Designing Tools to Support Teacher Activity Focused on Student Thinking to Inform Instruction

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Designing Tools to Support Teacher Activity Focused on Student Thinking to Inform Instruction

by

KATE DONOVAN HENSON

B.S. Siena College, 1998
M.S. University of Washington, 2007

A thesis submitted to the Faculty of the Graduate School of the University of Colorado in partial fulfillment of the requirement for the degree of Doctor of Philosophy

School of Education

2019
This thesis entitled:
Designing Tools to Support Teacher Activity Focused on Student Thinking to Inform Instruction
written by Kate Donovan Henson
has been approved for the School of Education

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The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

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Abstract

Henson, Kate Donovan (Ph.D. School of Education, Curriculum and Instruction, Science)

Designing Tools to Support Teacher Activity Focused on Student Thinking to Inform Instruction

Dissertation directed by Profession Erin Marie Furtak

The most recent science education reform, the Next Generation Science Standards (NRC, 2012) set forth a new and ambitious agenda for science education. These standards go beyond all of the previous versions and combine three dimensions: disciplinary core ideas, science practices and crosscutting concepts. They call on teachers to recognizing and build on the ideas students have when they arrive at school. While recognizing student ideas as resources that can be built on is not necessarily a new idea, it is not a familiar practice for teachers. For teachers to engage in activity focused on student ideas as resources, they will need professional learning opportunities that can support them in taking up a resource based view of student ideas as well as tools and routines to support this work. This dissertation explores how researchers can design tools to support teacher activity oriented toward student thinking to inform instruction as well as how the tools mediate teacher activity. I explore answers to these questions through two embedded cases studies which take a close look at physics teacher workgroup activity in two school. While there are not any one-size-fits-all answers to these questions, my findings suggest that we can support teachers in activity oriented toward student thinking with well designed facilitation protocols, frameworks of student thinking, artifacts of student thinking and interpretive frameworks.
Dedications

This dissertation is dedicated to my family who made it possible for me to complete this degree.

To my husband, Eric, who supported and encouraged me, taking on more than his fair share so I could find time to write.

To my children, Owen and Wyatt, who reminded me why I do this work by sharing their ideas about the ways the world works every day.

To my parents, Carol and Tim Donovan, who have always loved and supported me, no matter what.

To all the strong, amazing women in my life who inspire me every day.
Acknowledgements

I would like to acknowledge the following individuals:

The teachers who have participated in the Aspire project for the four years that I worked on the project. Their dedication to their students has inspired me to continue my work to improve science teaching and learning.

My advisor, Dr. Erin Furtak for her commitment to my success over the last ten years. Her confidence in me brought me to this doctoral program (twice). Along the way, she provided guidance in every aspect of educational research and because of that I am a better thinker, writer, and communicator. For that, and so much more, I am grateful.

Additional faculty members, in particular, those who served on my dissertation committee, including Bill Penuel, Melissa Braaten, Vicki Hand and Cathy Regan served as teachers and mentors to me over the last four years. Their feedback, time and attention improved the quality of this work.

Finally, to my colleagues and friends who were always there to code a transcript when I needed them, especially Jason Buell and Rebecca Swanson, thank you.
# Table of Contents

Chapter 1. Introduction .............................................................................................................. 1  
  Purpose of Study .................................................................................................................. 2  

Chapter 2. Conceptual Framework .......................................................................................... 4  
  A Sociocultural Perspective on Learning .......................................................................... 4  
  A Brief History of Science Education Reform ...................................................................... 11  
  Student Thinking and Student Ideas .................................................................................. 14  
  Supporting New Forms of Teacher Activity Centered Around Student Thinking .............. 20  
  The Institutional Context Where Reform Takes Place ......................................................... 24  
  Tools to Support New Forms of Teacher Activity Focused on Student Thinking .............. 26  

Chapter 3. Context .................................................................................................................. 34  
  Research Practice Partnerships ......................................................................................... 34  
  The Aspire RPP .................................................................................................................. 35  

Chapter 4: Method .................................................................................................................. 56  
  Research Design ................................................................................................................ 56  

Chapter 5. Results, Tools to Support Teacher Activity in the Context of Force and Motion .... 85  
  Initial Design of the Tools .................................................................................................. 86  
  Design Decisions ............................................................................................................... 90  
  Summary of Teacher Conversations About Student Responses, Carver ......................... 93  
  How Tools Mediated Teacher Activity at Carver ............................................................... 95  
  Second Iteration of the of Tools ...................................................................................... 103  
  Design Decisions ............................................................................................................ 107  
  Summary of Teacher Conversations about Student Responses at Mayfield .................... 110  
  How Tools Mediated Teacher Activity at Mayfield .......................................................... 114  
  Case 1, Summary ............................................................................................................. 121  

Chapter 6. Results: Tools to Support Teacher Activity in the Context of Energy ............... 123  
  Context ............................................................................................................................. 124  
  Reflect on Enactment, January 2018 ................................................................................. 125  
  Explore Student Thinking, September 2018 .................................................................... 136  
  Case 2, Summary ........................................................................................................... 152  

Chapter 7. Discussion ............................................................................................................. 154  
  Significance ..................................................................................................................... 161  
  Limitations ....................................................................................................................... 162  
  Future Research .............................................................................................................. 164  
  Conclusion ....................................................................................................................... 165  

References ............................................................................................................................. 166  

Appendix A: Planning tool used in FADC .............................................................................. 184  

Appendix C: Force and motion assessment items. ................................................................. 187  

Appendix D: Energy learning progression .............................................................................. 196  

Appendix E: Phenomenon based item cluster .................................................................... 197  

Appendix F: Modeling Energy Flows learning progression .................................................. 206
Appendix G: Score reports................................................................................................................. 207
Appendix H: Elevate facilitation guide.............................................................................................. 211
<table>
<thead>
<tr>
<th>Table Number</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Wertsch’s claims about mediated action.</td>
<td>5</td>
</tr>
<tr>
<td>3.1</td>
<td>Discipline specific workgroup participation at partner schools.</td>
<td>37</td>
</tr>
<tr>
<td>3.2</td>
<td>Learning progressions and associated items.</td>
<td>42</td>
</tr>
<tr>
<td>3.3</td>
<td>Learning progressions plan Year 1, Aspire 2</td>
<td>43</td>
</tr>
<tr>
<td>4.1</td>
<td>Timeline of activity</td>
<td>58</td>
</tr>
<tr>
<td>4.2</td>
<td>Participants, Case 1</td>
<td>60</td>
</tr>
<tr>
<td>4.3</td>
<td>Data corpus, Case 1</td>
<td>66</td>
</tr>
<tr>
<td>4.4</td>
<td>Codes applied to field notes, Case 1</td>
<td>72</td>
</tr>
<tr>
<td>4.5</td>
<td>Timeline of physics teacher workgroup meetings</td>
<td>74</td>
</tr>
<tr>
<td>4.6</td>
<td>Participants, Case 2</td>
<td>79</td>
</tr>
<tr>
<td>4.7</td>
<td>Opportunities for activity related to student thinking</td>
<td>80</td>
</tr>
<tr>
<td>4.8</td>
<td>Codes applied to transcripts, Case 2</td>
<td>82</td>
</tr>
<tr>
<td>5.1</td>
<td>Timeline of activity, Carver</td>
<td>85</td>
</tr>
<tr>
<td>5.2</td>
<td>Design decisions and rationale, Part 1</td>
<td>90</td>
</tr>
<tr>
<td>5.3</td>
<td>Frameworks for student thinking</td>
<td>99</td>
</tr>
<tr>
<td>5.4</td>
<td>Design decisions and rationale, Part 2</td>
<td>107</td>
</tr>
<tr>
<td>6.1</td>
<td>Timeline, Case 2</td>
<td>124</td>
</tr>
</tbody>
</table>
## List of Figures

<table>
<thead>
<tr>
<th>Figure Number</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Timeline of funding for projects in the Aspire partnership, 2014-2021.</td>
<td>35</td>
</tr>
<tr>
<td>3.2</td>
<td>Formative assessment design cycle</td>
<td>39</td>
</tr>
<tr>
<td>3.3</td>
<td>Force and motion learning progression adapted for Aspire</td>
<td>44</td>
</tr>
<tr>
<td>3.4</td>
<td>Running downhill formative assessment task</td>
<td>46</td>
</tr>
<tr>
<td>3.5</td>
<td>Energy learning progression and associated tools</td>
<td>48-49</td>
</tr>
<tr>
<td>3.6</td>
<td>Formative assessments from physics teacher workgroups</td>
<td>52</td>
</tr>
<tr>
<td>3.7</td>
<td>Modeling energy flows learning progression</td>
<td>53</td>
</tr>
<tr>
<td>3.8</td>
<td>Phenomenon based item clusters</td>
<td>54</td>
</tr>
<tr>
<td>4.1</td>
<td>Force and motion, item 5</td>
<td>59</td>
</tr>
<tr>
<td>4.2</td>
<td>Sample artifacts</td>
<td>62</td>
</tr>
<tr>
<td>4.3</td>
<td>Sample research team field note</td>
<td>64</td>
</tr>
<tr>
<td>4.4</td>
<td>Sample field note, teacher workgroup meeting.</td>
<td>65</td>
</tr>
<tr>
<td>4.5</td>
<td>Research memo</td>
<td>67</td>
</tr>
<tr>
<td>4.6</td>
<td>Sample narrative</td>
<td>70</td>
</tr>
<tr>
<td>4.7</td>
<td>Skateboarder pre and post assessment</td>
<td>75</td>
</tr>
<tr>
<td>4.8</td>
<td>Facilitation guides</td>
<td>77</td>
</tr>
<tr>
<td>5.1</td>
<td>Final versions of score reports, Carver</td>
<td>87-88</td>
</tr>
<tr>
<td>5.2</td>
<td>Facilitation guide, Carver</td>
<td>89</td>
</tr>
<tr>
<td>5.3</td>
<td>Score reports designed for Mayfield</td>
<td>105</td>
</tr>
<tr>
<td>5.4</td>
<td>Facilitation guide, Mayfield</td>
<td>106</td>
</tr>
<tr>
<td>Figure Number</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>5.5</td>
<td>Force and motion item 5</td>
<td>109</td>
</tr>
<tr>
<td>5.6</td>
<td>Force and motion item 15</td>
<td>113</td>
</tr>
<tr>
<td>6.1</td>
<td>Facilitation guide 1/25/18</td>
<td>126-127</td>
</tr>
<tr>
<td>6.2</td>
<td>Questions from skateboarder pre and post assessment</td>
<td>132-133</td>
</tr>
<tr>
<td>6.3</td>
<td>Facilitation guide 9/25/18</td>
<td>137-138</td>
</tr>
<tr>
<td>6.4</td>
<td>Performance expectation specific learning progression</td>
<td>140</td>
</tr>
<tr>
<td>6.5</td>
<td>Student work sample 1</td>
<td>144</td>
</tr>
<tr>
<td>6.6</td>
<td>Student work sample 2</td>
<td>148</td>
</tr>
</tbody>
</table>
Chapter 1. Introduction

Dr. Erin Furtak and I arrived at Carver excited to share the new tools our research team had developed with the physics teachers, including score reports and teacher facing version of the force and motion learning progression. The teachers had piloted assessment items related to force and motion with their students and had expressed interest in seeing the score reports we had promised to provide. We expected the teachers to be as interested and curious about the tools as we were. As we handed out the packets of materials that our team had carefully designed and prepared, we stunned by the response the tools evoked, particularly from one teacher, Alex, whose comments dominated the meeting. Alex’s immediate negative reaction included comments such as:

“As a classroom teacher, I would tear this up and throw it away.”

“What do I do with these data?”

“The questions don’t make a lot of sense.”

“That’s asinine.”

I wondered, what factors could contribute to a teacher reacting so strongly to score reports? and why didn’t we anticipate this potential negative reaction? Given the complexities of the modern public school system, it’s no wonder teachers are overwhelmed by the volume of information they are asked to make sense of on a daily basis including attending standardized test data, classroom assessments, teacher evaluations and new school wide initiatives. As researchers, how can we support teachers in activity that will help them make sense of the information that really matters, in the contexts in which they work so that can provide rich and meaningful learning opportunities for their students?
Purpose of Study

The most recent science education reform, the Next Generation Science Standards (NRC, 2012) set forth a new and ambitious agenda for science education. These standards go beyond all of the previous versions that came before and combine three dimensions: disciplinary core ideas, science practices and crosscutting concepts. The guiding document for the standards, *The Framework for K-12 Science Education* (NRC, 2012) suggests that for teachers to support science learning in this new, three dimensional approach, they will need to begin by recognizing and building on the ideas students have when they arrive at school. While recognizing student ideas as resources that can be built on is not necessarily a new idea, in some schools other frameworks that may not privilege student ideas, dominate (e.g. Clement, 1982). For teachers to engage in pedagogy focused on student ideas as resources, they will need professional learning opportunities that can support them in taking up a resource based view of student ideas.

These kinds of professional development opportunities, where teachers work collaboratively with their colleagues and engage in problems of practice, can help support new forms of activity oriented toward student thinking (Kazemi & Franke, 2004; van Es & Sherin, 2008). As part of this work, teachers will need the right kinds of tools and routines organize their work, tools that can help them bring student thinking into their professional development contexts to inform their instruction. Certain types of tools such as learning progressions (e.g. Furtak & Heredia, 2014), assessment tools (e.g Alonzo & Steedle, 2009), interpretive tools (e.g. Alonzo & Elby, 2019) and facilitation tools (e.g Gibbons & Cobb, 2017) have the potential to support collaborative teacher workgroups in this way.

Over the last four years, I have facilitated regular teacher workgroup meetings with several teams of high school science teachers. For nearly four years, I have been the lead
facilitator for two communities of physics teachers with whom I meet one to two times a month. My dissertation research grew out of my knowledge of and interest in particular aspects of these teachers’ work.

For the purposes of this dissertation, I conducted two embedded case studies that aimed to answer questions about how researchers can design tools to support these new forms of activity and how these tools mediate that activity. In the following chapters I detail the ways in which I approached these questions. In Chapter 2, I present my literature review as well as my theoretical and conceptual frameworks. In Chapter 3, I provide the context of the study and in Chapter 4 I describe my methods. Chapters 5 and 6 detail my findings. Finally, in Chapter 7, I discuss my findings and their implications in greater detail.
Chapter 2. Conceptual Framework

In this chapter, I begin with an introduction to sociocultural theories of learning and a summary of the concept of mediated action. I describe how, under the umbrella of a sociocultural perspective, mediated action provides a way to understand learning in a social, cultural, and institutional context. I follow this description of my theoretical framework with a summary of bodies of literature relevant to my study, beginning with a summary of recent science education reforms and how they foreground an approach to science teaching that prioritizes student thinking to inform instruction. I then describe teacher professional development and how particular structures of professional development can support teachers in ways that encourage their use of student thinking to inform instruction. Next, I identify some of the institutional factors that may impact the actions teachers engage in and discuss the tools and resources that researchers have designed to support teachers as they carry out their work in the context of their school settings. The chapter ends with a summary of my conceptualization of how the components described above can be understood through the lens of mediated action.

