impetus conception may think the force from the kick continues to act on the football (LP-2a or LP-P:3a) and may indicate that force in their model. Students with canonical understandings (LP-P:4) recognize that net force does not have to act in the direction of motion and may indicate the force of gravity and/or friction in their model. While the slow-motion video does not provide opportunities to elicit students' ideas about impetus and other ideas represented on the LP-P, Seth's decision to expand the frame beyond what was visible allowed him to draw on features from which to elicit a broader range of ideas related to the DCI. Similarly, Will drew on his understanding of student ideas to focus his students' attention on features of his anchoring phenomenon to elicit their thinking about the DCIs. Will was able to scaffold students' attention to changes in bond energies between reactants and products of the gummy bear combustion reaction, which elicited ideas consistent with LP-C:3 (and occasionally LP-C:4). In these examples, both Seth and Will may have drawn on their understanding of student ideas—related to their respective learning progression—to identify and highlight particular features of their anchoring phenomenon as a context in which to elicit ideas related to the DCI(s).

## Practical Recommendations for Teacher Educators

The findings of this research suggest two important considerations when working with preservice teachers to elicit student thinking. First, this research suggests that, in the context of phenomenon-based instruction, teacher educators may elevate features, segments, and alignment with DCI(s) as characteristics to support preservice teachers in structuring elicitation tasks designed to uncover their students' thinking. Second, teacher educators may consider supporting preservice teachers learning to elicit student thinking by introducing learning progressions as tools for understanding student thinking. Caution may be required to ensure that preservice teachers consider a range of student ideas. In particular, preservice teachers may need support to (a) elicit both ideas at more levels of the learning progression and ideas not on the learning progression and (b) listen to and interpret all student ideas, rather than only listening for ideas in the learning progression.

## Limitations and Future Work

While the findings of this research suggest important considerations when working with preservice teachers to elicit student thinking, there are limitations of this study that are important to acknowledge. First, I was the only researcher coding the data, so there was no opportunity to seek inter-rater reliability of coding. However, over the course of this dissertation I had numerous conversations about coding and analysis with my research advisor, and these conversations provided repeated opportunities to check, and recheck, the coding and analysis. Second, I was a member of the LP team that designed and implemented the learning progression-based work sessions within the methods course. I supported one group of preservice teachers (the physics II group: momentum) and have previously worked on learning progression-based research projects. In addition, in a different year I served as a course instructor for the AST-based methods course that was the context for this study, and I see value in positioning anchoring phenomena at the center of science instruction. These experiences and perspectives may have influenced how I perceived the data. However, in the context of this research, I was not directly involved with the physics I or chemistry groups (for Seth and Will, respectively), so I maintained some distance from the subjects involved in this study.

In addition, this study explored elicitation practices of only two preservice teachers in a particular methods-course setting. Further research could expand beyond this specific context to deepen our understanding of teachers' use of anchoring phenomena and knowledge of student ideas to elicit student thinking. For example, the two teachers included in this research were both quite successful in eliciting student thinking. However, future research is necessary to identify if and how preservice teachers who exhibit less successful elicitations draw on the same or different characteristics of their anchoring phenomenon. Similarly, both Seth and Will exhibited a strong understanding of their respective content, but follow-up studies could be conducted with preservice teachers to investigate if and how preservice teachers' content knowledge shapes how they plan for, elicit, and reflect on student ideas represented in a learning progression.

Additionally, this research was conducted within the confines of a university-based methods course with college peers serving as "students" in brief microteaching lessons representing disconnected snapshots of the teaching and learning that might occur in a full enactment of an AST unit. While microteaching to peers can help limit the degree of uncertainty inherent in teaching, working with 25 or more middle or high school students in a classroom setting adds other challenges related to eliciting, interpreting, and continually working on and with student thinking. What happens when preservice teachers enact a series of connected lessons in a "real" classroom with "real" students over time? While involving additional students may increase the range of responses elicited by a given task, does a more "authentic" context support preservice teachers in learning elicit and work on and with student thinking in ways that are more effective than within a methods course?

Lastly, the concepts associated with the DCIs in both Seth and Will's NGSS PEs are ubiquitous in secondary physics and chemistry courses, respectively. In the context of microteaching to peers, each preservice teacher enacted a given lesson only once, but in many secondary school contexts it's likely that teachers will have more than one section of the same class within a given year (or at least teach the same class in a subsequent semester or year). What happens when they teach the same unit, using the same anchoring phenomenon, next time? Learning progressions represent context-free student ideas, but after teaching their lessons in a microteaching context, both Seth and Will have an improved understanding about what students think about their respective anchoring phenomenon: Seth's students thought that the force of gravity started acting at the top of the trajectory; Will's students thought that breaking chemical bonds releases energy. Given this "new" knowledge of how student ideas might surface in the context of their respective anchoring phenomenon, would Seth or Will change or launch their elicitation tasks differently? What about other ideas that are *not* represented on their respective learning progressions (e.g., ideas about rotational inertia of the football that students might wrestle with as they more accurately describe the motion of the football along its path)? How might teachers' assumptions about student thinking shape how they work with "new" ideas from "new" students?

Despite limitations of the present study, the findings suggest important considerations when working with preservice teachers to elicit student thinking. While further research is needed to identify potential differences in how preservice teachers who exemplify less effective elicitation practices draw from characteristics and their understanding of student thinking to elicit student thinking, the findings of this study suggest refinements to characteristics of anchoring phenomena and how learning progressions may support preservice teachers' development of the "knowledge that counts for practice" (Ball & Forzani, 2009, p. 503).

# APPENDICES

## APPENDIX A: AST Tools for Planning and Reflecting

A-1: Collaborative Tool: Planning for Engagement with Big Science Ideas

A-2: Teaching Practices Tool: Eliciting Students' Ideas and Adapting Instruction

A-3: Teaching Practice Tool: Supporting On-Going Changes in Student Thinking

A-4: Teaching Practice Tool: Pressing Students to Construct Evidence-Based Explanations

## A-1: Collaborative Tool: Planning for Engagement with Big Science Ideas



# Collaborative Tool: Planning for Engagement with Big Science Ideas

Note: Before using this tool, please read primer for *Planning for Engagement with Important Science Ideas*.


The series of prompts below will help you transform common topics found in textbooks, curricula, and Standards into big ideas worth teaching. The purpose of this is NOT for you to justify why you have started out with a particular topic. It is to help you *question* the topic's importance, to *learn more* about it, *compare* it against the Next Generation Science Standards (or your current state standards), and identify the *core ideas* you will teach.

Two important notes: (1) In using this tool you will quickly reach the "edge" of your science knowledge. You should take a break from working on it yourself (after Step 1 is a good time) and start *sharing your ideas and questions* about the subject matter with some colleagues. (2) This tool is *not linear*. You will likely go back to previous steps to revise what you had recorded there. This is expected and it is a productive way to develop an anchoring event based on big science ideas for your unit.

### Step 1 Start by comparing your curriculum topics against the *Standards*

1.1 State below what your curriculum currently identifies as the main topic (just a word or phrase), then list between 8 and 10 of the most important curriculum sub-topics you also see. Topics at this stage can initially be expressed as a process or thing or theory or concept.

1.2 Now identify where the topics above topics fit with the *Next Generation Science Standards* (http://www.nextgenscience.org/) or your state standards. Copy and paste below all the possible disciplinary core ideas and performance expectations that relate to your topic (this is the *only* part of the tool where you should copy and paste from another source).

1.3 Which of the curriculum ideas fit with the NGSS? How might you re-cast your curriculum ideas to better address the Standards? The Standards *take precedence* over the curriculum topics, but it is possible to teach some curriculum ideas that are not mentioned directly in the Standards.

At this point you will need to talk with a collaborator before moving on…Where are you unsure? Need input about?

## Step 2 Moving from topics and Standards toward "big ideas"

2.1 Which one of the ideas from the curriculum and Standards now seems the most central—meaning they might help explain other ideas you've listed and explain a wide range of natural phenomena? You must use more than a name to express your idea, *express it as a set of relationships*. Explain your choice clearly enough so a colleague could understand why you made the choice you did. To think about this, imagine filling these sentences in*: If my students could only understand how _[core idea]_, then they could use that to understand most other ideas in the unit. And here's why [give reasons for why your big ideas link to other ideas or have explanatory power].*

If you have trouble, the text in the box may help you think about how to identify what the big idea is…

> Does your current choice for a central idea have a more fundamental or underlying idea that should really be the target of instruction? For example, energy transfer is what "underlies" the idea of food webs; kinetic molecular motion "underlies" the Gas Laws; and, the idea of unbalanced forces "underlies" simple machines. ALTERNATIVELY: Your topic could be a smaller part of a *larger system of activity* that is really what is important to teach. For example, in earth science the tides should be taught within the larger context of the regular movement of bodies in space and the gravitational effects of these bodies.

2.2 What about the big idea would students see as relevant to their own lives? Think about what kinds of experiences and events students have had and how the science concepts might be meaningful (not just relevant) to students. Where students encounter such ideas/science phenomena?

## Step 3 Learning more about your "big idea"

You will need to deepen your understanding of topics with which *you may think* you are very familiar. You don't need college level textbooks, just use *Wikipedia*, *How Stuff Works*, the *National Digital Library* or other reputable source. Read with the expectation that you'll have to generate a causal explanation (a "why-does-it-happen-this-way" story) for some phenomenon related to your topic.

3.1 Write below three ***new facets*** of the topic you've learned about and if new relationships between ideas have come to light—***what facts, concepts, connections did you not already understand?*** Do not write definitions or formulas or trivial details; you need to UNPACK the meaning of a science idea in order to consider how to help students reconstruct the idea.

Do not copy and paste from any source.

## Step 4 Coordinating an important phenomenon (Anchoring Event) with its explanatory model

Now we return to selecting an anchoring event or process (the observable world) and the underlying causal model for those events (the unobservable world). Answer these two sets of questions that help establish a relationship between the two.

4.1 What is an actual, observable event or set of events that students can come to a deep understanding of over a period of days? Explain why students will find this puzzling and not just an exercise found in a textbook. DO NOT NAME A CONCEPT, NAME AN ACTUAL EVENT THAT UNFOLDS OVER TIME, EVEN IF IT IS A BRIEF AMOUNT OF TIME.

4.2 Give the event some context. How can the phenomena be made into a context-rich case of something "local" or "personal" to students rather than being a generic science idea? Can earthquakes, for example, be about the case of the Nisqually Earthquake? Can food chains be about the case of the decline of the Orca populations in Puget Sound? Can cell division be about a case of wounds healing in an athlete?

4.3 Now outline a causal storyline for this phenomenon. Use the abstract or unobservable characters, events, properties to form the explanation. This should be a "gapless" explanation that is just beyond what you think students at your relevant grade level might be capable of.

4.4 *In addition* to the written explanation, create on a separate piece of paper a diagrammatic/pictorial template for the explanation that you'd ask students to draw into. You can break the model into "before, during and after" sections, or you can compare two events side-by-side. Below this template, include a list of key observable and unobservable features.

## Step 5 What success looks like

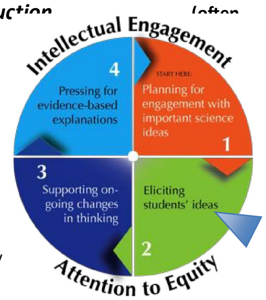
In this final step, you should imagine what your students will be able to do if they are successful in understanding the big idea and engaging in scientific practices. Look at how the performance expectations are written in the NGSS—they require students to both use a scientific practice (or more than one practice) and also to understand a set of specific science concepts.

Write two performance expectations for your students that pair up one or more scientific practices with the understanding of key concepts. Because modeling, explanation and arguing with evidence are at the heart of authentic disciplinary work, your performance expectations should include these three, either individually, or in combination with one another in a performance expectation.

This is the end of the tool, you should now have enough of an understanding of your big idea to prepare you for planning instruction…but keep testing and comparing ideas with your colleagues—professionals are never "done" thinking about science ideas!

# A-2: Teaching Practices Tool: Eliciting Students' Ideas and Adapting Instruction

**Teaching Practices Tool:** ***Eliciting students' ideas and adapting instruction*** **(often referred to as Discourse 1 or "D1")**




**Purpose of practice?** To *inform instructional decisions* for the next few days— how?—by eliciting *all* students' initial hypotheses about a scientific idea, and making a public record of these.

**When to use tool?** At outset of any new sequence of lessons. Begin with a *rich task for students* that has potential to open up broadest range of thinking by students on target ideas.