A Sociocultural Perspective on Learning

As a social theory of learning, the sociocultural perspective extends the view of learning beyond individual cognition to consider the social and cultural contexts within which individuals think and learn. The sociocultural perspective was built upon a Vygotskian (1987) tradition which aimed to bring the individual together with the environment. Vygotsky proposed that for humans, learning is the result of social interactions, first, and then interactions in an individual's mind. Learning is part of a social and cultural process; therefore, knowledge cannot be separated from that social context. Evidence of learning is found within the activity that takes place as individuals participate with others within their social and cultural contexts (Rogoff, 1998).
Within those contexts, learning has often be defined as a change in participation; that is, individuals’ actions may differ as they participate in activity relative to their contexts (Lave & Wenger, 1991) and that differential participation provides evidence of learning.

As a social process, learning is mediated by cultural tools (Vygotsky, 1987). Vygotsky identified language as a primary tool; however, material artifacts are included as tools as well. Tools give communities the ability to make sense of the world and gives the world the ability to make sense of individuals and their communities as they are used in social settings (Lemke, 2000).

**Mediated Action**

Mediated action is the study of how humans use cultural tools and was described by Wertsch (1997) as a way to understand human action and its relation to the sociocultural, historical, and institutional contexts in which it takes place. He specifically focused on how action carried out by agents is mediated by tools. Wertsch detailed ten claims about mediated action as listed in table 1.1 and described in detail below.

*Table 1.1 Wertsch’s Claims about Mediated Action*

<table>
<thead>
<tr>
<th>Wertsch’s Claims about Mediated Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>
6. New tools transform action.

7. Mastery characterizes the relationship between agents and tools.

8. Tools are appropriated by agents.

9. Tools are often used for different purposes than intended.

10. Tools are associated with authority and power

The first claim focused on an irreducible tension that exists between tools and agents. This tension both results in and defines mediated action. To understand that action it is important to look at the constellations of tools and agents that form, how they mix, and how, in certain circumstances, one tool or another may carry particular significance. For example, in an instance where an agent is carrying out an action, it is the agent’s skill and the features of the tool together that carry out that action. The action that results would not be possible without both the skill of the agent and the tool itself. Tension arises from the interaction between the tool and the individual when, for example, a new tool stresses or strains an individual’s skill or a new skill stresses or strains the design of a tool. The action that occurs next is a result of this tension.

Wertsch drew on the example of a pole vaulter to explicate his meaning. He explained how a pole vaulter (agent) needs a certain type of skill and a certain kind of pole (tool) to engage in a desired action. A particular combination of skill and pole could vault the athlete to the desired height (goal) while other combinations of these factors would result in other outcomes.

In his second claim, Wertsch made clear that the type of tool he focused on is material. However, he referenced Vygotsky and his writing on language as a tool noting that even tools
such as spoken language, which may not appear to be material, possess material properties. In addition, the materiality of tools persists beyond that of the agents who use them.

Goodwin (1994) provided an example of how material tools are related to mediated action. He described the Munsell color chart and how this material tool has been used by archeologists to standardize the classification of dirt at archeological dig sites. This tool has focused professionals around the world on color as a characteristic of dirt. The tool served to “structure perception of dirt” (p. 6) by individuals providing them with a number of options for classification resulting in a situation where the “worker views the world from the perspective the tool establishes” (p. 6).

The third and fourth claims centered on both the multiple goals and pathways of mediated action. Mediated action often serves several purposes or goals that do not necessarily align with each other or with purposes held by a single actor in a setting. Consider the example of the Girl Scouts, an organization whose stated goals are related to leadership development for girls (girlscouts.org). Girls scouts are organized into troops whose leaders use tools such as agendas and activities to structure the girls’ time together. Multiple actors have multiple and varied goals related to their participation in this organization. The participant herself may be oriented toward the goals of having fun and spending time with friends while her parents’ goals might be related to the skills and values she might develop through her participation.

In addition to multiple goals, mediated action exists on one or more developmental pathway. For instance, the tension between agents and tools, described in the first claim, has a history, present and future; within this trajectory both the agents and the tools are undergoing change. For example, the tools that Girl Scout leaders have used over time have changed. While some of the activities, such as selling cookies, have stayed the same, others have changed. One
example is the addition of activities related to STEM. In addition, the girls themselves have changed as has their cultural and social context. It is important to consider both where the tool and the agent have come from, historically, and where they might go in the future.

Wertsch’s fifth and sixth claims focused on how tools both enable and constrain action as well as how new tools can transform action. Tools may free agents from particular constraints that enable action, but in doing so they introduce new constraints. The limitations of tools are often difficult to predict prior to their use. The introduction of new tools into places of work can make particular skills irrelevant. For example, consider the role automation has played in the manufacturing industry. While some individuals may change to take on new functions at the factory others may lose access to participation in the activity; in this case, their job.

While a new tool may be deemed superior to the old, decisions agents make about tool use may have more to do with “historical precedent and with cultural or institutions power and authority” (Wertsch, 1997, p. 42). Wertsch described how the now inefficient tool, the QWERTY keyboard served as one such example. He explained how the QWERTY keyboard was developed during the time when the typewriter was the main tool of formal writing. Its development was a response to time lost from jamming when frequently used keys were placed near to one another. The solution was to spread those high frequency keys out. This improved efficiency because it reduced the time lost to fixing the jammed machine. However, now that we don’t use typewriters, and are not concerned with time lost to jamming, it is no longer important that the high frequency keys are spread out; in fact the QWERTY arrangement of the letters is actually less efficient in terms of typing speed. While there are more efficient keyboards available, due to historical precedent, most people are unaware of their existence and continue to use the less efficient design. In this case, historical precedent constrains present activity. Beyond
enabling and constraining action, new tools can transform action; that is, the new tools can create an imbalance that can change the agents or the action. When this happens, it is important to consider whether the action agents take is an altered form of previous action or a new form of action altogether.

Claims seven and eight related to skill mastery and tool appropriation. The relationship between agents and tools can be characterized in terms of mastery; tools are related to skill development rather than intelligence. Wertsch conceived of individuals internalizing tools through mastery or “knowing how” rather than intelligence. For example, we might notice “differences in the facility of groups to use particular cultural tools” (p. 48) as evidence of mastery rather than innate ability. In addition to mastering skills related to tools, agents may appropriate tools to varying degrees, where appropriation is defined as taking something that belongs to someone else and making it your own. According to Wertsch, appropriation always results in resistance or friction between tools and their use. One reason for this is that agents don’t always have a choice regarding tool use. They may be required to use certain tools and this can lead to differential appropriation. Agents may reject tools because they fail to master the skill necessary to use them or because the tool itself caused a conflict that left the agent unwilling to use it.

In the educational context, teachers are often required to master skills related to the use of tools. In schools, student learning objectives (SLOs) are an example. SLOs typically require teachers to identify measurable goals toward a particular student learning outcome, often related to state standards. In some districts, the data generated from measuring student progress toward the goal is used as a part of the teacher evaluation process. While most teachers are able to develop the “know how” necessary to use the tools associated with SLO activity, the extent to
which they appropriate them, identifying with and making a part of their own practice is more variable. In some cases, the use of tools such as SLOs for evaluative purposes is rejected by teachers whose identities are in conflict with the requirement (Buchanan, 2015).

Wertsch’s ninth claim concerned what he called “spin-off”: using a tool differently from its intended purpose. Tools are often produced for reasons other than to facilitate mediated action. Frequently, it is because of historical or institutional precedent, rather than design, that tools are used in certain ways. Spin-off happens regularly in classrooms, particularly in science classrooms. For example, the product Knox gelatin is and continues to be marketed for its use in making desserts of a certain consistency (e.g. mousse). Knox gelatin also has the ability to be formed into blocks which can serve as a model of the animal cell. The properties of the gelatin make it an ideal substance for demonstrating the process of diffusion. For this reason, it is widely used in high school biology classes as a tool for engaging in learning about cell biology as well as a tool associated with engagement in scientific practices. In physics classes, teachers often use foam pipe insulation, found in any big box store, as a tool to support learning about energy. This circular foam substance, designed to insulate exposed copper pipes in locations like basements, can be cut in half and used as a track to roll marbles in. Students often create roller coasters out of this flexible foam and study the transfer of kinetic and potential energy. In each of these examples, tools are used for actions other than their originally intended purpose.

The tenth and final claim is related to the ways in which tools are associated with power and authority. Sometimes individuals use tools to gain power and authority and other times the power and authority tools carry with them determine whether or not they are used. For example, the use of certain tools may give more power or authority to an agent’s action in certain contexts, and certain tools carry with them more power and authority than other tools. In schools, tests are
one example. Administrators, teachers, students and parents often view formal assessments, such as tests, as a more authoritative or powerful measure of learning when compared to classroom tasks or more informal classroom interactions that students engage through the course of their school day. Teachers may use results from tests to convey particular messages about student progress and might chose a test over another tool to measure progress because of its authority.

The ten claims described here detail the ways in which mediated action provides a framework to understand how tools function in learning environments as mediational means and how these tools are situated with individuals in their historical, cultural, social, and institutional contexts. The following literature review will attend to the factors necessary to understand how certain tools have mediated activity in the past as well as how they have the potential to mediate action in the context of teacher learning.

A Brief History of Science Education Reform

The historical context of science education reform is important to consider to understand the reform efforts taking place in the present. Historically, each reform effort has resulted in the development of a series of tools which have mediated the action that researchers and educators have taken to implement those reforms. These tools have emerged as authoritative within the educational context and are embedded in and reflective of the sociocultural, historical and institutional processes that lead certain tools and forms of knowledge to be privileged. The predominant tool of each reform effort has been science education standards, documents that detail what and how students should learn about science as they progress through their public school experience. However, these standards may not go far enough in supporting the vision of the reforms. Additional tools and an understanding of teachers’ context surrounding their use will be necessary (e.g. Hayes, Lee, DiStefano, O’Connor, Sietz, 2016; Sinapuelas, Lardy, Korb,
to support teachers in implementation. Understanding the history of science education reform will help situate the present challenges that researchers and practitioners face as the take on these reforms.

The publication of *A Nation at Risk: The Imperative for Educational Reform* (NCEE, 1983) spurred the modern standards movement (DeBoer, 2014). This report, commissioned by then president Ronald Reagan, used a variety of statistics to paint a bleak picture of the future should the United States continue to lag behind other nations in education. Experts in each of the disciplinary fields taught in American schools, such as science, literacy and mathematics, took up this charge in different ways. In the sciences, the American Association for the Advancement of Science (AAAS) launched Project 2061, a science education focused initiative which resulted in the publication of *Science for All Americans* (AAAS, 1989), recommendations about the essential ways of thinking and types of knowledge all citizens should have to be scientifically literate. A second publication, the *Benchmarks for Scientific Literacy* (AAAS, 1993) translated these recommendations into guidelines for the design of curriculum based on what students should know and be able to do. What followed next was the publication of the first comprehensive science education standards, the *National Science Education Standards* (NRC, 1996) that specified not only content standards but also teaching and assessment standards, among others, that would support the implementation of the standards in schools. These publications were intended to be used as guides by states as they developed their own local standards documents.

Since the publication of the *National Science Education Standards* (NRC, 1996), advances in research in the field of cognitive science resulted in influential publications such as *How People Learn: Brain, Mind, Experience and School* (NRC, 2000) *How Students Learn:*
History, Mathematics and Science in the Classroom (NRC, 2005) and Taking Science to School (NRC, 2007). These publications aggregated the research base necessary to guide the future of science education. They stressed the idea that children, and all people, have conceptual resources that can be built on (NRC, 2000); that the ideas children come to school with are based on their experiences in the world and therefore reasonable (NRC, 2005). Teacher learning was addressed as well, and the authors proposed professional learning for teachers to learn about content, pedagogy and their students’ development. These publications also stressed that the mechanism through which children learn is at least as important as the content they are learning and that learning should be centered around learners, knowledge, assessment, and community (NRC, 2000).

Collectively, these reports informed the two-step development of the most recent national science education standards. The first step in this process was the publication of A Framework for K-12 Science Education (NRC, 2012) which was authored by experts in the scientific disciplines and in science education and policy. The Framework laid a foundation for the Next Generation Science Standards (NGSS), developed by Achieve, Inc. through a collaborative process with input from states and a variety of stakeholders (NGSS lead states, 2013). The Framework’s authors recognized room for improvement upon the previous standards (DeBoer, 2014) and in response, the NGSS went beyond the previous focus on scientific literacy and inquiry. The NGSS identified three components that students should experience as part of their science learning. First, they defined the content students should learn at each grade level or band, called the disciplinary core ideas, including ideas such as matter and interactions, energy, and biological evolution. Next, they defined the key practices of the disciplines, called the science and engineering practices, which included practices such as developing and using models,
analyzing and interpreting data, and engaging in argument from evidence. Finally, they established crosscutting concepts that span each of the traditional disciplines including, structure and function, energy and matter, and stability and change. Together, these three components are known as the three dimensions of the NGSS. Since the inception of the NGSS the three dimensional vision of teaching, learning and assessment has come to be widely recognized as a means to achieving the goals laid out in the Framework. The NGSS have become the central tool of current science education reform efforts.

Through the implementation of the NGSS in the K-12 educational system, the goals of the Framework to are to facilitate the “...linkage of science education to students’ interests and experiences, and the promotion of equity.” (NRC, 2012, pg. 24). In order to achieve these goals, one of the foci of the Framework is on student ideas and student thinking. While the idea of foregrounding student thinking is not new, the NGSS put a greater emphasis on its importance by creating a series of developmental progression tools for viewing increasing sophistication in student thinking over time (NGSS Lead States, 2013). These progressions are designed “…to help children continually build on and revise their knowledge and abilities” (NRC, 2012, pg. 11) from their initial ideas to those which are more scientifically based ideas.

**Student Thinking and Student Ideas**

**Frameworks for Thinking About Student Ideas**

While the NGSS made a case for viewing student ideas as resources to be built upon, this way of thinking about student ideas is not necessarily the norm in most science classrooms. For many teachers, the business-as-usual way of viewing student thinking looks much different from the vision set out in the Framework (Banilower et al., 2018) and positioning student ideas as resources represents a fundamental shift at the center of reform. In this dissertation, I view the
shift that teachers are expected to make as they take on NGSS related reform as a form of mediated action; that is, in order to achieve the goals of the reform, teachers’ action will be mediated by related tools. As forms of classroom activity that proponents of the NGSS and the Framework hope to see are not necessarily the norm, the current activity taking place in classrooms will require a transformation.

Research on student thinking that took place in the 1970s and 1980s, focused on a view of student thinking and student ideas from a conceptual change and misconceptions framework and these frameworks continue to persist in today’s classrooms. Conceptual change (Posner, Strike, Hewson & Gertzog, 1982), is defined as “the process by which people’s central, organizing concepts change from one set of concepts to another set, incompatible with the first” (p. 211). This framework was widely taken up by scholars and educators as a way to replace students’ incorrect ideas with scientifically accurate ideas through cognitive conflict. In this model, conflict is the mechanism for conceptual change and that change can be facilitated when students’ current concepts are challenged.

Other related work focused on confronting misconceptions in the central science domains. Misconceptions (e.g. Clement, 1982) are the persistent, incorrect ideas students have been documented to hold. Once they are identified, misconceptions can then be confronted and replaced with scientifically accurate ideas. While the misconceptions view was taken up widely in educational contexts, it was also criticized as problematic. Smith, diSessa and Roschelle (1994), pushed back on the misconceptions framework and questioned its usefulness as a lens for viewing student learning in mathematics and science. Specifically, they criticized the tendency to focus on the discontinuities of student ideas rather than the continuities as learners progressed from novice to expert in a domain. They also challenged the notion of replacing a misconception
with a scientifically accurate idea as out of line with knowledge building as it “essentially denies
the validity of students’ ideas” (Smith et al., 1994, p. 126). Further, they suggested that
confronting students’ misconceptions could create additional problems by convincing students to
hold more tightly to their original ideas, closing them off from new learning opportunities.

In contrast to the misconceptions view, other scholars took a more resource-based
position on student ideas. For example, diSessa (1988,1993) proposed the knowledge-in-pieces
view that student ideas are made up of a “fragmented system of intuitive knowledge” (diSessa,
1988, p. 70) called phenomenological primitives or p-prims and that these fragments often
contain ideas that are inaccurate or naive that students can organize in a way that aligns with
scientifically accepted ideas. Other scholars (e.g. Hammer, 1996; Roschelle, 1998; Sherin, 2001)
进一步 explored the use of knowledge-in-pieces, primarily in physics contexts, and built on
diSessa’s ideas through teachers’ interactions with student ideas in classroom settings. These
resource-based views of student ideas are more aligned with the vision set out in The Framework
that views student ideas as productive and worth paying attention to.

Today, teachers who align with a resource-based view of student thinking might practice
responsive teaching, characterized by teachers’ attention to the substance of student ideas,
connections to the discipline, and the pursuit of that substance (Robertson, Atkins, Levin &
Richards, 2015). Responsive teaching takes a firm stance that “…the ideas students bring to the
table are sensible and productive” (Richards & Roberts, 2015, p. 44). Responsive teachers focus
on students’ ideas because they believe that those ideas, not a pre-scripted plan, should drive
instruction forward. The responsive teacher remains focused on the substance of students’ ideas
and follows them even if it means deviating from previously planned classroom instruction
(Robertson et al., 2015).
Teacher noticing, considered by some scholars (e.g. Colestock & Sherin, 2015) to be a practice associated with responsive teaching, has been defined by van Es and Sherin (2002) as a practice where teachers identify what is important in the classroom context, connect to broader ideas of teaching and learning, and reason about what they noticed. Teachers who practice noticing do so in order to sift through all of the complex interactions that happen in the classroom so they can attend to what is important (Sherin, Jacobs, Philipp, 2011), the student ideas that have the greatest potential to influence student learning (Stockero, Rupnow & Pascoe, 2017). Teacher noticing can be supported by tools such as frameworks for classroom interactions, lists of common student ideas, challenges to scientific practices and feedback guides (Benedict-Chamber & Aram, 2017) all of which have the potential to mediate teacher activity towards student thinking.

Yet another practice associated with a resource-based view of student thinking is formative assessment. Formative assessment includes eliciting, interpreting and acting on student thinking through teacher feedback or instructional opportunities (e.g. Cowie & Bell, 1999; Furtak, 2012) through the use of classroom practices or tasks (Bennett, 2011). While formative assessment tasks are tools that mediate teacher and student activity in the classroom, formative assessment practices can also be supported by tools such as frameworks of student ideas or feedback structures. In a formative assessment oriented classroom, students are encouraged to share their ideas so that teachers can pay attention to their substance and, specifically, the disciplinary substance of those ideas (Coffey, Hammer, Levin & Grant, 2011) in order to make instructional decisions.

Teachers who engage in the practices described as associated with responsive teaching, noticing and formative assessment are likely to share some common commitments to the
The importance of student ideas as resources for instruction. While the tools of science education reform, such as the *Framework* and the NGSS provide guidance to make a shift toward viewing student ideas as productive resources, it is not necessarily the case that this shift has happened at the classroom level in a widespread manner. If researchers and educators are serious about realizing the vision of the *Framework*, it is critical to understand how teachers come to learn about these practices and how they might continue to engage in routines and be supported by tools, beyond the reform documents and throughout their professional careers that help them place student thinking at the center of their instruction.

**How Teachers Learn About Student Thinking**

The way that teachers think about and act on student ideas in their classrooms is based in part on the historical nature of their own experiences. In addition to the lessons teachers learned from their own education, most teachers continued to learn about teaching practices in some form of a teacher preparation program. When it comes to a focus on student thinking, research has suggested that many teacher preparation programs may fall short. While dedicated teacher educators have actively engaged in confronting this problem (e.g. Windschitl, Thompson, Braaten & Stroupe, 2012) many programs still prepare teachers to focus more on what students are doing, in terms of activity, rather than what students are thinking (van Es & Sherin, 2002).

In fact, studies of pre-service teachers have indicated that in this early developmental stage of teaching it is common for emerging teachers to determine that students “know nothing” about a topic when students are unable to produce formal definitions of science ideas using academic language, discounting knowledge from life experience and privileging only school-based knowledge (Otero, 2006; Otero & Nathan, 2008). Other studies have supported this finding: that pre-service teachers do not view student ideas as nuanced and are unable to see
subtle but important differences in a range of student responses; rather, they see student ideas as dichotomous, either right or wrong (Gotwals & Birmingham, 2016). This way of thinking about student ideas is referred to by Otero (2006) as a “get it or don’t” view and has been widely cited in the literature. In many cases, these conceptions are deeply held and may take years to change, time beyond the scope of most teacher education programs (Adams & Krockover, 1997).

Looking toward the years beyond teacher preparation, Schneider and Plasmann (2011) found that many practicing teachers, particularly those early in their careers, continue to think of students as blank slates who come to school without scientific ideas. This tendency can also be compounded by a deficit framing of students and their ideas (Battey & Franke, 2015) and can be especially problematic in schools with high proportions of students traditionally underrepresented in STEM fields. This view has often manifested as an attitude that students and/or their families are responsible for their inability to succeed based on traditional measures in school.

However, Schneider and Plasmann (2011) did note a shift over time in teachers’ views of student thinking. As they spent more time interacting with students they began to use instructional tools and practices, such as classroom discussion or formative assessment, to uncover student ideas. Later in their careers they were able to recognize that students have ideas based on their experiences and that these ideas are the basis for learning. Although some teachers may hold onto their ideas of student as blank slates, experienced teachers are more likely to draw out student ideas, interpret them, and match them with instruction.

Given that, historically, many teacher preparation programs may not adequately prepare teachers to focus on student thinking as well as the fact that it takes time and practice for teachers to come to value student ideas as the basis for instruction, it is clear that teachers must be
supported during their professional careers with professional development involving routines and tools oriented toward student thinking. While little attention has been paid to the ways in which teacher educators and/or researchers create learning experiences for teachers that can support them in taking on what reforms such as the NGSS are asking of them (Putnam & Borko, 2000), in the context of science and mathematics education, researchers have been gaining traction in this area.

**Supporting New Forms of Teacher Activity Centered Around Student Thinking**

Research on what constitutes high quality professional development has pointed to critical conditions, social structures and professional tool-supported routines that can shift teacher practice and improve learning outcomes for students. This includes professional development that is collaborative, time intensive, coherent with teachers’ work, and provides opportunities for active learning (Garet, Porter, Desimone, Birman & Yoon, 2001).

Over the past several decades, teacher communities have gained popularity in schools in the United States (McLaughlin & Talbert, 2001) and abroad (Bloam et al., 2005). The literature describes these communities using a variety of nomenclature including teacher learning communities (TLCs) (e.g. Little, 1999) and professional learning communities (PLCs) (e.g. McLaughlin & Talbert, 2001). In some instantiations, these communities subscribe to a particular set of principles or rely on structured protocols to guide conversation (e.g. critical friends groups; Curry, 2008). However, in the context of teachers working together, the term “community” has been used widely without fidelity to any particular set of characteristics (Grossman, Wineburg & Woolworth, 2001; van Es, 2012). As such, this dissertation uses the term “workgroup” to describe groups of teachers working together in schools (Horn, 2010).
With the proliferation of collaborative workgroups, it has become increasingly common to find the characteristics described above at the core of job embedded professional development, where teachers collaborate together as a part of the course of their regular work day (Gibbons & Cobb, 2017). These workgroups have the potential to support teacher learning in ways that can help them enact the practices necessary to use student thinking to inform instruction (McLaughlin & Talbert, 2006). While we know that not all teacher communities are productive, there are certain routines, activities and orientations that seem to be associated with communities that are successful (Horn & Little, 2010). One of these is an orientation toward problems of practice, or the real dilemmas teacher face in the course of their work. Examples of problems of pedagogical practices related to student thinking could include, *how do I provide my students more opportunities to engage in discourse to share their thinking?* or *how do I design classroom tasks that draw out the range of ideas that students have?*

Researchers have spent time working with teachers to address these types of questions by engaging in routines and designing tools that support teachers in taking a resource-based view of student ideas. These types of professional development opportunities have often involved routines aimed at to bringing artifacts of teacher practice into the realm of teacher workgroups (Borko, Eiteljorg & Pittman, 2008; Borko et al., 2017). Examples of these routines include looking at student work, watching classroom video, and designing formative assessment tasks together.

Kazemi and Franke (2004) investigated how a group of teachers developed a deeper understanding of their students’ thinking through the interrogation of their students’ work. Over the course of a school year, teachers participated in a routine where they posed a similar mathematical problem to their students and returned to the group monthly with student work.
samples as “artifacts of students’ mathematical thinking” (p. 229). When the group first began meeting, teachers focused on their students’ incorrect responses; however, as the school year progressed the teachers began sharing their students’ thinking and were surprised by the mathematical sophistication they saw in their students’ work. The routine of sharing student work, and the expectation that teachers were to bring tools that provided evidence of student thinking to their meetings, prompted teachers to change their classroom practices to engage in more discourse with their students and to create written tasks that gave students an opportunity to share their mathematical strategies. Over time teachers built on student thinking to discuss instructional implications and how students could build on their strategies to advance their own thinking.

Other routines have focused on mathematics teachers’ noticing student thinking in the context of a video club (e.g. van Es and Sherin, 2008). These teachers engaged in a routine once or twice a month where they watched video clips recorded by researchers in their classrooms and discussed the student ideas they noticed. Early in the school year, teacher discussion focused on what the student was doing student or a recounting of what happened in the clip. As time progressed teachers began to discuss mathematical thinking, evidence of student understanding, and the strategies students were using. In this case, the video clip served as a tool to mediated teacher activity. Similar routines have been used with groups of science teachers who were tasked with recording their own classroom videos, requiring teachers to notice student thinking before coming to their workgroup meeting (Luna & Sherin, 2017). In their workgroup sessions, teachers began discussing the substance of student thinking at their earliest meetings and over time they spent less of the meeting describing and evaluating student ideas and more of the time
interpreting those ideas. Notably, their discussions came to include the range of ideas that students have as teachers took on a “nuanced interpretive stance” (p. 292).

Furtak and colleagues (Furtak & Heredia, 2014; Furtak, et al., 2016) studied teacher workgroups as they participated in a routine called the formative assessment design cycle (FADC) where teachers explored student ideas, designed formative assessment tasks, practiced using tasks, enacted tasks with students and reflected on that enactment. These workgroups used a learning progression, discussed later in this chapter, for natural selection (Furtak, Morrison & Kroog, 2014) to support teachers in understanding how student ideas developed. The FADC was built, in part, on the premise that the formative assessment tasks designed by teachers would serve as tools to provide opportunities for students to share their thinking (Kang, Thompson & Windschitl, 2014) and through their participation in the professional development, teachers would provide more and better opportunities for students to share their thinking also improving their interpretation of and feedback to the ideas shared by students. Each of the stages of the FADC involved teachers engaging in activities such as using score reports, using teaching rehearsals, looking at student work and watching classroom video. Analysis following three years of teacher participation indicated that teachers did improve their formative assessment task quality, questions to elicit student ideas, interpretation of student ideas and response to student ideas.

In each of the examples discussed above, material tools such as student work, video and formative assessment tasks were used to support teacher learning about the use of student ideas for informing their instruction. Further, the teachers’ work was situated in the social, cultural, historical contexts of the institutions in which they work. The findings described above suggest that teachers can begin to take the actions necessary to orient the work of teaching toward
student thinking when they participate in professional development that includes routines and tools that support them in particular ways; however; further research is necessary to understand the complexities of how this happens, particularly as teachers take the most challenging step: using student thinking to inform instruction (Heritage, Kim, Vendlinkski & Herman, 2009). Taking these steps is further complicated by the fact that teachers’ work contexts are complex and require that they respond not only to the tools of standards-based reforms such as the NGSS but myriad other institutional requirements as well.

The Institutional Context Where Reform Takes Place

Even under ideal conditions, where tool-mediated collaborative workgroups oriented toward student thinking are supported in their schools, these workgroups exist within a multilayered and changing institutional context. For researchers, it is essential not only to build a better understanding of the tools and routines necessary to support shifts in science education, but also to attend to the institutional contexts where science education reform takes place. These contexts are full of contradictions that teachers must navigate as they work to make the shifts called for in the Framework. As it is, teachers are inundated with messages about how the limited time they have together in their workgroups should be allocated. These messages come from many sources, including district curriculum coordinators, school administrators, and other district administration and staff.

District science curriculum coordinators are often responsible for the coordination of district wide professional development opportunities that take place throughout the school year and in the summer. They may also be responsible for the coordination of district curricula, pacing guides and other curricular materials and, in some cases, individual or community coaching. In states that have adopted the NGSS, the professional development and associated
tools and resources are likely to be coordinated with the vision laid out in the Framework. In that case, district science coordinators would be focused on improving the quality of instruction in ways that align with the three dimensions of the NGSS and include a focus on student thinking to inform instruction. This orientation is what Jackson and colleagues (2018) referred to as instructional improvement which focuses on improving outcomes for students through teachers’ professional learning (Jackson, Cobb, Rigby & Smith, 2018).

However, building administrators, such as principals and assistant principals often convey messages to teachers that originate in the district central offices. These messages are, or are perceived to be, focused on student achievement and often translated into goals related to raising scores on standardized assessments. Principals, in particular, often have an instructional management orientation, focusing on short term goals to raise student test scores (Jackson et al., 2018) often at the expense of teacher learning.