**Step 1.** ***Introducing the puzzling event and eliciting observations (whole class)***
Introduce task: "I recently saw something that puzzled me…" OR "Let's think about this story and see what kind of sense you make of it…"

| *After task is introduced, you ask observation questions…* | *Then you need to listen for, plan to respond to:* |
|---|---|
| • What do you see going on here?<br>• What did you notice when ___happened?<br>• When or where does ___ occur? | What if students cite relevant features of the task?<br>What if students cite irrelevant ideas or cannot understand the representation/problem?<br>What if students give inferences rather than observations? |

Then: Establish agreement about what whole class has observed. Begin to mark some specific features of ideas or of vocabulary if necessary. "OK so we agree that…"

**Step 2.** ***Eliciting hypotheses about "what might be going on" (whole class or small groups)***
Ask students to comment about *observable conditions* that led up to the event or process, ask what might be "responsible" for the event or process.

| *You ask:* | *What you need to listen for, plan to respond to:* |
|---|---|
| • What do you think is causing this?<br>• What has happened here? (at level of inference)<br>• What would happen if ___? | What if students exhibit pre-conceptions?<br>What if students cite relevant facets of the big idea?<br>What if students *do* make connections to what they've experienced? |

**Step 3.** ***Pressing for possible explanations (have them work in small groups for part of this)***
Prompt briefly for "why" hypotheses—involving processes at the unobservable level. Label them as "hypotheses" so students feel at ease offering them.

| *You ask:* | *What you need to listen for, plan to respond to:* |
|---|---|
| • What might be going on here that we can't see?<br>• Why do you think this happens this way? (emphasize cause)<br>• What do you think causes ____? | What if students offer explanations congruent with scientific explanation?<br>What if students offer simplistic cause-effect?<br>What if students offer explanations that involve alternative conceptions? |

Then ***switch to small groups***, have students explore puzzling event more and create rough models. You can have them represent their ideas in labeled drawings.

**Step 4.** ***Summarizing and selecting the forms of ideas to make public (whole class)***
In this step, you can ask some of your students to share out their models with the rest of class (during this you would draw attention to important similarities and differences in the models) AND/OR ask the whole class to help you create a list of hypotheses that you'll address as the unit unfolds. Refer to these as **hypotheses** or **models** that we need to "work on".

| |
|---|
| *At different times in this public conversation you ask*:<br>"What are some things we are not sure about here?"<br>"How could we test our hypotheses?"<br>"What kinds of information or experiences do we need to learn more?" |

**Step 5. Adapting further instruction**

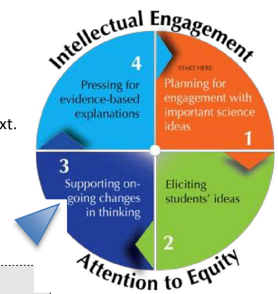
After instruction, use RSST Tool (page 3 of this guide) to analyze student responses and make instructional decisions.

| Pre-record your specific questions for each step of the practice | | | Complete this after you teach |
|---|---|---|---|
| *Generic questions for each step* | *Questions you will pose + discourse strategies (i.e. follow-up prompts, turn and talk, getting students to talk to one another)* | *What to listen for and plan to respond to* | *What did students say? What discourse strategies did you use?* |
| **Step 1.** ***Introducing the puzzling event and eliciting observations (whole class)***<br>• What do you see going on here?<br>• What did you notice when ___happened?<br>• When or where does ___ occur? | | • What if students cite relevant features of the task?<br>• What if students cite irrelevant ideas or cannot understand the representation/problem?<br>• What if students give inferences rather than observations? | |
| **Step 2.** ***Eliciting hypotheses about "what might be going on" (whole class or small groups)***<br><br>• What would you predict about ___?<br>• What has happened here? (at level of inference)<br>• What would happen if ___? | | • What if students exhibit pre-conceptions?<br>• What if students cite relevant facets of the big idea?<br>• What if students do make connections to what they've experienced? | |
| **Step 3.** ***Pressing for possible explanations (have them work in small groups for part of this)***<br>• What might be going on here that we can't see?<br>• Why do you think this happens this way? (emphasize cause)<br>• What do you think causes ____? | | • What if students offer explanations congruent with scientific explanation?<br>• What if students offer simplistic cause-effect? Example: "Why does water boil?" "Because you put it on the stove."<br>• What if students offer explanations that involve alternative conceptions? | |
| **Step 4.** ***Summarizing and selecting the forms of ideas to make public (whole class)***<br>• What are some things we are not sure about here?<br>• What kinds of information or experiences do we need to learn more? | | • What if students are unable to respond to any of these questions?<br>• What strategy will you use? | |

| Rapid Survey of Student Thinking (RSST).<br>Complete this part after teaching. | | |
|---|---|---|
| **Categories** | **Trends in student understandings, language, experiences<br>[sample sentence starters included below]** | **Instructional decisions based on the trends of student understanding** |
| Partial understandings? | [Many students have these facets of understanding already...] | [In my instruction I can build upon... / I may have to add or change...] |
| Alternative understandings? | [Many students believe this to be true....] | [I'll have to address... / I may have to change or add an activity...] |
| Everyday language you can leverage? | [I heard the use of the term_____, that I can refer to in upcoming lessons] | [I can use their descriptions as an entry point to talking about this example of academic language...] |
| Experiences they've had that you can leverage? | [They seemed to connect their experiences of __ with parts of the big ideas] | [I can use their everyday experiences with ____ to scaffold this part of the big ideas that explain the anchoring event] |

## A-3: Teaching Practice Tool: Supporting On-Going Changes in Student Thinking

### Teaching Practice Tool: *Supporting on-going changes in student thinking* (often referred to as Discourse 2 or "D2")




**Purpose of tool?** 1) To ensure students understand *why the activity makes sense to do* at this point in the unit. 2) To help students *bridge the activity with a larger scientific idea*. 3) To *support the development of students' academic language*, using the activity as a context.

**When to use tool?** When you are engaging students in a meaningful activity in order to build content knowledge and understand a scientific phenomenon.

**Step 1:** ***Providing students with an idea to use as leverage during the activity.*** Select some key idea from your target explanatory model. Provide a 10-15 minute presentation *of* content on this idea.

*You need to plan to:*
- Link verbally what was done by student previously to a "need to know" a new idea.
- Be explicit about new vocabulary being introduced.
- Use multiple representations of the idea, ask students to look across these and compare how the idea shows up.
- Plan for check-in questions to gauge understanding as you go.

**Step 2.** ***Getting the activity started: Helping students uncover observation and patterns*** **(use back pocket questions).**
Start activity, when students break into small groups, circulate among them and consider these questions.

| *You ask:* | *What you need to listen for, plan to respond to:* |
|---|---|
| • "What are you seeing here?" (or similar broad observational question)<br>• "What might these patterns tell you? "<br>• "You may want to focus on…" | What if students *can* cite relevant features of the activity?<br>What if students are focused on extraneous features of activity?<br>What if students mention patterns, but do not explain the significance? |

**Step 3.** ***Helping students connect activity to the anchoring event*** **(use back pocket questions).**
Your second round of interactions in the small groups tests whether kids understand **why** they are doing this activity in the first place. It's easier for them to discuss this after you've asked them what they are observing, inferring.

| *You ask:* | *What you need to listen for, plan to respond to:* |
|---|---|
| • "Can you explain what you are doing or what is happening in terms of [the anchoring event]?" | What if students hesitate or seem to rely on vocabulary?<br>What if students *can* make connections between activity and some aspect of big ideas? |

**Step 4.** ***Whole class coordination of student's ideas & their questions***
You return to whole class conversation. This is where you can help kids see broad trends or patterns of data for different groups in the classroom. You then need to help students "map" these onto a real world situation. Students' new questions should be addressed, not put on the shelf.

| *You ask:* | *What you need to listen for, plan to respond to:* |
|---|---|
| • "What did you find?"<br>• "I heard these three hypotheses, which ones do you agree with? Based on what evidence?" | What if students hesitate?<br>How will you handle a conversation about evidence? |

**Step 5. Creating or revising a public record of student thinking**

| | | |
|---|---|---|
| Option 1: Add to, revise, consolidate an explanation checklist | Option 2: Use post-it notes to revise your small group models (you need to do this once or twice in the middle of a unit, not after every activity). | Option 3: You could cite one or two possible explanations for your anchoring event and ask the whole class, "Which of these do we think is now more likely? Why?" |

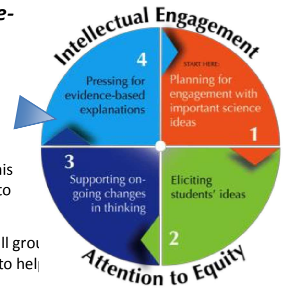
**After instruction, use RSST Tool to analyze student responses and make instructional decisions**

| Pre-record specific questions for each step of the practice | | | Complete this after you teach |
|---|---|---|---|
| *Generic questions for each step* | *Questions you will pose + discourse strategies (i.e. follow-up prompts, turn and talk, getting students to talk to one another)* | *What to listen for and plan to respond to* | *What questions did you ask? What discourse strategies did you use?* |
| **Step 1. *Providing students with an idea to use as leverage during the activity*** | [What representations are you using? What are the check-in questions you are planning?] | What will you do if students don't respond well to your check-in questions? | |
| **Step 2. *Getting the activity started: Helping students uncover observation, patterns.***<br>• "What are you seeing here?"<br>• "What might these patterns tell you? "<br>• "You may want to focus on…" | | What if students *can* cite relevant features of the activity?<br>What if students are focused on extraneous features of activity?<br>What if students mention patterns, but do not explain the significance? | |
| **Step 3. *Helping students connect activity to the anchoring event* (use back pocket questions).**<br>• "Can you explain what you are doing or what is happening in terms of [the anchoring event]?" | | What if students hesitate or seem to rely on vocabulary?<br>What if students *can* make connections between activity and some aspect of the anchoring event and relevant big science idea(s)? | |
| **Step 4. Whole class coordination of student's ideas & their questions**<br>• "What did you (addressing whole class) find in your activity • "I heard these three hypotheses, which ones do you agree with? Based on what evidence?" | | What if students hesitate?<br>What if *can* students describe patterns, insights? | |
| **Step 5. Creating or revising a public record of student thinking**<br>• "Let's now make changes to our original record, based on what we now know." | | How do you intend to talk about evidence?<br>How will you make sure the record is of students' thinking and not yours? | [What issues arose when you did try to create or revise this record of thinking?] |

| Rapid Survey of Student Thinking (RSST) | | |
|---|---|---|
| **Categories** | **Trends in student understandings, language, experiences [sample sentence starters included below]** | **Instructional decisions based on the trends of student understanding** |
| Partial understandings? | [Many students have these facets of understanding already...] | [In my instruction I can build upon... / I may have to add or change...] |
| Alternative understandings? | [Many students believe this to be true....] | [I'll have to address... / I may have to change or add an activity...] |
| Everyday language you can leverage? | [I heard the use of the term_____, that I can refer to in upcoming lessons] | [I can use their descriptions as an entry point to talking about this example of academic language...] |
| Experiences they've had that you can leverage? | [They seemed to connect their experiences of __ with parts of the explanatory model] | [I can use their everyday experiences with ____ to scaffold this part of the explanatory model] |

# A-4: Teaching Practice Tool: Pressing Students to Construct Evidence-Based Explanations

## Teaching Practice Tool: *Pressing students to construct evidence-based explanations* ***(often referred to as Discourse 3 or "D3")***




**Purpose of tool?** This tool helps students construct final evidence-based explanatory models for the anchoring phenomenon that has been the focus of the unit. The practice that precedes this—developing claims, evidence and reasoning—is not listed here.

**When to use tool?** This practice should happen near the end of a unit, but parts of this discourse can also be introduced at other times when you are trying to get students to talk about evidence.

This practice requires that several tools be available to students: 1) their current small grou models, 2) an explanation checklist, 3) the summary table, and 4) a scaffolded guide to hel them create, in writing and drawing, their final model.

**Step 1. *Updating students' explanatory models.***
Have students in small groups update their explanatory models. They should incorporate ideas from the summary table into their models. As students revise their models, they will want to compare their models against the explanation checklist.

**Step 2. *Prompting reasoning about gaps and contradictions in their explanations (in small groups).***
As students update their models, you circulate with questions that prompt students to consider if they are missing anything in their explanations.

| *You ask:* | *What you need to listen for, plan to respond to:* |
|---|---|
| • "Can you tell me what role [idea X] has in your explanation?"<br>• "How does this part of your explanation fit with the rest?"<br>• "Have has this idea in the checklist been included?" | • Students will often be able to verbally describe parts of an explanation but not represent it in the drawing; be ready to point this out and assist them. |

**Step 3. *Preparing students to persuade others with evidence.***
After the updated models have been completed, you ask students to prepare to defend one aspect of their explanatory model by using relevant evidence from a public record such as a summary table. They'll need a written guide for this.

| *You say:* | *What you need to listen for, plan to respond to*: |
|---|---|
| • "Let's focus on just one part of your explanation (such as before, during or after an event), and then an activity we've done that helps you understand that part of the explanation.<br>• Why did that activity convince you that [part of the explanation] is true?"<br>• "Is there a 'fit' between your evidence and your explanation?" | • What if student just name the activity, but don't say why it is evidence for a particular part of their explanation? |

**Step 4. *Public comparisons of evidence-based explanations*. [NEXT DAY]**
Here you have groups of students compare explanations with one another. These groups could defend one particular part of the explanation to the class, cite evidence used and the reasoning linking the evidence with the explanation.

| *You ask during or after groups present:* | *What you need to listen for, plan to respond to:* |
|---|---|
| • "Does this group's explanation differ from yours? How?"<br>• "Does their use of evidence make you re-think any part of your own explanation?"<br>• "Can more than one explanation be supported by evidence?" | • How can you get students to respond to each other's use of evidence and explanatory models?<br>• What if there is weak use of evidence, or inaccurate science but students do not pick up on it? |

**Step 5. *Making adaptations to the model.***
Here the teacher asks student groups to return to their explanations in order to make adjustments, and consider what unresolved puzzles they still have.

| *You say:* | *What you need to listen for, plan to respond to:* |
|---|---|
| • "Should we go back and change our models?"<br>• "What puzzles do we still have?" | • Be ready to prompt students with evidence or parts of explanations, presented by others, that they may not have been attending to. |

Another possibility is to have students apply their model to a new situation: "Now that we have a good evidence-based model, what other kinds of phenomena would our model help us explain or predict?" "Are there situations in which our model would not work? Why not?"

| Designing your specific questions/prompts for each step of the practice | | | |
|---|---|---|---|
| *Generic questions for each step* | *Specific questions or prompts you'll pose in this step* | *What to listen for and plan to respond to* | *After you teach* |
| **Step 1. *Updating students' explanatory models.*** | | *Then you need to plan for:*<br>• You'll need 4 tools at hand: 1) students' models, 2) the explanation checklist, 3) the summary table, 4) a guide for students to write about evidence and explanation. | *What did you actually say to prompt students about what to focus on (the actual words you used)?* |
| **Step 2. *Prompting reasoning about gaps and contradictions in their explanations.*** | | *What you need to listen for, plan to respond to:*<br>• Students will often be able to verbally describe parts of an explanation but not represent it in the drawing; be ready to point this out and assist them.<br>• What if students have gaps, contradictions or inaccuracies in their models? | *What did you actually say to students (the actual words you used)?* |
| **Step 3. *Preparing students to persuade others with evidence.*** | | *What you need to listen for, plan to respond to:*<br>• What if student just name the activity, but don't say why it is evidence for a particular part of their explanation? | *What did you actually say to students (the actual words you used)?* |
| **Step 4. *Public comparisons of evidence-based explanations.*** | | *What you need to listen for, plan to respond to:*<br>• How can you get students to respond to each other's use of evidence and explanatory models?<br>• What if there is weak use of evidence, or inaccurate science but students do not pick up on it? | *What did you actually say to students (the actual words you used)?* |
| **Step 5. *Making adaptations to the model.*** | | *What you need to listen for, plan to respond to:*<br>• Be ready to prompt students with evidence or parts of explanations, presented by others, that they may not have been attending to. | *What did you actually say to students (the actual words you used)?* |

## APPENDIX B: Methods Course Assignments

B-1: TE 407: Teaching Plan

B-2: TE 407: Reflection on Teaching Report

# TE 407: Teaching Plan

| Name: |
|---|

## Part I: Information about the Lesson

### Topic:

### Generating Big Ideas (Use the Big Idea Tool)

1. What is the Big Idea? *What makes this topic so important to study, that is, beyond knowing labels, definitions and examples? (4-8 sentences) …*

2. Creating the Big Idea: *Coupling a rich phenomenon with its explanatory model. What is an* ***observable event*** *(for example earthquakes, die-offs of species, different kinds of rusting) that exemplifies the big idea and that kids can come to a deep understanding of over a period of days? What underlying events provide a "why explanation" for this phenomenon? Use unobservable events, processes, and things to create a causal storyline that has no gaps.*

Do NOT skip this step! Draw for yourself a full explanatory diagram (your model) that combines representations of observable things and unobservable processes at work.

3. What does success for students look like? *Kids should be able to use the Big Idea to explain new phenomena that are different from the ones you've used in class—and/or use the Big Idea to predict "what if" scenarios or conduct thought experiments. What might these new phenomena or thought experiments be?*

*Kids should be able to use different kinds of evidence to support or refute parts of any explanatory model. What kinds of experiences might students draw evidence from to support their explanatory models?*

## Part II. Objectives for Student Learning

Use the table below to list the Michigan Objectives (probably one or two) that apply to your lesson and a small number of specific lesson objectives that you will be addressing during this lesson. The Michigan Objectives should be copied from the Content Expectations and the NGSS performance expectations should be copied directly from the NGSS document (both are available via the websites provided in the syllabus).

Note: Each lesson objective should be an observable outcome. They are **not** teaching activities. They are what you want students to be able to do that will indicate that they understand at the appropriate level. For example, "understand photosynthesis" does not describe what a student with that understanding will be able to do. Also, "Conduct an experiment on plant growth under different environmental conditions" is a good learning activity, but not a good objective. It doesn't say what students will learn to do as a result of conducting the experiments.

| **Michigan Objectives** |
| --- |
| 1. |
| 2. |
| **NGSS Performance Expectations** |
| 1. |
| 2. |
| **Specific Lesson Objectives** |
| 1. |
| 2. |
| |

## Part III: Classroom Activities

*This section contains your plans for the activities that you will actually do in the classroom.*

### Materials

**List materials you will be using**. Attach the files of materials that you have in electronic form.

- Presentation materials (Video, Powerpoint presentations, etc):
- Copied materials (Handouts, worksheets, tests, lab directions, etc.):
- Reading: Book:______________________ Pages:_______
- Laboratory materials: For the teacher or the class as a whole
- For each laboratory station
- Other materials:

### Sequence of Activities:

*Reminder this a single lesson plan (1-2 days). Use your planning tools (i.e., Eliciting Students Ideas Tool; Supporting Ongoing Changes in Thinking Tool; or Pressing for Explanations Tool) to write this part of the plan. Include specific questions that you will ask the students at each point in the lesson.*

1. **How will you start your lesson? (Time)**

2. **How will you transition to the first activity?**

3. **Activity #1 (Time)**

4. **How will you transition to the second activity?**

5. **Activity #2 (Time)**

6. *... (Insert more as needed)*

7. **How will you bring the class together, summarize the lesson, and give students next steps?**

## Part IV. Ensuring Equitable Instruction

*How will you ensure that you are meeting the needs of ALL students? Describe specific aspects of the activity that will support students from non-dominant groups. What might you need to do to make your lesson (e.g., the content, the activities) accessible for ALL students? (4-6 sentences)*

## Part V: Assessment of Students

### Assessment Task

*You will need to collect written work from your students. This can be a warm-up, an exit slip, [pictures of] students' models, ... .*

**Describe the assessment task in detail including the actual question(s) and what an "ideal response" might be to the task.**

**Rubric /70**

| | Pts Possib. | Pts Earned | Comments |
|---|---|---|---|
| **Big ideas**<br>Complete and accurate<br>Topics → big ideas<br>Phenomenon<br>Model | 15 | | |
| **Objectives**<br>Includes all relevant state & NGSS objectives<br>Lesson objectives are observable outcomes that match state & NGSS objectives and are appropriate for students | 10 | | |
| **Materials**<br>Complete and realistic | 5 | | |
| **Activities**<br>Coherent plan<br>Includes questions<br>What to listen for | 20 | | |
| **Ensuring Equity**<br>Includes specific decisions made to include non-dominant group of students | 10 | | |
| **Assessment**<br>Includes specific Qs<br>Matches objective(s)<br>Includes ideal response<br>Involves each student and reveals students' reasoning | 10 | | |

## B-2: TE 407: Reflection on Teaching Report

# TE 407: Reflection on Teaching Report

| Name: | Partner: |
| --- | --- |

### Purpose

*The purpose of this assignment is to learn how to use data from your lesson to improve your teaching. You will not be graded on how well your students did, but on well you analyze and draw implications from the data.*

### I. Lesson Context

***A. Lesson objective***

*You can cut and paste this from your lesson plan.*

***B. Story of What Happened***

*Write a brief story of what happened when you taught the lesson (about 500 words).*

*Make sure to include:*

*What you said and did and what "your students" said and did.*

*How did your students react to your phenomenon?*

*What did your students focus on? Did your students focus on what you thought they would?*

### II. Lessons learned (Use your "Rapid Survey of Student Thinking")

*Use this section to explicitly reflect on the ideas that students brought and how you are going to use these ideas in upcoming lessons.*

**Partial ideas?** *[Many students have these facets of understanding already…]…[In my instruction, I can build upon… / I may have to add or change…]*

**Alternative ideas?** *[Many students believe this to be true….] [I'll have to address… / I may have to change or add an activity…]*

**Everyday Language?** *[I heard the use of the term_____, that I can refer to in upcoming lessons] [I can use their descriptions as an entry point to talking about this example of academic language…]*

**Experiences?** *[They seemed to connect their experiences of __ with parts of the big idea]… [I can use their everyday experiences with ____ to scaffold this part of the big idea]*

## III. Implications Section

*In this section, consider what you wrote above about students' range of understandings to answer the questions. Make sure to think about how you can provide learning opportunities for ALL students (e.g., Economically Disadvantaged, Diverse Racial and Ethnic Groups, Students with Disabilities, and English Language Learners)*

### B. Implications for your lesson plan

*Based on your analysis, what parts of your lesson were successful? Which parts needed improvement? Describe a specific improvement for your lesson plan. Explain your answers.*

### C. Implications for how you interact with students

*Based on your analysis, which part of your interaction with students was most instrumental in understanding what they know and/or helping them towards high level explanations? Least helpful? Describe a specific improvement for an interaction with students. Explain your answers.*

### D. Implications for your assessment

*Which informal / formative assessment activities (asking questions, discussion, students asking questions…) were most and least revealing of students' thinking. Describe a specific improvement for your informal/formative assessment activities. Explain your answer.*

**Score: /100**

| | Pts Poss | Pts Earned | Comments |
|---|---|---|---|
| **Story of what happened**<br>Coherent<br>Includes students and teacher | 15 | | |
| **Lessons Learned: Partial Understandings**<br>Trends<br>Instructional Decisions | 10 | | |
| **Lessons Learned: Alternative Understandings**<br>Trends<br>Instructional Decisions | 10 | | |
| **Lessons Learned: Everyday Language**<br>Trends<br>Instructional Decisions | 10 | | |
| **Lessons Learned: Experiences**<br>Trends<br>Instructional Decisions | 10 | | |
| **Implications for your lesson plan**<br>Conclusions match evidence<br>Implications are useful<br>Specific improvement proposed | 15 | | |
| **Implications for interactions**<br>Conclusions match evidence<br>Implications are useful<br>Specific improvement proposed | 15 | | |

## APPENDIX C: Learning Progressions

C-1: Nature of Chemical Energy

C-2: Force and Motion

## C-1: Nature of Chemical Energy Learning Progression

**LEARNING PROGRESSION**
**Nature of Chemical Energy**

| Level | Description | Key Student Ideas |
| --- | --- | --- |
| 4 | Reactants and products are considered to determine whether a reaction is endo- or exo-thermic. | ● Breaking chemical bonds requires energy, making chemical bonds releases energy<br>● Whether a reaction is endothermic or exothermic depends on the bond energy in both the reactants and the products.[1]<br>○ Exothermic: The sum of the bond energy of the products is greater than the reactants.<br>○ Endothermic: The sum of the bond energy of the reactants is greater than the products. |
| 3 | Energy & matter are separately conserved, but are commonly linked due to chemical energy. However, products are not considered for change in energy. | ● A: Breaking bonds releases energy & making bonds requires energy.<br>○ Student may suggest that specific types of bonds (typically high energy) bonds break to release energy<br>● B: Chemical energy referenced as a source of energy, however it is unclear that the student is able to use the term beyond this |
| 2 | Energy comes from matter (and vise versa), but not explicitly as chemical energy | ● A: Energy & matter are separate and have no relationship. Therefore, energy sources are often misidentified due to lack of awareness of chemical energy as a form of energy.<br>● B: Matter turns into energy:<br>○ Explicitly as a way to “conserve” or “not destroy” them, and/or<br>○ Some matter is a form of energy. Commonly seen with questions that involve fuel substances, e.g. gasoline |
| 1 | Concern is for the needs of the subject or event, to start it or sustain it. Students do not appear to think a transformation is occurring. | ● Example needs for a flame:<br>○ Material - air, wood<br>○ Action - friction, striking action<br>● Students may draw from one or both categories<br>● Students may not see distinction between categories |

[1] The definitions of exothermic and endothermic reactions provided in this modified learning progression are incorrect, but this error did not seem to impact how the chemistry group interacted with the LP.