While it is not always the case, these two orientations - instructional improvement and instructional management - are often out of sync with one another. This misalignment can be problematic because a lack of coordination across district leaders can be harmful to the goals of improving instruction and outcomes for students. One way this manifests is in the context of teachers’ collaborative time, over which building leaders have a tremendous amount of influence (Cobb, Jackson, Hendrick & Smith, 2018). For example, district administrators who take an instructional management approach might require teachers to allocate their collaborative time to design classroom tasks that mirror state test formats, a move that then requires teachers to devote instructional time to test preparation. However, if teachers are focused on summative outcomes, they will as a result have less time to focus on classroom teaching and learning. The focus on
these short term goals often comes at the expense of long term goals that include capacity building at the teacher level toward reform-oriented instructional improvement.

For teacher workgroups, activities such as those focused on standardized test preparation become routines carried out in service of filling a requirement (Timperley & Earl, 2009) rather than a learning experience. As this happens, and teachers focus more on standardized assessment data and less on student thinking, they are taken away from focusing on the classroom assessments that draw out student thinking and are relevant to their work (Mandinach, 2012). Further, they see the work related to standardized assessment data as unrelated to their teaching (Farrell and Marsh, 2016). A narrow focus on what counts as data can lead teachers to teach to the test and focus exclusively on those students on the edge of moving from one proficiency category to the next (Evans et al., 2018) pulling them further away from a student thinking framework and away from the range of ideas all students in the classroom have and how they can respond to them instructionally. What is most concerning, particularly in schools serving the most vulnerable student populations, is that although the goal of data initiatives might be grounded in ideals around equity and learning, they often exacerbate existing inequities or create new inequities and reinforce deficit views about student and families (Braaten, Bradford, Kirchgasler, Barocas, 2017).

**Tools to Support New Forms of Teacher Activity Focused on Student Thinking**

Despite what might seem like irreconcilable differences between the expectations teachers are tasked with following in their institutional contexts, views such as instructional management and instructional improvement are not necessarily incompatible (Jackson et al., 2018). Specifically, students who experience the kind of instruction that would be associated with instructional improvement are more likely to perform better on standardized tests. However,
if professional development that supports teachers engage in activity that helps them learn to use student thinking to inform instruction must attend to teachers in the real contexts in which they work, supporting them with the tools that will help them navigate the complexities of their work.

Several promising lines of research have investigated the kinds of tools that can help meet teachers’ need in this area. At the center are learning progressions, supported by assessments, and interpretive tools. An additional, crucial tool is the facilitation of teacher workgroup routines that supports the utilization of these tools as teachers engage in new forms of activity designed to help them understand student thinking and how it can be used to inform instruction.

**Learning Progressions**

Learning progressions, primarily used in science education, are research-based hypotheses describing how student thinking develops over time (Corcoran, Mosher & Rogat, 2009). On one end, learning progressions are anchored by the initial ideas students have about a particular concept or domain, in the middle, they suggest intermediate understandings that are “reasonably coherent networks of ideas and practices and that contribute to building a more mature understanding” (Corcoran et al., 2009, p. 220). Anchoring the other end are the scientifically accepted or sophisticated understandings educators want to guide their students toward. Learning progressions have been developed in a number of domains as models of student thinking including, natural selection (Furtak, 2012), force and motion (Alonzo & Steedle, 2009), matter (Adadan, Trundle, & Irving, 2010; Smith, Wiser, Anderson, & Krajcik, 2006), energy (Neumann, Viering, Boone & Fischer, 2013), the water cycle (Gunckel, Covitt, Salinas, & Anderson, 2012), energy in carbon transforming processes (Jin & Anderson, 2012), space science (Plummer & Maynard, 2014), and genetics (Duncan, Rogat, & Yarden, 2009; Todd &...
In addition, researchers have recently begun to explore the utility of learning progressions for scientific practices; for example, modeling (Pierson, Clark, & Sherard, 2017; Schwarz et al., 2009) and argumentation (Berland & McNeill, 2010) as well as two dimensional learning progressions that view hypothesize learning pathways for content and practices together, such as biodiversity and explanation (Songer, Gotwals, and Wenk, 2009). Three dimensional learning progressions that, in addition to content and practices, consider learning about crosscutting concepts are being explored in evolution in conjunction with multiple science practices and crosscutting concepts (Wyner and Doherty, 2017) and energy and modeling (Buell et al., 2019).

Research conducted on learning progressions, and their math education counterparts, learning trajectories (Daro, Mosher & Corcoran, 2011) suggests that they have the potential to help teachers make sense of student thinking as part of instruction (Franke, Kazemi and Battey, 2007). Further, they can help teachers move away from a dichotomous or misconceptions view of student thinking, combating the tendency to revert to a view of what students don’t know or can’t do (Wilson, Sztajn & Webb, 2017). When teachers use these hypothesized progressions or trajectories they can better understand what students are thinking, why they might have those ideas and what teachers can do to support them (Ebby, 2018). Using progressions and trajectories in this way can help teachers use students’ thinking to support their future learning (Sztajn, Confrey, Wilson, & Edgington, 2012).

Explorations of how learning progressions in science might be used as tools to support teacher activity is still an emergent area of research (Alonzo & Gotwals, 2012). For example, Furtak and colleagues (Furtak, 2012; Furtak & Heredia, 2014; Furtak et al., 2014) examined the ways in which a set of learning progressions for natural selection might serve as the centerpiece
for high school teachers as they engaged in the routines of the FADC, as discussed earlier. However, while learning progressions hold great promise for teacher use, as they are written, some caution that they are not ready for use in classrooms as stand alone tools (Gotwals, 2012). In addition, rather than advocating for teachers to use them in their current form, their use should be supported as a launching point for discussing and developing understanding about students’ thinking (Alonzo & Elby, 2019). This can be accomplished by coordinating learning progression use with other tools.

**Assessment Tools**

In science education, several research teams have developed assessment items linked to learning progressions as way to support teacher understanding of student thinking and inform classroom practice. Ordered multiple choice (OMC) items are one example of item types that have been created for use with various developmental progressions in science. These include earth and the solar system (Briggs, Alonzo, Schwab & Barocas, 2006), force and motion (Alonzo & Steedle, 2009), natural selection (Furtak et al., 2014), and the structure and composition of matter (Hadenfeldt, Bernholt, Lie, Neumann & Parchmann, 2013). OMC items are different from traditional multiple choice items because, rather than one correct and three incorrect answer options, each of the OMC answer options are linked to a different level of the a learning progression. This linkage creates a scenario where “the distractors capture students’ ways of thinking with more richness and authenticity than is typically the case with traditional multiple choice items” (Alonzo & Elby, 2019, p. 26). As it can be difficult to both develop and interpret OMC item information, students’ performance on OMC items are typically analyzed in sets to obtain an estimate students’ levels of understanding relative to a learning progression.
In addition to OMC items, other researchers have developed formative assessment tasks linked to learning progressions. In the example of the Daphne and Elevate projects, discussed earlier in this chapter, teachers and researchers used a learning progression to guide their development of formative assessments designed to provide students with an opportunity to share a range of ideas (Furtak, 2012; Furtak & Heredia, 2014). Teachers developed the items in their workgroups to specifically draw out the range of ideas the learning progression hypothesized that students might have. These formative assessment tasks included open-ended items, constructed response, concept maps and data interpretation questions. Based on the structure of the formative assessment task, student thinking can be interpreted relative to an appropriate framework.

**Interpretive Tools**

Tools, such as score reports (e.g. Alonzo & Elby, 2019; Furtak et al., 2014, Minstrell, Anderson, Kraus & Minstrell, 2008), or written guides intended to help teachers interpret student response patterns to assessments relative to the information contained in learning progressions, have been developed and used to provide teachers with useable data about student responses (e.g. Alonzo & Elby, 2019). Score reports can help facilitate teacher understanding of the ideas their students have and can help them in deciding on what instructional next steps to take. In their study of teachers interacting with score reports, Alonzo and Elby (2019) found that teachers were generally curious about the information contained in the score reports about their students’ thinking, took an “inquiring stance” (p. 24) and “...used the score report to generate and test hypotheses about students’ thinking” (p. 23).

While score reports can provide useful information related to OMC or other, more traditional types of assessment items, it is more difficult to use this kind of report with open ended or non-traditional items. Routines for sorting student work can support teachers as they
interpret qualitative student responses from classroom assessments include open ended or constructed responses. The FADC (Furtak, 2018) included a routine where teachers engaged in the piling activity where teachers looked for evidence of student thinking relative to the learning progression and sorted the artifacts into 3-6 piles based on the ideas students have. After teachers made piles, they discussed the ideas included in each of the piles, what students in each pile might be thinking or understand, what feedback teachers would give to students and what instructional steps teachers might take to address the student ideas. Teacher activity in the context of these routines is often guided by a facilitator.

**Facilitation Tools**

One of the critical tools for teacher workgroups is facilitation (Richmond & Manokore, 2010). Facilitation happens when a more knowledgeable or experienced other, such as a lead teacher, an instructional coach or a university researcher, uses their expertise to guide the work of teacher communities. The use of a facilitator can help to move teachers away from conversations about logistics and planning toward the substance of the student ideas at the core of the activity (Frederiksen & White, 1997; Sherin & Han, 2004). Effective facilitators promote productive discourse (Zhang, Lundeberg & Eberhardt, 2011), articulate explicit goals, select the artifacts that support teacher activity and orient teachers toward improving instructional practice (Gibbons & Cobb, 2017; Tekkumru-Kisa & Stein, 2017). Facilitators press teachers with follow up questions that provide them with opportunities to unpack their thinking (Horn, Kane & Garner, 2018). They coordinate a multitude of practices including, pressing for explanation, asking for clarification, and providing counter examples (van Es, Tunney, Goldsmith & Seago, 2014). In addition, when coupled with a well-designed protocol, that specifies in advance the types of questions facilitators might pose, facilitators can create
opportunities for teacher learning (Andrews-Larson, Wilson & Larsi-Cherif, 2017). Facilitators can orient teacher learning around student thinking and can help teachers come to place more value on student ideas through thoughtful analysis of student thinking (Sherin and Han, 2004). They can promote an orientation towards “students as sense-makers” (Andrews-Larson et al. 2017, p. 31) and can help teachers recognize the complexity of the ideas that students have (Rosebery, Warren & Tucker-Raymond, 2016).

**Summary of Conceptual Framework**

The research summarized above highlights the efforts of education researchers to use tools such as learning progressions, assessment items, interpretive frameworks and facilitation as tools to support teacher workgroups as they work to realize the vision of the Framework and learn to center their collaborative work on the substance of student ideas and their potential for informing instruction. It is the combination of these tools that has the potential to support this type of work. Learning progressions can provide the framework teachers need to have robust conversations about student ideas. The assessment items and interpretive frameworks that accompany learning progressions link the ideas from teachers’ current students to the hypothesized trajectory of student ideas in the learning progression. Skilled facilitators can then guide teachers in productive activity related to student thinking to inform instruction.

These tools; however, do not exist in isolation, they are situated in complex sociocultural, historical and institutional contexts. Understanding how the tools described here mediate activity in teacher workgroups will require locating teachers’ work within the history of science education reforms and the frameworks of student thinking teachers may be familiar with based on their own educational experiences. In addition, it will be important to attend to the institutional contexts of teachers’ schools and the logics they are accountable to as part of their
work. As a theoretical framework, mediated action provides a lens through which we can understand how certain tools might mediate teacher activity related to prioritizing student thinking to inform classroom instruction. In addition, this framework provides an opportunity to better understand how the social, cultural, institutional and historical contexts described above might shape and be shaped by that activity.

In this dissertation I draw on Wertsch’s (1997) ten claims related to mediate action to answer the following research questions:

● How can researchers design tools to support teacher activity that privileges student thinking to inform instruction?

● How do the tools of the activity system mediate activity oriented around using student thinking to inform instruction?
Chapter 3. Context

The data analyzed in this dissertation are drawn from the Aspire research-practice partnership (Penuel, Coburn & Gallagher, 2013), a long-term collaboration between the science curriculum coordinators in a large ethnically, culturally, and linguistically diverse school district and researchers at the University of Colorado, Boulder.

Research Practice Partnerships

Research-practice partnerships (RPPs) are an emerging strategy that developed in response to critical needs in schools. In contrast to a researcher-driven relationship where researchers typically identify needs and solutions and direct practitioners toward those solutions while studying the response, the research-practice partnership engages researchers and practitioners as equal partners. RPPs are characterized by five components: they are long-term, focused on problems of practice, committed to mutualism, strategic to intentionally foster partnership, and productive of original analyses (Coburn, Penuel & Geil, 2013). They push back on the popular translation metaphor where it is the job of the researcher to translate findings from educational research into tangible and applicable tools and resources for practitioners (Penuel, Allen, Coburn & Farrell, 2015). The translation model is problematic because it fails to honor practitioners’ contribution as a partner or encourage them to participate in an ongoing relationship with researchers. Further, it doesn’t account for the fact that practitioners do not usually take up research exactly as it is written or interpret it as narrowly as the research may suggest (Penuel et al., 2015). It assumes a one-way flow of knowledge, from researcher to practitioner and makes the assumption that researchers have little to learn directly from practitioners. In the field of education, the RPP often takes the form of a research team in partnership with administrators (practitioners) within a school district.
The Aspire RPP

The Aspire RPP was founded in 2014 and grew out of problems of practice related to the Sunshine school district’s needs and priorities (Coburn et al., 2013). On the university side of the partnership, the research team is led by Erin Furtak, faculty in the School of Education, who initially was contacted by a science instructional coordinator from Sunshine Public Schools\(^1\) in 2014 regarding the possibility of working with the district to support science teacher formative assessment practice aligned with the NGSS. Recognizing their shared commitment and the potential for a long term collaboration, the partnership was initiated. Since that time, the partnership has received funding to engage in research specific to several related projects (Figure 3.1) and the work has expanded to involve a co-PI, a research team and additional district personnel. This includes two science instructional coordinators and the Director of Assessment and Research as well as a research associate based out of the university and a teacher on special assignment based out of the district.

![Timeline of funding for projects in the Aspire partnership 2014-2021.](image)

*Figure 3.1. Timeline of funding for projects in the Aspire partnership 2014-2021.*

\(^1\)All school and individual names are pseudonyms.
Sunshine Public Schools is a large, socio-economically and linguistically diverse school district outside of a large Western city. This district serves approximately 40,000 students making it one of the largest in the state. Historically, Sunshine has underperformed on standardized tests and has had low graduation rates when compared to state averages. According to statistics published for the 2017-2018 school year, the districts’ students hail from more than 130 countries and speak over 160 languages, with the majority of the non-English speakers speaking Spanish. District wide, approximately 35% of students are characterized as English language learners and 70% qualify for free or reduced lunch. This scenario creates a critical need for the district in the context of science instruction. Where science instructional coordinators have few resources they have turned to external partners, such as university researchers, who can bring in funding and personnel to support district goals.

The Aspire Project.