## C-2: Force and Motion Learning Progression

**FORCE & MOTION LEARNING PROGRESSION**
adapted from Alonzo & Steedle (2009)

| Level | Description | Key Student Ideas |
|---|---|---|
| 4 | Acceleration (change in speed and/or direction) is proportional to applied net force (which may not be in the direction of motion). | • Force is proportional to acceleration<br>• If there is motion, the (net) force might not be in the direction of motion<br>• If there is no motion, there is no <u>net</u> force.<br>  ○ Recognize normal force |
| 3 | Velocity is proportional to applied net force.* | • Force is proportional to speed/velocity<br>• If there is motion, there is a net force in the direction of motion<br>  ○ One of the forces in the net force may be impetus (force carried with moving object)<br>• If there is no motion, there is no <u>net</u> force.<br>  ○ Recognize normal force<br>  ○ May balance forces acting on two different objects (Newton's third law confusion) |
| 2 | Motion is directly associated with applied force.* (Force implies motion; motion implies force; non-motion implies no force; no force implies no motion.) | • Force is associated with motion<br>• If there is motion, there is only a force in the direction of motion<br>  ○ May be impetus (force carried with moving object)<br>• If there is no motion, there is no force.<br>• If there is no motion, there may be a force acting, but something else (not identified as a force) is in the way. |
| 1 | No general relationship between force and motion. Forces and their effects depend on properties of objects such as mass. | • Conflating force and motion<br>• If there is no motion, it is because a (net) force is preventing motion. |

** Ideas at Levels 2 and 3 may include a conception of force consistent with the impetus idea (that a moving object carries a force with it, proportional to its speed).*

## APPENDIX D: Work Session Materials

D-1: Work Session 1: Instructor's Materials (Chemistry)

D-2: Work Session 1: Instructor's Materials (Force and Motion)

D-3: Work Session 1: Completed Features Sheets

D-4: Work Session 2: Interpreting Student Ideas (Chemistry)

D-5: Work Session 2: Interpreting Student Ideas (Force and Motion)

D-6: Work Session 3: Directions for Group Reflection (MT1)

D-7: Work Session 4: Transitions Between Levels

D-8: Work Session 4: Instructional Next Steps

D-9: Work Session 5: Video Protocol (groups of 3)

D-10: Work Session 6: Directions for Group Reflection (MT2)

D-11: Work Session 7: Assessment Items (Chemistry)

D-12: Work Session 7: Assessment Items (Force and Motion)

## D-1: Work Session 1: Instructor's Materials (Chemistry)

**Tasks:**

**TASK 1:** What conception do the students have in each pile? Comparing the piles may help with this. [Each pile represents student responses at a different level of the learning progression]

**TASK 2:** How does this new set of student responses compare to each of the previous piles? What's the conception in this pile? [This pile represents student responses at a single level of the learning progression.]

**TASK 3:** Organize the piles from Tasks 1 and 2 into a pathway of increasing sophistication.

**TASK 4:** Here is a mix of student responses. Put them into piles of similar conceptions & describe/summarize the conception of each pile you create. [The student responses represent a range of levels of the learning progression.]

**TASK 5:** Add these new piles to your pathway of increasing sophistication.

**TASK 6:** What would be a student response that would be evidence of a more full understanding/more sophisticated response? Is this problematic for any future content they may learn (another HS course or college course)?

**TASK 7:** Let's try out the organization using a different prompt & student responses set. [The student responses represent a range of levels of the learning progression.]

**TASK 8:** Characterize the pile. Can you imagine this for the match burning question? If so, write a "student response". If not, why not?

- The atoms cannot change into a whole new atom or be destroyed, so they either turn into energy or change to an atom that can be made when a chemical change happens to the atom that it started with.
- The atoms cannot simply disappear into empty space and they cannot bond with the molecules in the air, so the molecules must be converted into heat or energy.The atoms cannot be burned up and disappear because atoms cannot just disappear, but they can be incorporated into carbon dioxide and water vapor, because it has carbon, oxygen and hydrogen in it. I don't think that the atoms can be converted into heat or energy, but I think that it could be converted into something that produces heat or energy.
- The atoms can't be incorporated into other elements or destroyed, but they can be used/converted into different energy sources.

**TASK 9:** Characterize the pile. Can you imagine this for the match-burning question? If so, write a "student response". If not, why not? Can you think of other prompts that would get these kind of answers?

- Fat is stored energy, so that energy could be used to create thermal energy or chemical energy.
- Fat is a form of energy and therefore cannot be created or destroyed so it can't disappear, but it can be converted into different atoms.

**TASK 10:** Any categories from the Match-Burning-Prompt that did not get a FAT-&-Exercise response? How would a kit with this conception answer this question?

**Questions:**

1. **MATCH:** When a match burns, there is heat and light energy in the flame. Where did that energy come from? (Associated T/F questions referencing air, wood, water vapor, the person striking the match, the flame)
2. **FAT:** Fat is mostly made of molecules such as stearic acid: $C_{18}H_{36}O_2$. How does fat provide the energy needed to exercise? What happens to the atoms during this process?

**Relationship between matter & energy—Student Ideas:**

- **Level 2:** Centered around needs (either material or activities) of the subject. Not clear that students are thinking about energy transformation.

  *Materials needed*
  - "I know you need oxygen to create a flame so I figure this is where most is coming from."
  - "Fire cannot burn without air"
  - "Particles in the air, such as water vapor enable the match to light."

  - When he exercises, his body needs energy so it uses up the fat to produce more energy. When he works harder, his body heats up, requiring energy as well. (maybe?)
  - It's common knowledge that fat keeps the body warm.

  *Action needed*
  - "The friction of the person who struck the match plays a big role in where the light energy in the flame comes from."
  - "When you strike it, the sparks ignite the flame."
  - "The flames came from friction"
  - "The amount of force used to strike the match."
    - "The heat and light energy came from the friction from the person who stated the flame and the flame was created while the flame burned."

  - Unlikely to have fat answers readily fall into this category. Might be interesting to think about how a kid (who thinks this way) would end up answering a question like this.

- **Level 3A:** *Energy comes from matter (and vise versa), but not explicitly as chemical energy*
  - The energy that came from the match could only come from the wood because the energy could not be created from anywhere else.
  - "The heat and light energy from the flame comes from, the wood of the match, because the wood of the match makes the whole thing light up, so all the flammable chemicals came from the wood. Also we know that wood can easily make fire."
    - "The light and heat energy in a match comes from the oxygen in the air, some of it comes from the person who struck the match, some comes from the wood of the match and none of it comes from water vapor." (Maybe?)

  - The atoms can become CO2, H2O, energy, heat, and lots of other things.
  - The fat is converted into energy that they use as they are exercising.
  - When the person exercises, the atoms of fat in their bodies are converted to different energies like heat and chemical.
  - By exercising you are pushing your body to use more energy and your body pulls that energy from your fat 'burning' it and converting the fat into energy because all fat is is stored energy.
    - When a person exercises, the oxygen in the fat converts to energy while the hydrogen burns up and the carbon is used for some energy.
    - Some of the fat turns into heat which is why you get hot when you exercise.
    - He uses the stored energy in the fat and converts it into whatever nasty things are found in human waste.

- **Level 3ai:** Matter turns into energy, explicitly as a way to "conserve or not destroy" them.
    - The atoms can't be incorporated into other elements or destroyed, but they can be used/converted into different energy sources.
    - The atoms cannot simply disappear into empty space and they cannot bond with the molecules in the air, so the molecules must be converted into heat or energy.
    - The atoms cannot change into a whole new atom or be destroyed, so they either turn into energy or change to an atom that can be made when a chemical change happens to the atom that it started with.
    - The atoms cannot be burned up and disappear because atoms cannot just disappear, but they can be incorporated into carbon dioxide and water vapor, because it has carbon, oxygen and hydrogen in it. I don't think that the atoms can be converted into heat or energy, but I think that it could be converted into something that produces heat or energy.

    - How might this look for the match burning question?

- **Level 3aii:** Some matter is a form of energy. (Can also be seen in questions that involve substances that are seen as fuel, i.e. gasoline)
    - Fat is a form of energy and therefore cannot be created or destroyed so it can't disappear, but it can be converted into different atoms.
    - Fat is stored energy, so that energy could be used to create thermal energy or chemical energy.

- **Level 3B:** *Energy & matter are separate and have no relationship. (Missing chemical energy...therefore, energy sources are often misidentified.)*
    - Heat and light energy would be unable to come from the air, wood or water vapor, due to the fact that matter cannot be converted into energy. Hence, the only source the energy could come from is the transfer from the person who strikes the match to the light and heat coming off of the flame.
    - The energy has to come from the motion of the person striking the match because it's the only energy available to be turned into light and heat.
    - The person striking the match transfers energy to the match which uses friction against another match which is energy. Energy is never lost or gained just transferred or converted.

    - Unlikely to have fat answers readily fall into this category. Might be interesting to think about how a kid (who thinks this way) would end up answering a question like this.

- **Level 4:** Energy & matter are separately conserved, but are commonly linked due to chemical energy. Products not considered for change in energy.

  *4A: No mention of chemical bonds*
    - From chemical energy in the wood.
    - The energy comes from the chemical energy that turned to light energy when the match was struck.
    - The light and heat energy in the flame come from chemical energy given off by the match.
    - It comes from the motion energy and chemical energy.

- The energy stored in the fat is converted into the energy the for exercise. The atoms stay C, H and O, just reorganized into different molecules (like CO2 and something else I can't remember).

*4B: Breaking bonds releases energy, (making bonds requires energy.)*

- The light and heat energy comes from chemical bonds held in the match. When struck, those bonds are broken through a chemical reaction which releases light and heat energy.
- Matter cannot be turned into energy, it can only be transformed. Therefore, the energy comes from the breaking of chemical bonds as the flame burns and a little bit from the person who struck the match.
- The energy in the flame came from the stored up energy in the match and some chemicals in the air.

- The fat atoms are breathed out as carbon dioxide and water vapor. The chemical bonds being broken causes heat to be produced.
- Molecules in the fat are broken up for energy, but the atoms themselves are not.
- Their chemical bonds break and that creates energy, then the molecules bond with other molecules in the environment.
- The fat isn't 'converted' into any form of energy, the bonds however can be broken to release energy and form new molecules.
    - The bonds between atoms are the energy, and the atoms themselves are released in breath and sweat.
    - When a person is working out the bonds between the atoms are broken and reformed which releases and conserves energy. (not sure that the products bond energy are the reason that energy is released?)

*4C: Specific types of bonds (typically high energy) bonds break to release energy*

- Heat and light energy in the flame comes from the high energy chemical carbon to carbon and carbon to hydrogen in the wood of the match. These chemical bonds are broken by the person who struck the match when they struck the match. Because the air and water vapor do not have high energy bonds, they are allowing the chemical bonds in the match to break rather than contributing to the energy being released. *(Attending to products, but incorrectly)*
- The energy could not have came from water vapor or the air because there are no high energy bonds. Some of the energy could have came from the person converting some of their chemical energy into the match to light it and some of the energy could have came from the wood since it contains high energy bonds.
- The heat and light energy comes from the chemical reaction that occurs when the flame burns. The high energy bonds are broken as wood molecules are converted into carbon dioxide and water vapor, creating heat and light energy.
    - The energy in the flame was in the high energy bonds in the wood in the match. When the match started burning, the molecules in the wood were broken, and energy was released from the high-energy bonds.
    - Heat and light energy come from high energy bonds being broken such as the high energy bonds in wood.
    - The heat and light energy from the match comes from the initial strike of the match and then the wood which has high energy bond breaking creating heat and light in the form of fire.

- The heat and light energy in the flame comes from the high energy bonds in the air and the motion energy from the person who struck the match. (+misidentifying where most of the energy is found)

- He breaks apart the fat molecules which give him energy from the high energy bonds,the atoms go into water and $CO_2$ molecules.
- The CH bonds in the fat are broken to release energy, and what is left gets converted into waste like $CO_2$ and water. It does not convert into energy directly, because matter cannot change into energy.
- He breaks apart the fat molecules which give him energy from the high energy bonds, the atoms go into water and $CO_2$ molecules.
    - The fat does not exclusively create energy-giving molecules, but stores them. (Maybe 4b or 4c?)

**Level 5:** Reactants and products must be considered to determine whether a reaction is endo- or exo-thermic.

- “The heat and light energy comes from high-energy chemical bonds in the match. Molecules in the match combine with oxygen molecules. The high-energy bonds break and the atoms then reform into new molecules, releasing heat and light energy.” (maybe?)

- The bonds in $C_{18}H_{32}O_2$ are broken and $CO_2$ and $H_2O$ are formed. But you need $O_2$ too. The energy is released because of the way the $O_2$ and fat molecules bond compared to the way the $CO_2$ and $H_2O$ molecules bond. (maybe?)

## D-2: Work Session 1: Instructor's Materials (Force and Motion)

*We are going to look at some student responses to questions that are designed to reveal aspects of their understanding of force and motion.*

**TASK 1:**

**QUESTION 1:**

**A rocket sled is traveling on a very long frictionless track with the engine on. The speed of the sled steadily increases while the engine is on. What is true about the force exerted by the engine?**

**Purpose:** Notice the difference between Levels 2, 3, and 4 in terms of What Force is Proportional to (motion vs. speed/velocity vs. acceleration)

**Complete on "Worksheet"**

Feature: What Force is Proportional to
Student Ideas:

- Motion – B
- Speed/velocity – A
- Acceleration - C

Pile A [Level 3 – Force proportional to speed/velocity]:

1) The more force, the faster the sled travels.
2) The force gets faster and faster.
3) The force exerted by the engine is pushing out faster and faster making it so the rocket sled moves faster and faster.

Pile B [Level 2 – Force proportional to motion]:

4) Since the engine is on of course it will move.
5) It is greater than the other force acting on it because it moves forward.

Pile C [Level 4 – Force proportional to acceleration]:

6) The force stays the same.
7) The sled is accelerating with the same force.

**What do you notice about the three piles? How would you characterize the responses in each pile? What makes the piles different? Which pile seems the most sophisticated? The least sophisticated?**

**[If needed] What do students in each group think about the relationship between force and motion? What type of motion do they think would result from a constant force?**

*Let's see how these ideas play out in response to a different question.*

**TASK 2**:

**Purpose:** Practice noticing the difference between Levels 2, 3, and 4 in terms of What Force is Proportional to (motion vs. speed/velocity vs. acceleration)

**QUESTION 2:**

**Jeff's car ran out of gas, so he has to push it along a flat icy road. There is no friction between the car and the ice. As long as Jeff pushes with a constant force, how will his car move? Please describe the car's motion with as much detail as you can.**

8) The car will stay at the same velocity the entire time because he is putting the same amount of force on the car. [A - Speed/velocity]
9) The car will keep accelerating. [C - Acceleration]
10) He will push and the car will move forward until he stops pushing. [B - Motion]
11) The car will go faster and faster because there is no friction. [C - Acceleration]
12) The car will go as fast as he is pushing it. [A - Speed/velocity]
13) The car will move at a steady movement until stopped by an outside force. [A - Speed/velocity]

**Sort these responses into piles based on what you infer about what students think about the relationship between force and motion. (You might want to start by matching these responses to the piles from Question 1.)**

**Do any responses not fit into the piles from Question 1? If so, how would you characterize these responses?**

**Purpose:** Notice tendency to conflate force and motion

**Complete on "Worksheet"**

*Feature: What Force is Proportional to*
Student Idea: Conflating force and motion

[*If needed], let's look more closely at a couple of responses in Pile A.*

**What do you notice about Responses 2 and 12? What do these two responses have in common?**

*In both, the student appears to conflate force and motion. [This may also be the case for Responses 3 and 7.]*

*Now let's look at responses to a different question that reveals another aspect of student thinking.*

**TASK 3:**

**Purpose:**

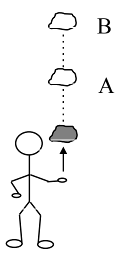
Notice impetus conception (and reason about why this idea might be reasonable, given students' everyday experiences)
Notice the difference between Level 2a, Level 3a, and Level 4 on Why Motion (only force in the direction of motion vs. net force in the direction of motion vs. (net) force might not be in the direction of motion

**Complete on "Worksheet"**

Feature: Why Motion
Student Ideas:

- Only force in the direction of motion (IMPETUS) - D
- Net force in the direction of motion (including IMPETUS) - E
- (Net) force might not be in the direction of motion - F

**QUESTION 3:**




**Derek throws a stone straight up into the air. It leaves his hand, goes up through point A, gets as high as point B and then comes back down through A again.**

**Ignoring air resistance, what force(s) are acting on the stone when it is moving up through point A?**

Pile D [Level 2a – Impetus]:

14) Derek's hand.
15) The force applied by Derek.
16) The force the hand puts on it.
17) The amount of force that Derek had put on it.

Pile E [Level 3a – Impetus as part of net force in direction of motion]:

18) The force caused by Derek and gravity.
19) The force of the person's hand pushing it up & gravity.
20) Force from his hand, which made the rock go up, and gravity pulling it down.
21) The force of gravity is pulling down, but its less then the force the hand used to push it up.

Pile F [Level 4 – Force not needed – and not necessarily – in direction of motion]:

22) Gravity.

**What can you infer about students' ideas about force and motion based on these responses?**

**How would you order these piles? (Which is most sophisticated? Which is least sophisticated?) Why?**

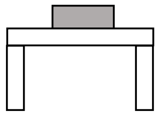
*Pile D considers only force in the direction of motion, whereas Pile E includes the idea of net force. In both piles, there must be a force in the direction of motion. (Since a force is no longer being applied, this is "impetus.") In contrast, in Pile F, students seem to recognize that there does not need to be a force in the direction of motion (and, in fact, that there can be a force in the opposite direction).*

**Why might students provide responses in your two less sophisticated piles? (Why might these responses make sense to them?)**

*In all of their experience in the world (with friction), a force has to be applied in the direction of motion. Therefore, students (and people in general) assume that – if a force is not actively being applied – it must have been imparted to the object in order for it to keep moving.*

*Now let's look at responses to a different type of question.*

**QUESTION 4:**



**Use your understanding of force to explain why the box sitting on the table above is not moving.**

**TASK 4:**

**Purpose:**

Notice the difference between Level 1, Level 2-X, Level 2-Y, and Level 3 on Why No Motion (force keeping it down vs. table in the way vs. no force vs. no net force)

**Complete on "Worksheet"**

Feature: Why Motion
Student Ideas:

- (Net) force
- No force
- No net force
- Table in the way

Pile G [Level 2 – No motion because no force]:

23) There are no forces acting on it since it's immobile (not moving).
24) The box on the table is not moving because an outside force is not acting on it.

Pile H [Level 3 – No motion because no net force]:

25) Because gravity is pulling it down and the table is pushing it up with the same amount of force.
26) The box doesn't move because the force of the table is equal to the force pushing the box down.

Pile I [Level 1 – No motion because force is keeping it down]:

27) Gravity is keeping it down.
28) There is more force pressing down on it than there is pressing up so it doesn't move.

Pile J [Level 2 – Table in the way]:

29) Gravity is causing a force going down, but because the table has no slope the box is stopped by the table.
30) Gravity is pulling it down, but the table stops it from touching the floor.

**What do you notice about the four piles? How would you characterize the responses in each pile? What makes the piles different? Which pile seems the most sophisticated? The least sophisticated?**

*Here are a few more responses…*

**Purpose:**

Notice specific student idea about Why Motion

**Complete on "Worksheet"**

*Feature: Why Motion*
Student Idea: N3L confusion: Balancing forces acting on two different objects

<u>**TASK 5**</u>**:**

Pile K [Level 3 – No motion because no net force, but N3L confusion]:

31) Because the box is pushing down and the table is pushing up.
32) Because the force of the box and the table are balanced.
33) In Newton's 1st Law, an object in motion, stays in motion & an object at rest stays at rest unless an unbalanced force is acted on it. The box doesn't have an unbalanced force acting on it. It is pushing down & the table is pushing up so it's an equal force.

**What do you notice about this pile? How would you characterize the responses in this pile? Do these responses align with any of the other piles for this question? If not, why not? If so, is there any difference between these responses and those in the other pile?**

*These responses are like Pile H, in that they indicate that no motion requires no net force (or balanced forces). However, these responses display a common Newton's Third Law confusion (treating a Newton's third law pair – forces acting on two different objects – as a set of balanced forces – which makes sense only if the forces are acting on the same object).*

## D-3: Work Session 1: Completed Features Sheets

| FEATURES OF STUDENT IDEAS (things to look/listen for) | STUDENT IDEAS (what I might see/hear) |
|---|---|
| CHEMICAL ENERGY | focus on needs (materials or activities); not clearly thinking @ energy transformation<br>*from match, air, etc<br>*from friction, striking, etc |
| | energy comes from matter (+ vice versa)<br>→ *matter turns into energy explicitly (to conserve)<br>*some matter is a form of energy |
| | energy + matter are separate – + have no relationship |
| | energy + matter are separately conserved, but linked thru chemical energy?<br>products not considered for energy Δ<br>→ *no mention of chemical bonds<br>*breaking bonds releases energy / making " requires "<br>* specific types of bonds ("high energy bonds") break to release energy |
| | + have to consider reactants + products to know if exo- or endo-thermic |
| | |

| FEATURES OF STUDENT IDEAS (things to look/listen for) | STUDENT IDEAS (what I might see/hear) |
|---|---|
| What force is proportional to | Motion |
| | Speed/velocity |
| | Acceleration |
| | |
| | Conflating force and motion |
| Why motion | <u>Only</u> force in the direction of motion (IMPETUS) |
| | Net force in the direction of motion (including IMPETUS) |
| | (Net) force might not be in the direction of motion |
| | |
| | |
| Why no motion | (Net) force |
| | No force |
| | No net force |
| | <u>Role of the table</u><br>Exert a force<br>In the way |
| | N3L confusion: Balancing forces acting on two different objects |

## D-4: Work Session 2: Interpreting Student Ideas (Chemistry)

**When a match burns, there is heat and light energy in the flame. Where did that energy come from? (Associated T/F questions referencing air, wood, water vapor, the person striking the match, the flame)**

1. The heat and light energy from a match comes from the match and air, this is because the air gives the match energy and the wood keeps the match going with heat and light energy.

How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?

What is confusing or unclear about this student response?

What question(s) could you ask the student to help you to decide where to put the response?

**When a match burns, there is heat and light energy in the flame. Where did that energy come from? (Associated T/F questions referencing air, wood, water vapor, the person striking the match, the flame)**

2. The energy came from the wood as it burned because as the match is burning the wood molecules have high energy bonds in them which turn into heat and light energy in the flame.

**How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?**

**What is confusing or unclear about this student response?**

**What question(s) could you ask the student to help you to decide where to put the response?**

**When a match burns, there is heat and light energy in the flame. Where did that energy come from? (Associated T/F questions referencing air, wood, water vapor, the person striking the match, the flame)**

3. From the friction that is caused by striking the match on fire.

**How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?**

**What is confusing or unclear about this student response?**

**What question(s) could you ask the student to help you to decide where to put the response?**

**When a match burns, there is heat and light energy in the flame. Where did that energy come from? (Associated T/F questions referencing air, wood, water vapor, the person striking the match, the flame)**

4. The heat and light energy come from what the person who lit the flame used to light it, and from the match.

**How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?**

**What is confusing or unclear about this student response?**

**What question(s) could you ask the student to help you to decide where to put the response?**

**When a match burns, there is heat and light energy in the flame. Where did that energy come from? (Associated T/F questions referencing air, wood, water vapor, the person striking the match, the flame)**

5. This is because there is energy in the atoms of the match.

**How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?**

**What is confusing or unclear about this student response?**

**What question(s) could you ask the student to help you to decide where to put the response?**

**Fat is mostly made of molecules such as stearic acid: $C_{18}H_{36}O_2$. How does fat provide the energy needed to exercise? What happens to the atoms during this process?**

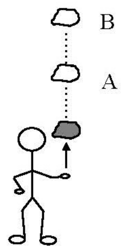
15. Burning fat will not create carbon dioxide. The fat will convert into different energy. Atoms can not be created or destroyed so they can't burn up and disappear, some of the calories give off heat. Some sweat comes from fat.