Aspire I. The partnership originally received funding from the National Science Foundation for the Aspire I project to support science teachers in the design, enactment and reflection of formative assessments linked to the scientific practices described in the NGSS. This support was structured in monthly, hour-long meetings held at a central district location that middle and high school teachers had the option to attend. By reflecting on the early emergence of tensions in the RPP the partners recognized that teachers needed more support than the monthly meetings could provide and renegotiated the direction of the work (Furtak, Henson & Buell, 2016).

Aspire II. After receiving additional funding from the NSF CORE program the partnership’s focus moved into science teachers’ school-based disciplinary workgroups to focus on how physics, chemistry and biology teachers use learning progressions to inform formative
assessment design and enactment. Additional project goals include measuring the effect of learning progression based professional development on student learning, understanding the factors that mediate that learning as well as understanding how to psychometrically model student learning. Co-PI Derek Briggs and three Research and Evaluation Methodology graduate research assistants joined PI Furtak and her three to four Curriculum and Instruction graduate research assistants.

The partners worked together to identify three focal schools where the work of Aspire II would take place (Table 3.1).

**Table 3.1. Discipline specific work group participation at partner schools.**

<table>
<thead>
<tr>
<th></th>
<th>Physics (9th grade)</th>
<th>Chemistry (10th grade)</th>
<th>Biology (11th grade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>School 2</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Mayfield</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Carver</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

In each of these schools one or more disciplinary work group opted to join the project. Across the district there are two teacher workgroups in physics, chemistry and biology.

**Aspire Project Research Design**

The Aspire II project draws on a design-based implementation research (DBIR) paradigm to guide the activities of the partnership (Fishman, Penuel, Allen, Cheng & Sabelli, 2013). This approach is well aligned with the rationale behind RPPs and supports multiple stakeholders in addressing persistent problems of practice, through iterative and collaborative design, in service of developing theory and knowledge that will impact classroom learning, its implementation, and system-wide change (Penuel, Fishman, Cheng & Sabelli, 2011). DBIR supports the development
and implementation of tools, such as the learning progressions and assessments utilized in Aspire II. This approach also supports the partnership’s vision of promoting change in science teaching across the district.

The Aspire project uses complementary methodologies, both qualitative and quantitative. Qualitative methods include ethnographic field notes, interviews and observations. Quantitative methods are used to understand and model student learning. To date, classical item statistics have been used to analyze data from assessment items associated with learning progressions. Future analyses will conduct and test psychometric models. The project also intends to utilize a quasi-experimental approach to compare learning outcomes using state standardized test data for students whose teachers have participated in the Aspire project and those who have not.

Tools and Routines Used to Support Teacher Activity in the Aspire Project

The formative assessment design cycle. The design for teachers’ professional learning in the Aspire partnership is anchored by the formative assessment design cycle (FADC). This routine was developed by PI Furtak and colleagues in the Daphne and Elevate projects which took place from 2008-2014 (see Furtak, 2012, Furtak & Heredia, 2014, Furtak, 2018) to support teachers as they engaged in the design, enactment and reflection of formative assessment. This routine was used across all three years of the Aspire II study in all of the teacher workgroups. The FADC consists of five steps: explore student ideas, design tasks, practice using tasks, enact tasks and reflect on enactment (Figure 3.2).
Explore student ideas. The first stage of the FADC focuses on exploring student ideas which can be sourced from pre-test data, student work, video recordings, research on student learning or learning progressions. Each of these sources has the potential to serve as a resource to help teachers consider the ideas students might have in a particular domain. During this step of the FADC, facilitators guide teachers as they consider the range of ideas students have. As teachers explore student ideas, they also engage in their own sense making about the content being discussed (Borko, 2004). In this way, they take the time to discuss the science concepts and practices that students will be expected to engage with and they have a chance to learn from and with one another.

Design tasks. The second step of the FADC supports teachers as they launch into formative assessment task design. Tasks are designed for students to have an opportunity to share their thinking in writing (Cowie & Bell, 1999; Kang et al., 2014). Facilitators guide teachers in the use of tools, such as planning tools (see Appendix A) to help guide teachers as they identify their focal standards, map out the big ideas in their unit, locate formative
assessment opportunities among those big ideas and write assessment targets. These tools can help teachers organize the numerous elements that inform the assessment design process. After specifying the learning targets, teachers co-design a formative assessment task and evaluate it based on a set of criteria.

**Practice using tasks.** In this step of the FADC teachers may rehearse how they will enact the formative assessment with their students (Horn, 2010). This may take the form of a more formal rehearsal or less formal talking through of the process of launching the formative assessment with students.

**Enact tasks.** During this step, the teachers enact the formative assessment with their students. The facilitator may observe this enactment or video record it to bring back video clips to the group to discuss during the next stage.

**Reflect on enactment.** In this final stage of the FADC teachers bring artifacts of student work and/or video recordings of student discussion to the workgroup. Facilitators guide teachers as they reflect on the student thinking as represented in student responses on the artifacts (Ball & Cohen, 1999; Sherin, 2004). The central routine we have used is the *piling* activity where teachers focus on an aspect of the student work, usually related to their learning target, and sort the artifacts into piles based on the ideas students have, often informed by the levels of the learning progression. Following this activity, the facilitator supports teachers as they examine and make inferences about the ideas included in each of the piles, what students in each pile are thinking or understand, what feedback teachers would give to students and what instructional steps teachers might take to address the student ideas. This step also includes reflecting on the formative assessment task itself, prompting teachers to consider how the task was structured or
enacted and how that impacted the student ideas the task elicited. The facilitator prompts teachers here to discuss ways they might alter the task or its enactment in the future.

**Facilitation Guides.** Members of the research team iteratively develop facilitation guides to support each state of the FADC in teacher workgroups. These facilitation guides were originally based upon PI Furtak’s previous projects, Daphne and Elevate (Furtak, 2012, Furtak & Heredia, 2014). They were adapted to meet the goals and needs of the Aspire II project and as informed by DBIR are continually iterated on as their use is evaluated.

**Learning Progressions and Assessments.** In the Aspire project the research team drew on a number of learning progressions and associated assessment items to support our work (Table 3.2). As the vision of the project shifted over time, new tools were utilized and developed by the research team.
Table 3.2. Learning progressions and associated assessment items.

<table>
<thead>
<tr>
<th>Learning Progression and Assessment Tool Use in Aspire II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2016-2017</strong></td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Physics</td>
</tr>
<tr>
<td><strong>Learning Progressions</strong></td>
</tr>
<tr>
<td>- Force and Motion LP (Alonzo &amp; Steedle, 2009)</td>
</tr>
<tr>
<td><strong>Assessment Items</strong></td>
</tr>
<tr>
<td>- FM OMC items (Alonzo &amp; Steedle, 2009)</td>
</tr>
<tr>
<td>- Energy LP (Neumann et al. 2013)</td>
</tr>
<tr>
<td>- Energy MC items (Neumann et al. 2013; Park &amp; Liu, 2016)</td>
</tr>
<tr>
<td>Chemistry</td>
</tr>
<tr>
<td><strong>Learning Progressions</strong></td>
</tr>
<tr>
<td><strong>Assessment Items</strong></td>
</tr>
<tr>
<td>- Changes in Matter (Minstrell, n.d.)</td>
</tr>
<tr>
<td>- Changes in Matter MC Items (Minstrell, n.d.)</td>
</tr>
<tr>
<td>Biology</td>
</tr>
<tr>
<td><strong>Learning Progressions</strong></td>
</tr>
<tr>
<td><strong>Assessment Items</strong></td>
</tr>
<tr>
<td>- Carbon Time Assessment Items (Mohan, Chen, &amp; Anderson, 2009)</td>
</tr>
<tr>
<td><strong>Assessment Items</strong></td>
</tr>
</tbody>
</table>
Aspire II Year 1. The initial design of the Aspire II project called for researchers to use two learning progressions as tools to support teachers in the routines of the FADC in each content area. These included force and motion and energy in physics, atomic structure of matter and changes in matter in chemistry and natural selection and carbon and energy cycling in socio-ecological systems in biology (Table 3.3).

Table 3.3. Learning Progressions Planned for Year 1, Aspire II

<table>
<thead>
<tr>
<th>Content Area</th>
<th>Learning Progressions</th>
<th>Grade Band</th>
<th>Assessment Type</th>
<th># Items</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics</td>
<td>Force &amp; Motion</td>
<td>Top level 8th grade</td>
<td>Ordered Multiple-Choice</td>
<td>17</td>
<td>Alonzo &amp; Steedle (2009)</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>6-10</td>
<td>Multiple-Choice</td>
<td>120</td>
<td>Neumann et al. (2012)</td>
</tr>
<tr>
<td>Chemistry</td>
<td>Atomic Structure of Matter</td>
<td>9-12</td>
<td>Distractor-Driven Multiple-Choice</td>
<td>212</td>
<td>Minstrell (n.d.)</td>
</tr>
<tr>
<td></td>
<td>Changes in Matter</td>
<td>9-12</td>
<td>Distractor-Driven Multiple-Choice</td>
<td>95</td>
<td>Minstrell (n.d.)</td>
</tr>
<tr>
<td>Biology</td>
<td>Natural Selection</td>
<td>10</td>
<td>Ordered Multiple-Choice and constructed response</td>
<td>17</td>
<td>Furtak &amp; Heredia (2014); Furtak et al. (2014)</td>
</tr>
</tbody>
</table>

These learning progressions were selected because of their focus on core conceptual domains, relevance to the appropriate grade band and their linkage to assessment items.

While all of the learning progressions described in Table 3.3 were explored for use in the Aspire II projects, the focus of my dissertation is on the work the research team did with physics
teachers at the focal schools. For this reason, I will describe in greater depth the force and motion and energy learning progressions.

*Force and motion.* In these workgroups, the research team used the Force and Motion learning progression (Alonzo & Steedle, 2009) (see Appendix B) as a tool to support teacher activity. The learning progression was developed through an iterative process which established the upper level of what students should be expected to know as defined by the National Science Education Standards (NRC, 1996) and the Benchmarks for Science Literacy (AAAS, 1993). The target of this upper anchor was that students understand that “an object that is not being subjected to force will continue to move at a constant speed and in a straight line” (Alonzo & Steedle, 2009, p. 394). The lower levels were then populated using research about student understanding of ideas about force and motion (e.g. Clement, 1982; diSessa, 1993; Halloun & Hestenes, 1985). The iterations of the learning progression happened in conjunction with iterations of a set of OMC items (Briggs et al., 2006), whose answer options corresponded to the levels of the learning progression. The studies conducted though these iterations led the authors to detail a learning progression with four levels, further broken down into sublevels and 16 OMC items categorized in one of four ways (see Appendix C). These categories define the type of situation each question asked about and the type of answers students are expected to give. These were defined as 1) force: a force is acting on an object and students are asked about motion, 2) no force: no forces are acting on an object and students are asked about motion, 3) motion: an object is moving and students are asked about forces, and 4) no motion: an object is not moving and students are asked about forces. To coordinate with the OMC items, the learning progression then detailed the type of responses one might expect at each of the four levels for each of the
four question types. In the Aspire II project, our research team adapted the FMLP for use with physics teachers (Figure. 3.3).

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student understands</td>
<td>✓ force as a push or pull that may not involve motion</td>
<td>✓ motion implies a force in the direction of motion and that non-motion implies no force. Conversely, student believes that force implies motion in the direction of the force.</td>
<td>✓ an object is stationary either because there are no forces acting on it or because there is no net force acting on it. ✓ objects may be moving even when no forces are being applied. However, he or she does not believe that objects can continue moving at a constant speed without applied force. ✓ there may be forces acting on an object that are not in the direction of its motion. However, he or she believes that an object cannot be moving at a constant speed in a direction in which a force is not being applied.</td>
</tr>
</tbody>
</table>

Figure 3.3. FMLP as adapted for use by Aspire.

To simplify the learning progression, we included only the descriptions of student ideas at each of the four main levels, omitting the sublevels, the descriptions of student ideas for the four different question types (force, no force, motion, no motion) as well as the list of common errors in the version we shared with teachers (Fig. 3.3). Both physics teacher workgroups, those at Mayfield and Carver, administered the force and motion OMC items to their students during the 2016-2017 school year, the first year of Aspire II.

As part of the routine of the FADC, researchers planned to support teachers in formative assessment design related to student ideas in the FMLP. During year one of Aspire II, the teachers at Carver developed formative assessments for a unit related to force and motion as part of this work. This formative assessment was referred to as “running downhill” (Figure 3.4) and was administered twice during the unit.
A student has begun training for tryouts for lacrosse by running a two-mile loop through her neighborhood every morning. Part of the run is a very steep hill. One evening, she is running down the hill when she notices a dog lying in the middle of her path. To avoid hitting the dog, she tries to stop but has difficulty. With effort, she is able to stop right before running into the dog.

**Word Bank**

| Newton's 1st Law | Inertia | mass | force |

**Explain and describe** why it was so difficult for the student to stop. Be sure to include each of the items in the word bank.

The physics teacher workgroup at Mayfield joined the Aspire project in the fall of 2016 after they had finished their unit on force and motion. While they administered the force and
motion OMC items to their students after instruction on force and motion, they did not design any formative assessments for this unit as part of the project.

Energy. In year one of Aspire II, the research team also supported the use of a learning progression for energy (Neumann et al., 2013) as a tool to help teachers think about student ideas about energy. This learning progression was developed based on the authors’ research into energy curriculum and student understanding about the energy concept. Their hypothesized learning progression described progress along both a horizontal and vertical axis detailing what students are expected to understand at each level (Appendix D). Along the horizontal axis are four different dimensions: forms of energy, energy transfer and transformation, energy conservation and energy dissipation. Along the vertical axis there are also four dimensions: facts, mappings and relations, and concepts. The authors described their learning progression much like a staircase where students begin to understand energy forms before they understand transfer, transfer before degradation and degradation before conservation; however, these dimensions overlap and students do not need to progress to the highest level of forms (or any other dimension) before they progress to the next dimension.