**How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?**

**What is confusing or unclear about this student response?**

**What question(s) could you ask the student to help you to decide where to put the response?**

## D-5: Work Session 2: Interpreting Student Ideas (Force and Motion)




**Derek throws a stone straight up into the air. It leaves his hand, goes up through point A, gets as high as point B and then comes back down through A again.**

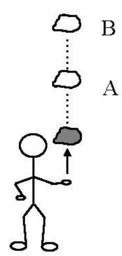
**Ignoring air resistance, what force(s) are acting on the stone when it is moving <u>up</u> through point A?**

Your hand made the rock move because you threw it up in the air

**How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?**

**What is confusing or unclear about this student response?**

**What question(s) could you ask the student to help you to decide where to put the response?**




**Derek throws a stone straight up into the air. It leaves his hand, goes up through point A, gets as high as point B and then comes back down through A again.**

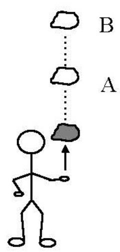
**Ignoring air resistance, what force(s) are acting on the stone when it is moving <u>up</u> through point A?**

Gravity, momentum

**How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?**

**What is confusing or unclear about this student response?**

**What question(s) could you ask the student to help you to decide where to put the response?**




Derek throws a stone straight up into the air. It leaves his hand, goes up through point A, gets as high as point B and then comes back down through A again.

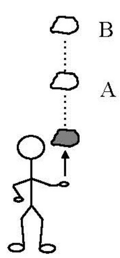
Ignoring air resistance, what force(s) are acting on the stone when it is moving up through point A?

Unbalanced

How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?

What is confusing or unclear about this student response?

What question(s) could you ask the student to help you to decide where to put the response?




Derek throws a stone straight up into the air. It leaves his hand, goes up through point A, gets as high as point B and then comes back down through A again.

Ignoring air resistance, what force(s) are acting on the stone when it is moving up through point A?

The motion of throwing it up, and gravity.

How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?

What is confusing or unclear about this student response?

What question(s) could you ask the student to help you to decide where to put the response?

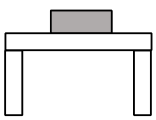
**Jeff's car ran out of gas, so he has to push it along a flat icy road. There is no friction between the car and the ice. As long as Jeff pushes with a constant force, how will his car move? Please describe the car's motion with as much detail as you can.**

It will move at a constant or accelerating speed.

**How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?**

**What is confusing or unclear about this student response?**

**What question(s) could you ask the student to help you to decide where to put the response?**



**Use your understanding of force to explain why the box sitting on the table above is not moving.**

An object at rest will stay at rest until acted on by an outside force.

**How does this response align with the student ideas you identified on Tuesday? Which idea(s) might this response represent?**

**What is confusing or unclear about this student response?**

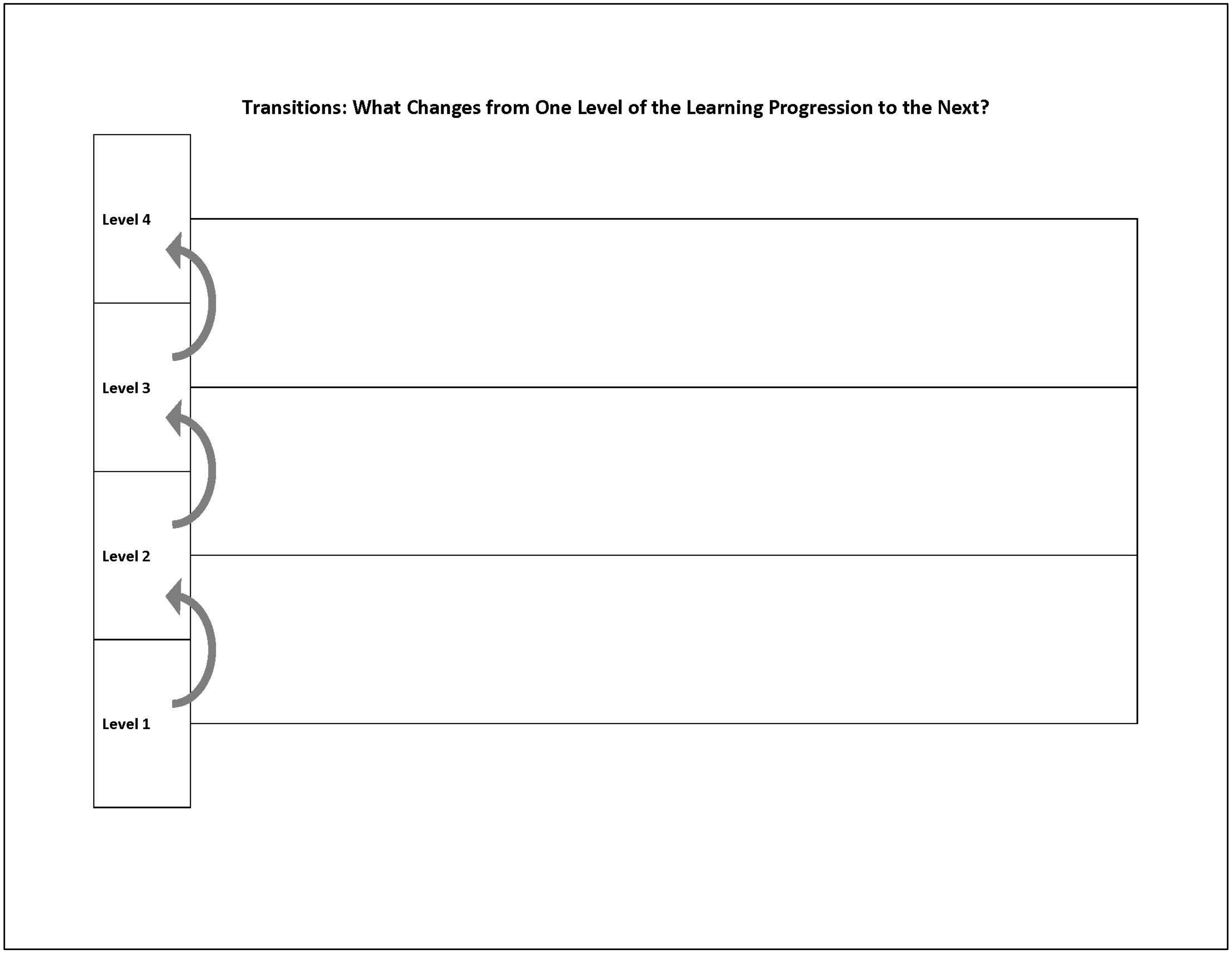
**What question(s) could you ask the student to help you to decide where to put the response?**

## D-6: Work Session 3: Directions for Group Reflection (MT1)

**Directions for Group Reflection on Microteaching #1**

1. Allow each person to have 5 minutes to tell the story of what happened when they taught (Keep track of time because you NEED to get to the next step).
    a. Give the overall flow of the lesson and anything that stood out to you (you will have time to focus on student ideas later)
    b. Share some feedback that you got from your "students" (use the feedback sheets) Specifically, focus on their thoughts about the phenomenon that you used. What worked and what might you think about shifting if you were to do this again?
2. Look at the right-hand column in the first table on the Eliciting Students' Ideas Tool (Fill this in after you teach: What did students say? What discourse strategies did you use?). Share what you have written for each section. Use these ideas as you work on #3.
3. Work together to fill out the table below.
    a. In the "categories" column, make a list of all of the **ideas/understandings**, **language**, and **experiences** that you heard (pool ideas from across all groups and from all sections from the table above!). Put them into the categories listed in the table (partial understandings, alternative understandings…). Make sure to use what you HEARD (using your notes from your Eliciting Student Ideas Tool AND your video) as well as what students WROTE in the work that you collected
    b. Think about trends or patterns in students' ideas, language, and experiences.
        i. When thinking of trends and patterns for Partial Understandings and Alternative Understandings, use your "Features of Student Thinking" sheet
    c. Brainstorm instructional decisions that you will need to make to as you start thinking about planning upcoming lessons for this unit. Look back at your Big Ideas Tool and NGSS Performance Expectations to make sure that you are addressing all components of the Disciplinary Core Ideas.

## D-7: Work Session 4: Transitions Between Levels



## D-8: Work Session 4: Instructional Next Steps

**Next Steps: If Students Hold a Particular Idea, What Instruction Could Support Their Learning Progress?**

Idea: ________________________________________________

| | Transition | Instruction to Accomplish Transition |
|---|---|---|
| **Level** ______ | Goals: | |
| **Level** ______ | Resources: | |

## D-9: Work Session 5: Video Protocol

This Video Protocol was used for groups of three preservice teachers. For groups of four preservice teachers, steps 2 and 3 were combined into one four-minute block during which group members watched the video once while focusing on both student ideas and teacher moves.

### Video Protocol

**Roles**

Presenter – teacher bringing teaching video and a question for the group to discuss.
Facilitator – colleague who coordinates the group process and monitors time while participating.
Participants – teacher colleagues who collaborate in the analysis of video.

| Step | Description | Time |
|---|---|---|
| **1** | **Overview:** Presenter gives an overview of the video. Please address the following factors:<br>○ Brief context of the part of the lesson<br>○ Is there a question or dilemma that the presenter wants to focus on? | **3 minutes** |
| **2** | **Watch video with a focus on student ideas:** Group watches video, and records student ideas. Pay particular attention to students' partial understandings. | **4 minutes** |
| **3** | **Watch video with a focus on teacher moves:** Group re-watches video, and records teacher moves (e.g., questions, statements). Pay particular attention to teacher moves associated with (i.e., eliciting or responding to) students' partial understandings. | **4 minutes** |
| **4** | **Clarifying questions:** Participants ask clarifying questions of the presenter. Clarifying questions have brief, factual answers. Presenter responds to the clarifying questions. | **3 minutes** |
| **5** | **Interpreting partial understandings**: Participants and presenter discuss if/how they see "student" ideas in the video related to those represented in the learning progression/features-of-student-thinking sheet. The goal is to better understand student ideas by clarifying the types of ideas students are expressing and where more information may be needed to unambiguously interpret a student idea. | **5 minutes** |
| **6** | **Consultancy:** Presenter very briefly states what they already know should be changed in the instruction so that suggestions by others are not redundant. The presenter then is a silent listener while participants engage in a larger discussion of the teacher moves and resulting student ideas. Participants are encouraged to include both "warm" and "cool" feedback in the discussion.<br>○ *Warm feedback* – identify what you see or hear about successful first steps that students made (or that the teacher made) in this lesson.<br>○ *Cool feedback* – suggest an area that has some room for improvement and provide the next step that could be taken. | **5 minutes** |
| **7** | **Reflection:** Presenter reflects on any new ideas, new perspectives, or new questions that emerged from the group discussion. Presenter also reflects on the central question in light of the discussion. | **3 minutes** |
| | **Debrief on group dynamics after everyone has taken their turn presenting**: Some ideas for debriefing include:<br>○ *Accountability to students' ideas*: How did group members give the student work a "generous reading" during the process?<br>○ *Accountability to science*: Did we reach any consensus about science behind this activity?<br>○ *Accountability to one another*: Did everyone have a chance to participate? How did we use strategies like paraphrasing and "wait time" to be active listeners?<br>○ *Overall*: How might we change ways we collect, analyze, and discuss student work? | **3 minutes** |

## D-10: Work Session 6: Directions for Group Reflection (MT2)

**Directions for Group Reflection on Microteaching #2**

1. Work together to fill out the table below.
    a. In the “categories” column, make a list of all of the **ideas/understandings**, **language**, and **experiences** from your student work (and what you heard while teaching. Pool ideas from across all groups. Put the ideas into the categories listed in the table (partial understandings, alternative understandings…). Make sure to use what you HEARD as well as what students WROTE in the work that you collected
    b. Think about trends or patterns in students’ ideas, language, and experiences.
        i. When thinking of trends and patterns for Partial Understandings and Alternative Understandings, use your “Features of Student Thinking” sheet and learning progression
    c. Brainstorm instructional decisions that you will need to make to as you start thinking about planning upcoming lessons for this unit. Look back at your Big Ideas Tool and NGSS Performance Expectations to make sure that you are addressing all components of the Disciplinary Core Ideas.

## D-11: Work Session 7: Assessment Items (Chemistry)

**Sunlight helps plants to grow. Where does light energy go when it is used by a plant? Please choose ONE answer that you think is best.**

- **a) The light energy is converted into sugar in the plant.**
- **b) The light energy is converted into ATP in the plant.**
- **c) The light energy is used up to power the process of photosynthesis.**
- **d) The light energy becomes chemical bond energy.**
- **e) The light energy keeps the plant warm so it can live and grow.**

For each of the level of the learning progression, how would you expect students with ideas at that level to respond?

Level 1: ____________

Level 2: ____________

Level 3: ____________

Level 4: ____________

**How does food contribute to a person's body heat? Please choose ONE answer that you think is best.**

- **a) Atoms in the food are converted into thermal energy (heat).**
- **b) Chemical energy in the food is converted into thermal energy (heat).**
- **c) Eating food produces thermal energy (heat), which can make the person warmer.**
- **d) Thermal energy (heat) is released when chemical bonds in the food are broken and new bonds are formed.**
- **e) Food contains high energy bonds, which are broken to release energy, including thermal energy (heat).**
- **f) Food is a form of energy, which can be changed into other forms of energy, such as thermal energy (heat).**

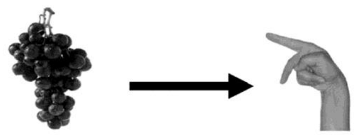
For each of the level of the learning progression, how would you expect students with ideas at that level to respond?

Level 1: ____________

Level 2: ____________

Level 3: ____________

Level 4: ____________



**The grape you eat can help you move your little finger.**

**Please describe how one glucose molecule from the grape provides energy to move your little finger. Tell as much as you can about any biological and chemical processes involved in this event.**

For each of the level of the learning progression, how would you expect students with ideas at that level to respond?

Level 1:

Level 2:

Level 3:

Level 4:

**In autumn, people pile fallen leaves and put them in a compost pile. After several weeks, the pile becomes warm. Where does the heat come from?**

For each of the level of the learning progression, how would you expect students with ideas at that level to respond?

Level 1:

Level 2:

Level 3:

Level 4:

## D-12: Work Session 7: Assessment Items (Force and Motion)

**A rocket in outer space is traveling toward a far off planet. An astronaut turns on the rocket's engines, which exert a constant force on the rocket. You may assume that there is no gravity or air resistance.**

1. **While the engines are on, how will the rocket move?**
    A. The rocket will move at a constant speed.
    B. The rocket will move faster and faster as long as the engines are on.
    C. The rocket will move faster and faster until it reaches its maximum speed.
    D. The rocket will move only while the engines are on.

2. **When the astronaut turns off the engines, what will happen to the rocket?**
    A. It will steadily slow down until the force from the engines is gone.
    B. It will steadily slow down because no forces are acting on it.
    C. It will continue moving with a constant speed because no forces are acting on it.
    D. It will continue moving with a constant speed because the force from the engines is still acting on it.

For each of the level of the learning progression, how would you expect students with ideas at that level to respond?

| | Question 1 | Question 2 |
|---|---|---|
| Level 1: | ______________________________ | ______________________________ |
| Level 2: | ______________________________ | ______________________________ |
| Level 3: | ______________________________ | ______________________________ |
| Level 4: | ______________________________ | ______________________________ |

**José drops a ball from the top of a tall building. There is no air resistance, but gravity is acting on the ball. What will happen to the speed of the ball as it falls?**

A. The ball's speed will be constant because the force of gravity is constant.
B. The ball's speed will increase until it reaches a constant speed because the force of gravity is constant.
C. The ball's speed will increase as it falls because the force of gravity is constant.
D. The ball's speed will increase as it falls because the force of gravity is increasing.

For each of the level of the learning progression, how would you expect students with ideas at that level to respond?

Level 1: ____________

Level 2: ____________

Level 3: ____________

Level 4: ____________

**On a visit to a science lab, Madison observes a blob of shiny material, suspended in the air. The blob isn't moving. What can she conclude about the force(s) acting on the blob?**

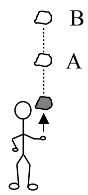
For each of the level of the learning progression, how would you expect students with ideas at that level to respond?

Level 1:

Level 2:

Level 3:

Level 4:




**Derek throws a stone straight up into the air. It leaves his hand, goes up through point A, gets as high as point B and then comes back down through A again. Ignoring air resistance, why does the stone come to a stop at point B?**

For each of the level of the learning progression, how would you expect students with ideas at that level to respond?

Level 1:

Level 2:

Level 3:

Level 4:

**Amelia hits a puck on a flat frictionless surface. Describe the motion of the puck a few seconds after the hit. Explain why the speed of the puck is or is not changing in terms of what you know about forces.**

For each of the level of the learning progression, how would you expect students with ideas at that level to respond?

Level 1:

Level 2:

Level 3:

Level 4:

## APPENDIX E: Post-Microteaching Interview Protocol

E-1: Microteaching Interview 1 Protocol

E-2: Microteaching Interview 2 Protocol

E-3: Microteaching Interview 3 Protocol

## E-1: Microteaching Interview 1 Protocol

**Microteaching 1 Interview Protocol**

**Equipment**:
- Video camera (with external microphone, if available)
- Tripod and extension cord
- Audio recorder (with spare batteries)
- Laptop computer with speakers
- Printed interview protocol (one copy)
- Two printed copies of each of the following:
  - Eliciting Tool assignment
  - Lesson Plan assignment
  - "Features" worksheet
  - Reflection assignment
    - The interviewer's copy should indicate pre-identified student ideas to highlight.
- Video of microteaching
- List of video clip(s) of microteaching
- Timer
- Printed giftcard log

**Interview considerations**:
Time: Plan for approximately 45-60 minutes to complete the interview. If possible, allow approximately 5-10 minutes before the interview to set up the interview space.

Environment: Reserve a small conference room in [redacted] to conduct the interview.

Interview arrangement: Sit across from the pre-service teacher, facing the pre-service teacher, at a large desk or small table. Position the lap top so both the interviewer and the pre-service teacher can see the screen.

Camera: The camera should be positioned behind the interviewer such that the pre-service teacher is facing the camera and is he or she is fully in the frame. The frame should also capture the desk or table space in front of the pre-service teacher as well as the laptop computer. The interviewer should be visible in the frame.

Audio recorder: Position the audio recorder on the table in front of the pre-service teacher, but not in the way of his or her immediate work area.

Strategies: Listen more and talk less; try not to interrupt the pre-service teacher.

[In a conversational tone, convey the following to each participant **before** recording:]

Hi [pre-service teacher's name]! Thanks for being willing to talk with me today.

For this interview, I'd like to talk with you about your microteaching in TE407 this fall. I'll ask questions about your planning for microteaching, your microteaching itself, and your reflection on microteaching.

I would like to audio and video record this interview so I can focus on what you are saying and not have to write down your ideas as you are talking. The recording will not be labeled with your name in any way. I will use an ID number to identify you.

Do you have any questions?

[If the pre-service teacher has questions, answer them now. If the pre-service teacher does not have questions, proceed.]

[**Start** the audio and video recorders, and then read this text with the appropriate information:]

This interview is after microteaching #1 with [pre-service teacher ID number] on [Date].

**Begin the interview:**

**PART I:** Let's start with the assignment you just turned in. [Pass the pre-service teacher a copy of his/her Reflection assignment.]

- What ideas did your "students" share during your microteaching? [Part II - Lessons Learned]
- Did your colleagues hear any other ideas while they were microteaching? [maybe Part II - Lessons Learned]
- Of these ideas, were there any in particular that you thought would come up?
    - *If so….*
        - Which ones?
        - What made you think that you might hear these ideas?
        - Was there a particular part of your lesson when you thought you might hear those ideas?
    - *If not…*
        - Were you surprised to hear these ideas? Why/why not?
- Did you think any other ideas would come up that didn't?
    - *If so…*
        - Which ones?
        - What made you think that you might hear these ideas?
        - Was there a particular part of your lesson when you thought you might hear those ideas?
- When you and your colleagues came together to share these ideas, which ones seemed most significant to you?
    - *Alternative/follow-up wording*: How did you think about which ideas to highlight in columns two and three?
    - What makes these ideas significant (*or important to highlight*)?
- Did your "students" express any of the ideas that you and your colleagues identified and recorded on the "Features" sheet? [Pass the pre-service teacher a copy of his/her Features sheet - or the set of Features sheets from the group so that he/she can pull out his/her own.]
    - Was the Features sheet something that you thought about while considering the ideas that "students" expressed during your lesson?
        - *If so…* How did you use the Features sheet to consider the "student" ideas?

**PART II:** Let's shift from thinking about your reflecting on your microteaching to **<u>enacting your microteaching</u>**.

- While you were microteaching to your peers, do you recall thinking about any of their ideas in the moment?
    - *Follow up with:* Do you remember what you were thinking about?

We'd like to get your thoughts on a couple of instances from your microteaching. I'll show you a few video clips and ask you about what was happening and what you were thinking.

[Watch the first short video clip from the pre-service teacher's microteaching together.]

- Do you recall what you were thinking during this segment of your microteaching?
    - *Follow-up:* Did you make any decisions "on the fly"?
    - *If yes, follow up with:* What did you decide? Why?
- *Clip-specific questions, such as:*
    - Clips with student thinking potentially related to Feature(s)
        - *[Do you remember what you were thinking when you heard this idea (or these ideas)?]*
        - *How did you interpret what your "student" said?*
        - *Now that you've had a chance to think about this idea without the pressure of actually teaching, do you have any other thoughts about what he/she said?*
    - Clips with teacher questions/responses - potentially indicating attention <u>or</u> inattention to Feature(s) <u>or</u> just unclear as to intention
        - *[Do you remember what you were thinking during this part of your lesson?]*
        - As appropriate: *Had you planned to [do X]? If not, how did you decide to [do X]?*
        - Whether planned for or decided "on the fly": *What were you hoping to accomplish here? [Were you trying to elicit any specific ideas from your "students"?]*
        - If decided "on the fly": *How well do you think that worked?*
            - *Now that you've had a chance to revisit this moment, would you do anything differently?*

[If there is more than one video clip, repeat the stimulated recall sequence above for each subsequent video clip.]

**PART III:** Finally, let's talk about your **planning** for microteaching.

Here is a copy of your Eliciting Tool assignment. [Pass the pre-service teacher a copy of his/her Eliciting Tool assignment.]

- How did you go about figuring out how to fill out Eliciting Tool where you had to imagine what ideas you might hear from your "students"?
    - *Follow up:* Was it difficult for you to imagine what ideas you might hear from your "students"?

**Only if there are parts of the planning assignments not addressed elsewhere in the interview…**

Can you tell me:

- When you were planning for your microteaching, what ideas did you expect to hear from your "students"?
    - *Follow up with:* What made you think you might hear those ideas?
    - *Follow up with:* Do any of these ideas relate to ones you identified on the Features sheet?

Here is a copy of your Lesson Plan assignment. [Pass the pre-service teacher a copy of his/her Lesson Plan assignment.]

Can you tell me:

- Why was [this activity] important for you to include?
    - *Follow up with:* What students ideas did you think you might elicit with [this activity]?

[Once the pre-service teacher has completed the interview:]
Thank you very much for helping us with this research!

[Ask the pre-service teacher to complete the giftcard log and explain that they will receive the Amazon gift card via email.]

## E-2: Microteaching Interview 2 Protocol

**Microteaching 2 Interview Protocol**

**Equipment**:
- Video camera (with external microphone, if available)
- Tripod and extension cord
- Audio recorder (with spare batteries)
- Laptop computer with speakers
- Printed interview protocol (one copy)
- Two printed copies of each of the following:
  - Learning Progression
  - Reflection assignment
    - Including student work
  - Lesson plan assignment
  - Supporting Changes in Student Thinking Tool assignment
- Video of microteaching
- List of video clip(s) of microteaching
- Timer
- Printed gift card log

**Interview considerations**:
Time: Plan for approximately 45-60 minutes to complete the interview. If possible, allow approximately 5-10 minutes before the interview to set up the interview space.

**Schedule November 10 - November 27 (before class)**

Environment: Reserve a small conference room in [redacted] to conduct the interview.

Interview arrangement: Sit across from the pre-service teacher, facing the pre-service teacher, at a large desk or small table. Position the lap top so both the interviewer and the pre-service teacher can see the screen.

Camera: The camera should be positioned behind the interviewer such that the pre-service teacher is facing the camera and is he or she is fully in the frame. The frame should also capture the desk or table space in front of the pre-service teacher as well as the laptop computer. The interviewer should be visible in the frame.

Audio recorder: Position the audio recorder on the table in front of the pre-service teacher, but not in the way of his or her immediate work area.