In conjunction with the hypothesized learning progression, Neumann et al. (2013) also developed the Energy Concept Assessment, a set of 30 assessment items, which they administered to students in grades six through ten. While the assessment does not include OMC items, the incorrect answer choices, or distractors, are based on student energy misconceptions as identified in the literature (see panel (b), Figure 3.5).
### Examples of energy conceptions and complexity levels of the hypothesized learning progression

<table>
<thead>
<tr>
<th>Level 4</th>
<th>Energy Forms</th>
<th>Energy Transformation</th>
<th>Energy Degradation</th>
<th>Energy Conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 3</td>
<td>A deflected pendulum has greater potential energy because of its height, that is transformed into kinetic energy when the pendulum is swinging down, resulting in a reduced height, but increased velocity and vice versa</td>
<td>If the wind stops blowing the windmill will stop even if no electrical energy is consumed</td>
<td>When a swinging pendulum stops, the energy originally available was transformed into thermal energy</td>
<td></td>
</tr>
<tr>
<td>Level 2</td>
<td>For a car of a particular mass the higher velocity, the higher the car’s kinetic energy</td>
<td>In a windmill, the higher the friction at the axis of rotation, the more energy is transformed into thermal energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>The kinetic energy of a car depends on the car’s speed</td>
<td>The kinetic and potential energy of a swinging pendulum may add up to the conserved quantity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>A moving car possesses kinetic energy</td>
<td>In a windmill, energy is transformed into thermal energy due to friction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>In a windmill, energy is degraded</td>
<td>The total amount of potential and kinetic energy may be conserved</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>When a skateboarder rides a half-pipe, energy is conserved</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Misconceptions used for construction of distractors

<table>
<thead>
<tr>
<th>Energy Forms</th>
<th>Energy Transformation</th>
<th>Energy Degradation</th>
<th>Energy Conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only living things can have energy. Non-living things do not have energy.</td>
<td>Energy is a byproduct of a process. Energy turns into friction.</td>
<td>Energy is not lost when it has brought an effect. Healing is an outcome of friction and not related to energy transformation process. Once friction is overcome no energy is lost.</td>
<td>Energy is not stored in object but created from the object. Energy conservation means to save up energy. Energy can be used up. If energy is conserved, it cannot change its form during a transformation process. Conservation is justified with reversibility rather than with compensation (i.e., energy is passed back and forth and conserved vs total energy used to account for the entire system)</td>
</tr>
<tr>
<td>Energy is related to human activity.</td>
<td>Energy is only related to movement.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy is (only) only related to movement.</td>
<td>Energy is movement.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy is the source of life.</td>
<td>Energy is the source for activity.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All energy is kinetic energy.</td>
<td>Energy is some kind of fuel.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy is some kind of ingredient.</td>
<td>Energy is some kind of substance.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy is some kind of substance.</td>
<td>Thermal energy and temperature are equivalent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The energy of a body is independent of its height (above a particular position).</td>
<td>Energy and force are equivalent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy and force are equivalent.</td>
<td>Energy is a process.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy is a process.</td>
<td>Energy and gravity are equivalent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy and gravity are equivalent.</td>
<td>Sources and forms of energy are equivalent.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Following their analysis of these data, the authors made recommendations for how the learning progression might be adapted for future use.

For use in Aspire II, the research team adapted the Neumann et al. (2013) learning progression by replacing the descriptive dimensions on the vertical axis with numbered levels one through four and created complimentary documents detailing possible misconceptions and examples of student ideas at each level (Figure 3.5, panel (a)). We also administered the 30 items from the Energy Concept Assessment as well as 21 additional energy items developed and tested by Park and Liu (2016).

Following year one of Aspire II, a number of questions and concerns arose about the feasibility of using so many learning progressions with teachers over the course of a school year. Some specific challenges arose around grain size and alignment (Furtak & Tayne, 2019).
example, in biology, one of the learning progressions used with teachers was the Carbon and energy Cycling in Socio-Ecological Systems learning progression (Mohan, Chen & Anderson, 2009). As this learning spanned across grades K-12, 11th grade biology teachers found it difficult to determine where their focus should be. Alignment also arose as a challenge in both physics and chemistry where the district curricula, Active Physics and Active Chemistry (Eisenkraft, 2016) used a spiraling approach where concepts were revisited in multiple units. Teachers found it difficult to align this spiraling with the more linear learning progressions.

Based on these challenges, conversations took place between the partners and between PIs Furtak and Briggs and the NSF advisory board to determine next steps. The outcome of these conversations was that the direction of the project shifted slightly toward developing and using a single learning progression for energy. Energy was identified as a concept where understanding could be build upon over the three-year physics first sequence in the district. Energy also presented a unique opportunity to align to the goals of the Framework because it is present as a DCI in each of the scientific disciplines as well as being a crosscutting concept relevant to all science learning K-12. Taken together, these factors made it possible to explore building a learning progression that would be relevant within and across each of the three science disciplines taught in the district.

Aspire II, Year 2. During the second year of the study, the research team continued to facilitate the FADC with teachers, supporting then in using student ideas to design, enact and reflect on formative assessment. In physics teacher workgroups we continued working with the energy learning progression (Neumann et al., 2013) as a tool to help teachers think about student ideas, but we also drew on other sources such as Teaching Energy Across the Sciences (Nordine, 2016) which defined the “five big ideas” of energy: forms, transformation and transfer,
dissipation and loss, and conservation and use, as well as tools to support teachers’ modeling practices. Using these resources, we built opportunities for teachers to share their thinking about energy and to identify where they recognized energy as being important in their curricula. While we supported teachers in the routine of the FADC, their participation also informed our development of a new learning progression for energy.

At the same time, the district partners, anticipating that the state would adopt the NGSS at a future date, began to introduce teachers to the performance expectations. To do this they introduced a set of priority standards, essentially a subset of NGSS performance expectations, for each discipline. Their intention was to help teachers gradually begin to explore the NGSS without overwhelming them with the an entirely new set of standards while they were still responsible for teaching the 2009 state adopted science standards. In teacher workgroup meetings, the research team worked to align the routines of the FADC with the priority standards related to energy and modeling identified by the science instructional coordinators.

Assessments. Toward the end of year two we began pilot testing versions of what later came to be known as Phenomenon-Based Item Clusters (PBICs) (see Appendix E). These assessments, in line with the goals of the framework and our developing learning progression, oriented items around a phenomenon that could be explained by modeling energy in a system. The PBICs consisted of a number of scaffolded questions that guided students through identifying energy forms, transfers and transformations, conservation and dissipation toward an opportunity to create and explain a model of the phenomenon. The items related to the phenomenon were followed by a selection of more traditional multiple choice items from outside sources generally related to energy, many of which had been administered in Aspire II, year one (e.g. Neumann et al., 2013).
In addition to administering the PBICs, teachers continued to design formative assessments related to the energy performance expectations that were our focus. At Mayfield, teachers developed a formative assessment to elicit student ideas about energy in the context of a skateboarder on a ramp as well as the context of convection currents under the Earth’s crust (Figure 3.6, panels a and b). At Carver teachers also designed a formative assessment to draw out student thinking related to the skateboarder on the ramp as well as for the context of a wind turbine (Figure 3.6, panels c and d).

*Figure 3.6. Formative assessments designed in year 2, Mayfield (panels a and b) and Carver (panels c and d).*
Aspire II, Year 3. In the third year of Aspire II, the research team began using the newly developed Modeling Energy Flows Learning Progression (Buell, et al., 2019) (Figure 3.7, see Appendix G) in conjunction with two priority performance expectations for energy and modeling identified collaboratively by the partners, in each of the discipline based teacher workgroups.

![Figure 3.7. Modeling Energy Flows Learning Progression](image)

To develop the Modeling Energy Flows learning progression the research team drew on the work done during year two of Aspire II as well as the work of other scholars who have developed learning progressions for energy (e.g. Jin & Anderson, 2012) and modeling (e.g. Schwartz et al., 2009). We also utilized the evidence statements defined by Achieve Inc. in the NGSS detailed for each performance expectation. The criteria for identifying each of these performance expectations was that their components included DCIs related to energy, the scientific practice of modeling and the crosscutting concept of energy and matter flows.
During the current 2018-2019 school year, teacher workgroups are actively using the Modeling Energy Flows learning progression as a tool to support their exploration of student thinking related to energy. They are also administering new versions of the PBICs to their students. In physics, these include How does a skydiver get enough energy to reach maximum speed? (Figure 3.8, panel a) and Where does the energy of an earthquake come from? (Figure 3.8, panel b) currently under development.

![Figure 3.8. PBIC development, year 3.](image)

In addition to using the Modeling Flows Learning Progression and the PBICs as tools to support their activity in professional development, discipline specific workgroups are also designing formative assessments to draw out student thinking. In physics, these formative assessments are iterations of the versions used in year two. Both the physics workgroups at Mayfield and Carver developed new versions of the skateboarder formative assessment and their second energy related formative assessment is currently under development.
Summary

While the specific activities of the partnership have changed over time, the core commitments of the partnership have remained. The partners are committed to improving science teaching and learning in the Sunshine School District. To fulfill that commitment, the partnership’s research agenda aims to utilize mixed methodology to systematically study the outcomes of our joint work. The Aspire project has evolved over time in response to the needs of the partners and lessons learned from each new development have informed the current work which continues to respond to the unique needs of the stakeholders.
Chapter 4: Method

In order to understand how researchers can design tools to support teacher activity related to privileging student thinking as well as how those tools mediate teacher activity, I conducted multiple case studies embedded within the Aspire project. I selected these cases because they both served as examples of situations within the larger research project where teacher activity was mediated by researcher designed tools. In this chapter, I will explain the case study approach and, for each case, the context, participants, sources of data and analytic approach as well as a discussion of how I established validity and reliability.

Research Design

To define the parameters and boundaries of my cases, I drew on Yin (2014) who defines a case study as “an empirical inquiry that investigates a contemporary phenomenon in depth and within its real world context...” (p. 16). I chose the case study approach because it supports understandings of events as and after they have occurred, attends to the context in which the cases are situated and can explain interventions and complex situations were there are multiple variables of interest and multiple sources of data. Specifically, I conducted two single, embedded case studies. Single case studies are appropriate when a case in unusual, revelatory and longitudinal. That single case is an embedded case study when the outcomes of the case may broader have broader implications; for example, to the larger research project. This approach aligned with my theoretical and conceptual framing which emphasized the importance of components of the context, such as tools.

Statement of Positionality

I participated in this research in two different roles. From June 2015-August 2019 I was employed by PI Furtak as a graduate research assistant. In that role, I facilitated regular teacher
workgroup meetings with biology and physics teachers at two different schools. Beginning in August of 2018, I accepted a position as a Teacher on Special Assignment at the Sunshine Public School District. This position, funded by the Spencer Foundation was designed to support the Aspire partnership by creating a hybrid position that could serve boundary crossing functions between the district and the university. In this position, I continued to fulfill the role of facilitating teacher workgroup meetings and assumed additional duties. These duties have included working with additional teachers, building administrators and district science coordinators to support the science instructional goals in the district.

I take seriously my commitments to the agreements we made with teachers and the district and am mindful of whether I am acting as a researcher or practitioner at all times. In addition to my profession roles, I am a former science teacher and taught biology for over ten years and physics for two years. I identify strongly with teachers and their commitments to their schools and their students.

**Case 1: Tools to Support Teacher Activity in the Context of Force and Motion**

To respond to the research questions, *How can researchers design tools to support teacher activity that privileges student thinking to inform instruction?* and *How do the tools of the activity system mediate activity oriented around using student thinking to inform instruction and how does the activity mediate the tools?*, I draw upon field notes and artifacts from research team and two physics teacher workgroup meetings that took place during the 2016-2017 school year.

**Case Context and Boundaries.** The boundaries of Case 1 were, on one side, the initial activities of the research team as we designed tools to support teacher activity. The tools were
used at Carver, iterated on and then used at Mayfield. The boundary on the other end of the case was the final teacher workgroup meeting that took place at Mayfield (Table 4.1).

*Table 4.1. Timeline of activity leading up to score report meetings at schools 8 and 9.*

<table>
<thead>
<tr>
<th>Carver</th>
<th>Mayfield</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
<td><strong>Date</strong></td>
</tr>
<tr>
<td>12/2016</td>
<td>2/7/17</td>
</tr>
<tr>
<td>1/24/2017</td>
<td>2/14/17</td>
</tr>
<tr>
<td>1/31/17-2/1/2017</td>
<td></td>
</tr>
<tr>
<td><strong>Activity Summary</strong></td>
<td><strong>Activity Summary</strong></td>
</tr>
<tr>
<td>Teachers at Carver administered Force and Motion items to students</td>
<td>First RT meeting where score reports were discussed.</td>
</tr>
<tr>
<td>RT meeting focus on Carver meeting debrief</td>
<td>RT meetings where iterations to score reports were discussed.</td>
</tr>
</tbody>
</table>

As described in Chapter 3, teachers had administered force and motion assessment items to their students following a unit of instruction on these topics. The assessment items were OMC items where each answer option corresponds to one of the four levels of the learning progression. For example, consider item 5 (Figure 4.1) developed to evaluate student thinking relative to the force and motion learning progression. This item contained four response options, and each option was associated with a single level of the learning progression.

---

2 RT=research team
The response option a student selected provides information about where that student’s understanding could be located along the learning progression. However, as students may reason inconsistently across items, a set of OMC items, like those for force and motion are used together to support higher-quality inferences about student thinking (Briggs et al., 2006). In addition to the OMC items developed by Alonzo and Steedle (2009), the research team designed a number of tools in order to support teacher activity around the interpretation of the results from the administration of the force and motion assessment. The design of these tools by the research team and the conversations they mediated will be analyzed in this case.

**Participants.** The study participants in Case 1 included the members of the research team who participated in design of tools to support teacher activity as well as the facilitation of teacher workgroup meetings. The research team consisted of six graduate research assistants and two faculty co-PI’s. Other participants included the teachers who made up the physics teacher work groups at Mayfield and Carver (Table 4.2).
Table 4.2. Participants, Case 1. (2016-2017)

<table>
<thead>
<tr>
<th>Participants</th>
<th>Highest Degree Earned</th>
<th>Undergraduate Major</th>
<th>Years teaching at time of case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mayfield</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taylor</td>
<td>PhD</td>
<td>Geology</td>
<td>1</td>
</tr>
<tr>
<td>Pat</td>
<td>BS</td>
<td>Geology/Engineering</td>
<td>19</td>
</tr>
<tr>
<td>Jamie</td>
<td>MS</td>
<td>Athletic Training</td>
<td>10</td>
</tr>
<tr>
<td><strong>Carver</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chris</td>
<td>MA</td>
<td>Chemistry</td>
<td>16</td>
</tr>
<tr>
<td>Andy</td>
<td>BA</td>
<td>Business</td>
<td>2</td>
</tr>
<tr>
<td>Alex</td>
<td>MA</td>
<td>Biotechnology</td>
<td>9</td>
</tr>
<tr>
<td>Kelly</td>
<td>PhD</td>
<td>Psychology/Chemistry</td>
<td>3</td>
</tr>
</tbody>
</table>

These teachers worked at two of the Aspire II focus schools and had volunteered to participate in the project. The teachers who were part of these workgroups met reliably each week to plan collaboratively as part of their regular work. Facilitators from the Aspire II project attended approximately two of these meetings per month to support teachers in the routines of the FADC. There were three teachers at Mayfield and four teachers at Carver who participated with their colleagues. In addition, a total of 706 enrolled in the participating teachers’ physics courses, responded to the force and motion assessment items as part of their regular instruction.

At Mayfield, the three teachers who participated as part of the physics workgroup were Taylor, Pat, and Jamie. The physics classes offered at Mayfield included three levels: Physics I, Pre-AP Physics and AP Physics. Taylor was a first year teacher who had recently completed a
PhD in geology as well as a teacher certification program. During the 2016-2017 school year, Taylor was teaching five sections of Physics I. Pat was a veteran teacher who had been teaching for 19 years. Pat had majored in geology and engineering and had completed an alternative teacher licensure program. During the 2016-2017 school year, Pat was teaching AP Physics, Pre-AP Physics, and Physics I. Jamie had been teaching for eleven years, had a background in athletic training and was teaching three sections of Physics I in addition to one section of Anatomy and Physiology and one section of Earth Science.

At Carver, four teachers participated as part of the physics teacher workgroup: Chris, Andy, Alex and Kelly. Carver’s physics class offerings included Physics I, Honors Physics and IB Physics. Chris had been teaching for 16 years, had earned a masters in education and was teaching AP Physics and Physics I. Chris was teaching Physics I and IB Physics in 2016-2017. Andy was a second year teacher, had a degree in business and was teaching two sections of Physics I, two sections of Honors Physics and one section of the Principles of Engineering. Alex had been teaching for nine years, had a degree in biotechnology and two master’s degrees, one in secondary science education and one in administration. Alex was teaching three sections of Honors Physics and two sections of Physics I for English languages learners. Kelly was a first year teacher who had recently earned a Ph.D in Educational Studies and was teaching three sections of Physics I and two sections of Engineering and Design.

**Sources of data.** I used field notes and artifacts as my primary sources of data. These data were generated by members of the research team between January and April 2017, the time period in which teachers administered force and motion items to their students and researchers developed tools to support teacher activity around interpreting student thinking relative to the learning progression. There were two different types of field notes used for the analysis:
fieldnotes from research team meetings and fieldnotes from teacher workgroup meetings. An additional source of data included artifacts such as assessment reports, created by members of the research team to support teacher activity in physics teacher workgroup meetings, facilitation guides and interviews.

**Artifacts.** Artifacts also served as an important data source. Artifacts included the tools used to support teacher activity at physics workgroup meetings. Examples of these tools include several iterations of the score reports (Figure 4.2, panel a) as well as the learning progression (see Appendix H).

![Figure 4.2. Sample artifacts including a score report (panel a) and a facilitation guide (panel b).](image-url)
In addition, I considered the facilitation guides developed by the research team for each of the teacher workgroup meetings (Figure 4.2, panel b), as well as the facilitation guides we drew inspiration from other research projects as artifacts.

**Interviews.** Interviews were conducted with each participating teacher at the end of each school year. However, as consistent interview data was not available for all participants these were used as a secondary source of data and as a source of confirming and disconfirming evidence.

**Sampling**

**Researcher meetings.** Aspire research team meetings occurred weekly and lasted for two and a half hours each. Most members of the research team attended these meetings in person; however, some team members joined virtually on occasion. At each research team meeting during the 2016-2017 school year, research assistants rotated the responsibility of recording field notes (Figure 4.3).
These field notes consisted of a running record of all topics discussed at each research team meeting and included direct quotes from researcher participants whenever possible, as well as researcher interpretations of ongoing events (Emerson, Fretz & Shaw, 1995). The field notes were broken down into three sections, the first included a header that identified the date, participants and the agenda, the second was a running record of what happened at the meeting, and the third was a list of action items to be completed before the next meeting.
**Teacher workgroups.** Field notes were created by research assistants and PI Furtak at each of the workgroup meetings where score reports were discussed. In total, there were two field notes from the score report meeting at Carver, created by PI Furtak and myself and one fieldnote from the score report meeting at Mayfield created by another research assistant who took careful notes while I facilitated the meeting. The field note format used by the research team is divided into three parts: the header, the body, and the FADC checklist (Figure 4.4).

![Field Note Example](image)

*Figure 4.4. Sample field note from teacher workgroup meeting.*

The header included a bulleted list which provided important information about when and where the meeting took place and who was in attendance (Figure 4.4, panel a). The body of the field note was a running record of what happened at the meeting with direct quotes captured whenever possible (Figure 4.4, panel a). Researchers also captured their own impressions in the
field notes and distinguished this from the running record by using regular text for the running record and brackets, italics and researcher initials for the impressions. For example, my impressions would be recorded as follows: \([KH-my impressions go here]\). The third portion of the field note was the FADC checklist where researchers made note of which tools were used during each stage of the FADC (Figure 4.4, panel b).

To answer research question one, *how can researchers design tools to support teacher activity that privileges student thinking to inform instruction?*, I was interested in identifying research team meetings where the design of score reports, and the facilitation guides for teacher workgroup meetings were discussed. To identify relevant field notes, I digitally searched all of the 38 weekly field notes from the research team meetings for the 2016-2017 school year using “score report” as a search term. I chose this phrase because when the research team discussed assessment reports they were referred to as “score reports” and this was captured in the notes any time these tools were discussed. This search identified 12 relevant field notes that included the term. I then carefully read each of the 12 field notes and determined that the content of the field notes was relevant to the analysis in nine instances. In the remaining three instances, score reports were discussed in other contexts, e.g. on-going work with chemistry or biology teachers, and were thus excluded from further analysis. In addition, I visually scanned all of the remaining field notes to ensure that any relevant content had not been overlooked.

*Table 4.3. Data corpus for Case 1.*

<table>
<thead>
<tr>
<th>Fieldnotes</th>
<th>Artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Team Meeting</td>
<td>Teacher Workgroup Meeting</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
</tr>
</tbody>
</table>
Analytic Approach.

I created several analytic tools to support my analysis. These included, research memos, design decision frameworks and case narratives.

Researcher meetings. I used the research team meeting field notes to create a research memo that detailed the research team’s activity over the course of the nine research team meetings identified as relevant. To do this I compiled all of the relevant portions of the research team field notes into a single document, omitting portions unrelated to the case (Figure 4.5).

![Figure 4.5. Combined research memo score report memo.](image)

In italics, I filled in any additional information that I recalled but was missing from the field notes or needed additional explanation. For example, if a researcher referred to a particular tool I added contextual information to provide clarity, making it possible for someone who was
not at the meeting to understand the memo. Another research assistant, who was primarily responsible for the generation of the score reports, authored the “development of physics score reports” memo which detailed the iterations of the score reports for both schools. This memo provided a record of each of the versions of the score reports that were developed as well as the score reports considered and not selected for further development.

Much of the score report development work happened outside of the research team meetings and so, to help create a more coherent story of both the conversation that occurred at the research team meetings and the iterations of the score reports, I combined the two memos to create a single analytic document. This document served as one of the central case study documents for Case 1.

Following the completion of the combined research memo, I used a design decisions framework (Penuel, Confrey, Maloney & Rupp, 2014) to inform my analysis. A design decision here was defined as instance that led to a change in the tools, in this case, either the score report or the facilitation of the teacher workgroup. I used the design decisions framework as a lens through which I hoped to understand the decision points and outcomes associated with each decision. I read through the memo to identify decisions that led to changes in the tools. This process identified a number of design decisions, many of which were minor. For example, the research team decided to print the score reports in color instead black and white, but to save ink we only colored in the top row of the learning progression table rather than the entire learning progression. While this decision led to a change in the tools, it appeared to be of little consequence to the teacher activity in the workgroup meeting. To narrow down the list of design decisions to only include those who resulted in changes to the tools that were significant, I
reviewed the list of potential design decisions with members of the research team to eliminate those that were insignificant to the substance of the tools design and teacher activity.

Following the identification of the design decisions, I read the research memos to determine the rationale for those decisions, defined as the criteria we used to make the decision. As I did this, I returned to the field notes to verify that the memo accurately captured the essence of the rationale. Following the identification of the design decisions and the rationale, I identified preliminarily outcomes, defined as the developments that followed the design decisions. At this stage, these outcomes were tentative as I had not yet analyzed the teacher workgroup meeting and did not fully understand the outcomes. Following the analysis described here, which was focused on the data generated by the research team, two members of the research team that were familiar with the research read through the case, including the memos and design decisions. Following this reading the three of us came together to discuss the case. We discussed discrepancies, established agreement and documented all changes.

Teacher workgroups. To analyze the field notes from the teacher workgroup meetings I read the field notes several times. I created a narrative summary of what happened during the meeting at each school (Figure 4.6).
Case Narrative

Note: All of the regular black text is from original field note. All of the blue text is from original field note. This document was created by taking field note which was more a running list of quotes from teachers and adding field note which was more of a summary. The two documents complement each other because one person took notes while the other person was facilitating the meeting.

and I arrived at School 9 on a teacher work day to meet four physics teachers: Alex, Chris, Kelly and Andy. When we arrived, we joined the teachers who were gathered together around two adjoining lab tables in the middle of a science classroom. As the meeting began, I handed out folders containing packets of score reports and briefly described the learning progression and its levels as a way to interpret the assessment data. She mentioned the fact that not all of the questions had answer choices that aligned to each of the four levels of the learning progression. Opening their folders, the teachers immediately flipped past the learning progression on the front page of their packets to look at their individual reports.

We suggested teachers take some time to review the reports individually, encouraging them to mark up their copies before we began a whole group discussion; however, the teachers began talking right away. The conversation proceeded as follows:

Figure 4.6. Sample Narrative
For Carver, this involved compiling two field notes into a single narrative and for Mayfield I created a narrative by filling in any gaps from my recollection to the field notes made by another researcher. This mainly involved turning a list of teacher quotes captured in the field notes into a dialog format to create a rich and descriptive narrative as a central document of the case. After I created the narratives, I read through each in relation to the design decisions and criteria previously identified and added further detail to the preliminary outcomes of those decisions. Following the analysis of the teacher workgroup data, the other researchers who had been present at each of the meetings reviewed and discussed these documents with me. Any differences in our interpretations or recollections of events were discussed, agreement was reached and all changes were documented.

Once the narratives of the teacher workgroup meetings were complete, I began to develop a coding system with the intent of capturing specific features of the teachers’ activity during the meetings. Drawing on grounded theory (Glaser & Strauss, 1967; Strauss & Corbin, 1998), I coded the narrative through a process of open coding. I read the narratives several times and identified a list of preliminary codes. I recorded a description of each code as well as an example of each. I read through the narratives again and refined the coding system, collapsing several codes and renaming several others to improve the clarity. I coded the narratives and, following my complete coding process, two members of the research team each read through the narratives of the teacher workgroup meetings and applied the codes. We came together to discuss any disagreements. I revised the codes based on our discussion and I re-coded the field notes. The final set of codes is presented in table 4.4.
Table 4.4. Codes applied to the field notes of teacher score report meetings.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tools</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning Progression</td>
<td>Reference to learning progression.</td>
<td>“An item goes with a level”</td>
</tr>
<tr>
<td>Score report/items</td>
<td>Reference to score report.</td>
<td>“So we can’t tell which misconception they have?”</td>
</tr>
<tr>
<td>Standards</td>
<td>Reference to standards (state NGSS etc).</td>
<td>If these are all one standard, there’s so much variation, there’s how many questions on here?</td>
</tr>
<tr>
<td>Curriculum</td>
<td>Reference to curriculum.</td>
<td>“If we were teaching that now, they would have gotten it.”</td>
</tr>
<tr>
<td><strong>Activity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpreting</td>
<td>Making sense of the tools or student ideas.</td>
<td>“It’s consistent in every single class”</td>
</tr>
<tr>
<td>Problematizing</td>
<td>Productively critical or evaluative view of tools.</td>
<td>She mentioned the fact that not all of the questions had answer choices that aligned to each of the four levels of the learning progression.</td>
</tr>
<tr>
<td>Rejecting</td>
<td>Talk indicating the tools or data are not useful, not valid etc.</td>
<td>“To me the questions don’t make a whole lot of sense.”</td>
</tr>
<tr>
<td><strong>Frameworks for Student Ideas</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resource based/LP Aligned</td>
<td>Expression of a range of student idea, or discussion of how LP thinking can help interpret student ideas.</td>
<td>“75% of kids answered at a level 2, and 25% answered at a level 3.”</td>
</tr>
<tr>
<td>Dichotomous Thinking</td>
<td>Framing student ideas or data as right or wrong.</td>
<td>“How do you know which one is correct?”</td>
</tr>
<tr>
<td>Proficiency</td>
<td>Reference to proficiency way of thinking or grading.</td>
<td>“Desegretate the students based on the items, so the items are matched to levels of proficiency.”</td>
</tr>
<tr>
<td>Bloom’s Taxonomy</td>
<td>Talk about Bloom’s taxonomy as a framework for understanding student ideas.</td>
<td>“If we’re planning again, we know that all of our students are at Bloom’s knowledge.”</td>
</tr>
<tr>
<td>Instructional Action</td>
<td>Talk about what’s next instructionally.</td>
<td>“We always talk about re-teaching but we never do”</td>
</tr>
</tbody>
</table>
When the final coding of the narratives was complete I read through the narratives and identified themes. These themes helped me revise the outcomes of the design decisions.

In sum, this case study involved a deep investigation into the process through which the research team designed tools intended to support teacher activity around discussing student thinking to inform instruction.

**Validity and Reliability**

Validity was established through triangulation, peer examination, and long term observation of the participants (Merriam, 2009). Triangulation occurred by multiple investigators, myself and two other members of the research team, who reviewed analytic documents such as the design decisions, research memos and the coding scheme to confirm emergent findings. All conflicts were resolved through discussion. Peer examination was carried out by a research assistant familiar with the case who read through the findings and offered constructive feedback which was addressed through discussion. As the case discussed in this paper was part of a larger study I, and other members of the research team, have observed the participants for over three years and interpreted the findings in the context of a deeper knowledge of their reality. This is referred to as intensive, long-term involvement (Becker & Geer, 1957; Maxwell, 2013) and can help rule out specious hypotheses.

Reliability was established by examining my assumptions and looking for alternative explanations through discussion with members of the research team who challenged my assumptions and conclusions. Following these discussions, I reanalyzed the data where necessary, as in the case of the coding scheme. I created an audit trail that detailed how the data were collected, how the coding system was developed and used, and how decisions were made (Merriam, 2009).
Case 2. Exploring Student Thinking in the Context of Energy

To respond to the research questions, *How can researchers design tools to support teacher activity that privileges student thinking to inform instruction?* and *How do the tools of the activity system mediate activity oriented around using student thinking to inform instruction and how does the activity mediate the tools?*, I drew upon field notes, audio recordings and artifacts from teacher workgroup meetings that took place during the 2017-2018 and 2018-2019 school years (Table 4.5).

*Table 4.5. Timeline of physics teacher workgroup meetings.*

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Explore Student Ideas</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Tasks</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Practice Using Tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enact Tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Reflect on Enactment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Explore Student Ideas</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Tasks</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Practice Using Tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enact Tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Reflect on Enactment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Case Context and Boundaries**

The boundaries of Case 2 were around the two meetings that took place at Carver designed to support teachers in activity where they considered student thinking to inform instruction using evidence from the skateboarder formative assessment (Figure 4.7).