Strategies: Listen more and talk less; try not to interrupt the pre-service teacher.

[In a conversational tone, convey the following to each participant **before** recording:]

Hi [pre-service teacher's name]! Thanks for being willing to talk with me today.

For this interview, I'd like to talk with you about your second microteaching in TE407.

I would like to audio and video record this interview so I can focus on what you are saying and not have to write down your ideas as you are talking. The recording will not be labeled with your name in any way. I will use an ID number to identify you.

Do you have any questions?

[If the pre-service teacher has questions, answer them now. If the pre-service teacher does not have questions, proceed.]

[**Start** the audio and video recorders, and then read this text with the appropriate information:]

This interview is after microteaching #2 with [pre-service teacher ID number] on [Date].

**Begin the interview:**

I have copies of your microteaching #2 assignments here. Feel free to refer to them at any time during the interview if you'd like to refresh your memory. [Place copies of the assignments near the pre-service teacher.]

**PART IA: GOALS & PLANNING**

- What goal(s) did you have for this lesson?
- We'll watch part of your lesson later, but could you tell me a little bit about how you planned to do that?
    - What ideas(s)/understandings were you expecting students to have coming into your lesson?
    - What ideas(s)/understandings were you hoping students would leave the lesson with?
    - What did you plan to do during the lesson (to meet your goals)?
        - How did you and your colleagues go about figuring out what to do during your lesson?
        - To what extent did you consider the ideas your "students" (or the "students" of your colleagues) expressed during microteaching 1?
            - *If the group tried to build on/address "student" ideas:* How did you figure out how to build on/address those ideas?
        - To what extent did you consider the ideas from the features sheet or the learning progression when planning your lesson?
- Did you see your students making progress toward your goal(s)?
    - What kinds of things did they say or write to make you think that?

**PART IB: STUDENT IDEAS**

- What ideas did your "students" share during your microteaching?
  - When did these ideas come up (i.e., were these expressed orally or part of students' written work)?
  - *If orally*: Did you notice these ideas while you were teaching?

- Of these ideas, were there any in particular that you thought would come up?
  - *If so….*
    - Which ones?
    - What made you think that you might hear these ideas?
    - Was there a particular part of your lesson when you thought you might hear those ideas?
  - *If not…*
    - Were you surprised to hear these ideas? Why/why not?
- Did you think any other ideas would come up that didn't?
  - *If so…*
    - Which ones?
    - What made you think that you might hear these ideas?
    - Was there a particular part of your lesson when you thought you might hear those ideas?

- Of the student ideas you've mentioned, were any of these on the learning progression? [Pass the pre-service teacher a copy of the learning progression.]
  - Did you discuss these ideas with your colleagues in one of the debriefing sessions?
    - *If so:* Do you remember if you had made a connection to the learning progression before the debrief discussion?

**PART II:** Let's shift from reflecting on your microteaching to **enacting your microteaching**.

- I'd like to start with the clip that you brought to the first debrief. Do you remember where that was in your video?
  - [Watch the video clip identified by the pre-service teacher.]
  - Why did you choose that clip to share with your colleagues?
  - Did you get any new insights from watching the clip during the debrief?
    - Were you able to see anything from watching the clip with your colleagues that you had not seen on your own (or while teaching)?

  [Ask questions below as appropriate, depending on whether the clip highlights teacher moves and/or student ideas.]
  [If any of the clip overlaps with segments selected for the interview, ask the clip-specific questions here.]

We'd like to get your thoughts on a couple of instances from your microteaching. I'll show you a few video clips and ask you about what was happening and what you were thinking.

[Watch the first short video clip from the pre-service teacher's microteaching together.]

- Do you recall what you were thinking during this segment of your microteaching?
    - *Follow-up:* Did you make any decisions "on the fly"?
    - *If yes, follow up with:* What did you decide? Why?
- *Clip-specific questions, such as:*
    - Clips with **student thinking** potentially related to the learning progression
        - *[Do you remember what you were thinking when you heard this idea (or these ideas)?]*
        - *How did you interpret what your "student" said?*
        - *Now that you've had a chance to think about this idea without the pressure of actually teaching, do you have any other thoughts about what he/she said?*
    - Clips with **teacher questions/responses** - potentially indicating attention <u>or</u> inattention to ideas related to the learning progression <u>or</u> just unclear as to intention
        - *[Do you remember what you were thinking during this part of your lesson?]*
        - As appropriate: *Had you planned to [do X]? If not, how did you decide to [do X]?*
        - Whether planned for or decided "on the fly": *What were you hoping to accomplish here? [What were you going for here?] How well do you think that worked?*

[If there is more than one video clip, repeat the stimulated recall sequence above for each subsequent video clip.]

[Once the pre-service teacher has completed the interview:]
Thank you very much for helping us with this research!

[Ask the pre-service teacher to complete the giftcard log and explain that they will receive the Amazon gift card via email.]

## E-3: Microteaching Interview 3 Protocol

**Microteaching 3 Interview Protocol**

**Equipment**:

- Video camera (with external microphone, if available)
- Tripod and extension cord
- Audio recorder (with spare batteries)
- Laptop computer with speakers
- Printed interview protocol (one copy)
- Two printed copies of each of the following:
  - Learning progression
  - Planning assignment
  - Reflection assignment
  - Student work [if available]
  - [If interviewing a student not present for 11/27 class] Example of one open-ended item associated with the appropriate learning progression
- Video of microteaching
- List of video clip(s) of microteaching and aspects of student work [if available in advance]
- Timer
- Printed gift card log

**Interview considerations**:

Time: Plan for approximately 45-60 minutes to complete the interview. If possible, allow approximately 5-10 minutes before the interview to set up the interview space.

**Schedule December 6 - 15**

Environment: Reserve a small conference room in [redacted] to conduct the interview.

Interview arrangement: Sit across from the pre-service teacher, facing the pre-service teacher, at a large desk or small table. Position the laptop so both the interviewer and the pre-service teacher can see the screen.

Camera: The camera should be positioned behind the interviewer such that the pre-service teacher is facing the camera and is he or she is fully in the frame. The frame should also capture the desk or table space in front of the pre-service teacher as well as the laptop computer. The interviewer should be visible in the frame.

Audio recorder: Position the audio recorder on the table in front of the pre-service teacher, but not in the way of his or her immediate work area.

Strategies: Listen more and talk less; try not to interrupt the pre-service teacher.

[In a conversational tone, convey the following to each participant **before** recording:]

Hi [pre-service teacher's name]! Thanks for being willing to talk with me today.

For this interview, I'd like to talk with you about your third microteaching in TE407.

I would like to audio and video record this interview so I can focus on what you are saying and not have to write down your ideas as you are talking. The recording will not be labeled with your name in any way. I will use an ID number to identify you.

Do you have any questions?

[If the pre-service teacher has questions, answer them now. If the pre-service teacher does not have questions, proceed.]

[**Start** the audio and video recorders, and then read this text with the appropriate information:]

This interview is after microteaching #3 with [pre-service teacher ID number] on [Date].

**Begin the interview:**

I have copies of your microteaching #3 assignments here. Feel free to refer to them at any time during the interview if you'd like to refresh your memory. [Place copies of the assignments near the pre-service teacher.]

**PART I: GOALS & PLANNING**

- What goal(s) did you have for this lesson?
    - What content ideas were you hoping students would leave your "unit" with?
    - What did you want to find out about your students' understanding of your "unit"?
- We'll watch part of your lesson later, but could you tell me a little bit about how you planned to engage your students with those content ideas?
    - What ideas(s)/understandings were you expecting students to have coming into your lesson?
    - How did you plan to use those idea(s)/understandings? Why?
- We'll watch part of your lesson later, but could you tell me a little bit about how you planned to elicit your students' ideas?
    - What assessment strategies did you plan to use?
    - How did you come up with that strategy?
        - Did you think about the learning progression in any way when designing (or refining) your assessment strategy?
    - [For students who were present for the 11/27 class session and only if the assessment strategy is sufficiently aligned with the learning progression] Could we talk through how students at different levels of the learning progression might approach your assessment?
        - How do you think a student at level [X] might interpret and respond to your assessment strategy?

**PART IB: REFLECTING**

- What did you bring to the microteaching debrief [Monday, December 4 class session] to discuss with your colleagues?
    - Why did you select that artifact?
    - What input were you seeking from your colleagues?
- *If video clip:*
    - Do you remember where that was in your video? Could we watch the clip together?
    - [Watch the video clip identified by the pre-service teacher.]
    - Why did you choose that clip to share with your colleagues?
    - [Ask questions below as appropriate, depending on whether the clip highlights teacher moves and/or student ideas.]
    - [If any of the clip overlaps with segments selected for the interview, ask the clip-specific questions here.]
- *If student work:*
    - Could you tell me about this response?
        - What makes this response significant?
        - Why did you choose this to share with your colleagues?
- Did you get any new ideas or insights from talking with your colleagues?
    - If so, what did you learn?

**PART II: STUDENT IDEAS**

~~[Not necessary to ask these questions if student ideas were discussed sufficiently in the previous section]~~

- What ideas did your "students" share during your microteaching (including through your assessment strategy)?
    - When did these ideas come up (i.e., were these expressed orally or part of students' written work)?
    - *If orally*: Did you notice these ideas while you were teaching?
    - Did you anticipate that these ideas would come up?
        - *If so*, which ones? Why did you think you might hear these ideas?
    - Did any of these ideas surprise you?
        - *If so*, which ones? Why were these ideas surprising to you?
- Did you think any other ideas would come up that didn't?
    - *If so*...which ones? Why did you think you might hear these ideas?
- [If we had an opportunity to identify specific aspects of student work to focus on... ] We'd like to get your thoughts on a couple of examples from your student work.
    - [Point out a specific aspect of the student work - either identified in advance or "on the fly"]
    - How do you interpret what your "student" wrote?
    - Do you have any ideas about what might be a good "next step" for this student? .

**PART III:** Let's shift from reflecting on your microteaching to **enacting your microteaching**.

We'd like to get your thoughts on a couple of instances from your microteaching. I'll show you a few video clips and ask you about what was happening and what you were thinking.

[Watch the first short video clip from the pre-service teacher's microteaching together.]

- Do you recall what you were thinking during this segment of your microteaching?
- *Clip-specific questions, such as:*
    - Clips with **student thinking** potentially related to the learning progression
        - *[Do you remember what you were thinking when you heard this idea (or these ideas)?]*
        - *How did you interpret what your "student" said?*
        - *Now that you've had a chance to think about this idea without the pressure of actually teaching, do you have any other thoughts about what he/she said?*
    - Clips with **teacher questions/responses** - potentially indicating attention or inattention to ideas related to the learning progression or just unclear as to intention
        - *[Do you remember what you were thinking during this part of your lesson?]*
        - As appropriate: *Had you planned to [do X]? If not, how did you decide to [do X]?*
        - *What were you hoping to accomplish here? [What were you going for here?] How well do you think that worked?*

[If there is more than one video clip, repeat the stimulated recall sequence above for each subsequent video clip.]

[Only for students who were not present for the 11/27 session]
**PART IV:** Now that we've talking about enacting your microteaching, I'd like to go back to your assessment strategy.

- In the class session right after Thanksgiving, we spent some time talking about how the learning progression might be used to think about assessment.
    - For example… [Show student the sample item and talk through how to use the learning progression to predict how a student with ideas consistent with a given level might interpret and respond to the item]
- I'd like to have you try doing that with the assessment strategy from your microteaching.
    - Suppose there was a student in your class who had ideas consistent with Level 4 of your learning progression… How do you think he/she would interpret your assessment strategy? How do you think he/she would respond to your assessment strategy? [If student needs help figuring out how to do this, provide support as needed…]
    - [Repeat for Levels 3, 2, and 1]
- How might you revise your assessment to allow students with ideas at a wider range of levels to respond?

**PART V:** Now that you've completed the full microteaching cycle, I'd like to ask you a few questions about the learning progression and your microteaching. [Hand the student a copy of the relevant learning progression]

- Thinking back over your microteaching experiences, can you tell me if and how you saw the learning progression as useful for thinking about:
  - How to elicit students' ideas (formative assessment)?
  - How to interpret students' ideas?
  - How to plan instruction?
  - How to plan for summative assessment?
- Were there (or are there) any aspects of the ideas included in the learning progression that were or still are confusing or unclear?
- Is there anything else you'd like to share with me?

[Once the pre-service teacher has completed the interview:]
Thank you very much for helping us with this research!

[Ask the pre-service teacher to complete the giftcard log and explain that they will receive the Amazon gift card via email.]

# REFERENCES

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