*Figure 4.7. Panel A Co-designed pre-assessment. Panel B. Co-designed post-assessment Panel C. Pre and Post assessment given by Chris and Avery*

These two meetings were selected because, although they represented different phases of the FADC, they focused on supporting activity related to student thinking specific to the skateboarder formative assessment task. The specific dates of these two meetings, January 25, 2018 and September 25, 2018, highlighted in yellow in Table 4.5, were each enactments of different stages of the FADC that took place during different school years.

During the January 25, 2018 meeting, the teachers participated in the *reflect on enactment* phase of the FADC. During the previous fall (2017), they explored student ideas related to energy, designed a formative assessment to surface student ideas about energy and enacted that formative assessment. The teachers worked with a formative assessment they had enacted that we referred to as “the skateboarder” which was used as both a pre and a post assessment during the unit. The goal of the workgroup meeting on January 25th was to reflect on the enactment of the post assessment.
The skateboarder formative assessment was designed to address the NGSS performance expectation *Create a computational model to calculate the change in energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known* (NGSS Lead States, 2013: HS PS 3-1). Previous to the January 2018 meeting, teachers planned to administer the formative assessment both as a pre-assessment prior to instruction and as a post-assessment following that instruction. While the specific classroom instruction each individual teacher enacted is not part of this data set, all of the teachers’ instruction included facilitating students as they experienced a PhET simulation (https://phet.colorado.edu/en/simulations/category/new) that guided them through what happens as a skateboarder moves back and forth on a halfpipe.

To structure the first meeting, the research team developed a facilitation guide (Figure 4.8) that focused teachers on the piling activity described in Chapter 3.
The plan was that teachers would sort student work into piles based on evidence of student thinking. The piles created by the teachers would then provide the basis for a conversation about student ideas and instructional next steps.

During the 2018-2019 school year the physics teacher workgroup began its work with the Aspire II project with the explore student thinking phase of the FADC in early September. The meeting of interest for this case occurred on September 25th. During this meeting, teachers used classroom data from the previous school year to explore student ideas about energy in the context of the skateboarder formative assessment, the same formative assessment they had enacted the previous school year. Following this meeting, the workgroup continued to participate in the phases of the FADC as the school year progressed.
In the time that passed between the two meetings, the research team developed the Modeling Energy Flows learning progression, discussed in Chapter 2. This new learning progression was used as a tool to support teachers as they explored student ideas about energy for the first time in the 2018-2019 school year. While we had used learning progressions for energy during the previous school year (Neumann et al., 2013) the Modeling Energy Flows learning progression was a tool specifically designed to support teacher activity in the context of the Aspire II project.

The facilitation guide that the research team developed for the September 25, 2018 meeting structured teacher conversation about the student ideas in the student work samples and their relationship to the learning progression.

**Participants.** Several of the Carver physics teachers who participated in the workgroup meetings in Case, were also participants in Case 2 (Table 4.6). These teachers were Chris, Andy and Alex. In the 2017-2018 school year, Kelly left the workgroup and two additional teachers, Avery and Blair, joined the workgroup. Avery had three years of teaching experience, a degree in education with a minor in biology, and was teaching three sections of Physics I and two sections of Honors Physics. Blair was teaching one section of Physics I and four sections of chemistry and was only part of the physics workgroup for a single year, 2017-2018.
Table. 4.6. Participants, Case 2.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Highest Degree Earned</th>
<th>Undergraduate Major</th>
<th>Years of Experience</th>
<th>2017-2018</th>
<th>2018-2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>941-Chris</td>
<td>MA</td>
<td>Chemistry</td>
<td>17</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>942-Andy</td>
<td>BA</td>
<td>Business</td>
<td>3</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>943-Alex</td>
<td>MA</td>
<td>Biotechnology</td>
<td>10</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>946-Avery</td>
<td>BA</td>
<td>Education</td>
<td>3</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>927-Blair</td>
<td>BS</td>
<td>Biology</td>
<td>17</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Sources of Data. The primary sources of data for Case 2 included field notes, audio recordings, transcripts of the audio recordings and artifacts. The artifacts included tools created by the research team, such as facilitation guides, as well as artifacts created during the teacher workgroup meetings, such as formative assessment tasks.

Analytic Approach

To answer the question *How can researchers design tools to support teacher activity that privileges student thinking to inform instruction?* I sought to understand how the facilitation guide served as a tool to support teacher activity. I began by comparing each of the facilitation guides with the activity that actually occurred. I listened to the audio recordings from each of the teacher meetings and created content logs where I summarized what was discussed at the workgroup meetings in five minute increments. Then, I conducted a comparison analysis between the facilitation guide and the content log. To do this I created a table where I put each
item on the facilitation guide in separate rows in one column and what actually happened at the meeting during the corresponding time period in the next column (Table 4.7).

**Table 4.7. Opportunities for activity related to student thinking in design of facilitation guide (1/25/18).**

<table>
<thead>
<tr>
<th>Facilitation Guide Structure</th>
<th>Opportunities for Activity around Student Thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reminder about norms for looking at student work</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Looking at student data</td>
<td>Yes</td>
</tr>
<tr>
<td>3. Instructional action and tool revision</td>
<td>Yes</td>
</tr>
<tr>
<td>4. Setting goals for the next cycle</td>
<td>No</td>
</tr>
<tr>
<td>5. Looking ahead</td>
<td>No</td>
</tr>
</tbody>
</table>

In addition, I indicated whether or not each item on the facilitation guide intended to create an opportunity for teachers to discuss student thinking and whether or not they actually did discuss student thinking.

To answer the second research question, *How do the tools of the activity system mediate activity oriented around using student thinking to inform instruction?* I used the content log as a guide to identify portions of the transcripts that should be transcribed. The portions of the transcript relevant to answering this question were places where teachers were discussing or had an opportunity to discuss student thinking. I returned to the audio recording to determine the exact time stamp that the transcription should begin and end. I created the transcript by listening...
to the audio recording many times to verify what I heard to create a complete and accurate transcript. Next, I read the transcripts several times and generated a list of potential codes using an open coding approach (Glaser & Strauss, 1967; Strauss & Corbin, 1998). I reviewed my list of potential codes and my preliminary coding rules with a colleague familiar with the research project. After I generated the codes, I applied them to both transcripts, revising them as I coded until I developed a complete set of codes. I described and provided an example of each code in the codebook (Table 4.8).
<table>
<thead>
<tr>
<th>Parent Code</th>
<th>Child Code</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Referencing Instruction</td>
<td></td>
<td>Participants reference past, current or future instruction.</td>
<td>We never did...It all depends on what class we had but we didn’t focus on the equations ’cause that was something…”</td>
</tr>
<tr>
<td>Referencing Learning Progression</td>
<td></td>
<td>Participants reference the <em>Modeling Energy Flows Learning Progression</em></td>
<td>“So I would give that a level 3.”</td>
</tr>
<tr>
<td>Referencing Science Ideas</td>
<td></td>
<td>Teachers reference general science ideas, state a scientific principle or facts NOT in conjunction with student work.</td>
<td>“You have to be careful because the true definition of conservation is…”</td>
</tr>
<tr>
<td>Referencing Student Responses</td>
<td></td>
<td>Teachers reference student ideas either from the task or ideas they think students have based on classroom interactions.</td>
<td>“I don’t see anything about mechanism on here.”</td>
</tr>
<tr>
<td>Evaluate</td>
<td></td>
<td>Teachers evaluate student responses saying it is correct, incorrect or otherwise assigning value to it.</td>
<td>“Yea, That’s a little misguided, the answer on d.”</td>
</tr>
<tr>
<td>Interpret</td>
<td></td>
<td>Teachers interpret what they think a student means either in their task or in a recollection from classroom interactions.</td>
<td>“Because I feel like they have this conception that it’s only at the bottom of the ramp where that’s true.”</td>
</tr>
<tr>
<td>Restate</td>
<td></td>
<td>Teachers restate what a student has said.</td>
<td>“Because once they are in the middle they become equal.”</td>
</tr>
<tr>
<td>Referencing Standards</td>
<td></td>
<td>Participants reference state, district or national standards.</td>
<td>“That would hit the standard?”</td>
</tr>
<tr>
<td>Referencing the Task</td>
<td></td>
<td>Participants reference the current task being reviewed in the meeting and/or future/possible iterations of the task.</td>
<td>“I mean we put a box around it (referencing the box around the model in the task).”</td>
</tr>
</tbody>
</table>
Once I developed a complete codebook, I uploaded the transcripts into the qualitative research software Dedoose and populated the codes in the program. I then used the software to code the transcripts. I used an exhaustive method in which I coded every utterance in the transcripts with some utterances having multiple codes applied to them. A second member of the research team independently coded the transcripts using the complete code book; following that coding we came together to discuss. We resolved our differences through discussion and changes were made to the code book to increase clarity. The transcripts were coded a final time using the updated version of the codebook. I read the coded transcript and identified themes in the specific ways that teachers talked about student thinking and how those instances may have been mediated by one or more of the researcher developed tools.

**Validity and Reliability**

As in Case 1, validity was established through peer examination, and long term observation of the participants and the collection of rich data (Merriam, 2009; Maxwell, 2013). Peer examination was carried out by a researcher familiar with the case who read through the findings and offered constructive feedback which was addressed through discussion. As the case discussed in this paper is part of a larger study, myself and other members of the research team have observed the participants for over three years and interpreted the findings in the context of a deeper knowledge of their reality (Becker & Geer, 1957). The collection of rich data occurs when data collection, in different forms, happens over a long period of time. Collectively this data supports and understanding of what is going on in the research context (Maxwell, 2013).

Reliability was established by examining my assumptions and looking for alternative explanations through discussion with members of the research team who challenged my assumptions and conclusions followed by reanalysis of the data. We created an audit trail that
detailed how the data were collected, how the coding system was developed and used and how decisions were made (Merriam, 1998).
Chapter 5. Results, Tools to Support Teacher Activity in the Context of Force and Motion

In the following chapter, I will present the results from Case 1, Tools to Support Teacher Activity in the Context of Force and Motion. To answer research question one, How can researchers design tools to support teacher activity that privileges student thinking to inform instruction?, I will provide a summary of the iterative process the research team engaged in as we designed tools to support teacher activity, highlighting the design decisions the research team made throughout this process and the implications of those design decisions at each school. To answer research question two, How do the tools of the activity system mediate activity oriented around using student thinking to inform instruction?, I will describe the teacher activity that occurred as teachers interacted with the tools and how this activity was mediated by the tools through two iterations. These results will be organized chronologically to represent how they unfolded in real time through two iterations and activity at two schools (Table 5.1). The summaries of the findings for each section include my interpretation of mediated action and how it explains the activity of both the research team and the teachers.

Table 5.1. Timeline of activity leading up to score report meeting at Carver (RT=Research team)

<table>
<thead>
<tr>
<th>Date</th>
<th>12/2016</th>
<th>1/24/2017</th>
<th>1/25/2017</th>
<th>1/31/2017</th>
<th>1/31/17-2/1/2017</th>
<th>2/2/2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity Summary</td>
<td>Teachers at Carver administered Force and Motion items to students</td>
<td>First RT meeting where score reports were discussed.</td>
<td>Research assistants shared digital copies of sample score reports.</td>
<td>Second RT meeting where score reports were discussed.</td>
<td>Asynchronous development of Facilitation Guide</td>
<td>Score report meeting at Carver.</td>
</tr>
</tbody>
</table>
Initial Design of the Tools

As described in Chapter 3, during the 2016-2017 academic year, the Aspire research team was comprised of co-PIs, Erin Furtak and Derek Briggs and several graduate research assistants, myself included. At the first of two meetings on January 24, 2017, where the research team discussed the force and motion score reports, we focused on what kind of feedback we wanted to provide to the teachers at Carver. We discussed score reports from other studies; the main focus of our discussion was a manuscript shared with the research team by Alicia Alonzo (Alonzo & Elby, 2019). Alonzo and Elby detailed how teachers were provided with score reports summarizing student responses from an administration of the force and motion items. The data that they provided teachers was from an administration to students at another school. When asked to respond to the score reports as if they were looking at data from their own classes, teachers discussed what they noticed in the score reports and related that to the learning progression. We drew heavily on this study because it focused on the use of our central tools, both the Force and Motion learning progression and score reports.

We reviewed a number of different score report tools including samples of teacher-level, student-level, and class-level reports. Each of these reports was designed to focus teacher conversation at a different level of detail around student response patterns relative to the learning progression. We discussed what we should do, which was to look at as many versions of score reports from different sources as we could, and what we needed to do, which was to provide teachers with score reports in a timely manner. We also discussed different goals for the score report meeting with teachers. The first goal was to provide score reports that would help teachers see “what were the ways students were thinking”, and the second was to get feedback from teachers on the format of the score reports to inform our future work.
Between the first and second meetings, members of the research team created and shared drafts of score reports for the research team to look at and then discuss at the January 31st research team meeting. At this meeting, we finalized our decisions on the reports we would create (Figure 5.1) and made a plan for their preparation.
The key design decision we made following the discussion that occurred at these two meetings was to create teacher level reports that were descriptive, item by item score reports displaying the proportion of students responding to items by level of the learning progression. This decision and its rationale will be discussed in a forthcoming section.

Next, we discussed how we would facilitate the score report meeting with the physics teacher workgroup. Following the second research team meeting, and prior to the workgroup meeting at Carver, we developed a facilitation guide asynchronously on-line. This facilitation guide development was informed by prior research (e.g. Furtak et al., 2014; Alonzo & Elby, 2019) and was designed to have an open structure to allow teachers to share their thinking as they interacted with the tools (Figure 5.2).
Figure 5.2. Facilitation guide from physics workgroup meeting at Carver High School.
Design Decisions

There were a number of decisions made over the course of the two meetings that influenced the versions of the score reports and the facilitation guide that we used as tools to support teacher activity at Carver. I identified two design decisions (Table 5.2) using my analytic framework that had significant, noticeable consequences; the team deliberated on and used this framework to redirect our work (Penuel et al., 2014).

Table 5.2. Design decisions and rationale, iteration 1.

<table>
<thead>
<tr>
<th>Design Decision</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create teacher level reports that were descriptive, item by item score reports displaying the proportion of students responding to items by level of the learning progression.</td>
<td>-a psychometric model was not available, and we could not reproduce the reports Alonzo and Elby had made -we wanted “simple” displays due to limited time with teachers -visually displaying the connection to the LP aligned with the goals of our project -two versions of the score report would allow us to generate teacher feedback on the format</td>
</tr>
<tr>
<td>Loosely structure the facilitation guide.</td>
<td>-limited time -work of other scholars: detailed score report interpretation (Furtak et al., 2014) think aloud score report interpretation (Alonzo &amp; Elby, 2017) -open structure of workgroup meeting to facilitate organic feedback</td>
</tr>
</tbody>
</table>

Design Decision I

The first design decision was to create teacher level reports that were descriptive, item by item score reports displaying the proportion of students responding to items by level of the learning progression. We ultimately designed two versions of the score report tools that displayed the data in different ways: by item and by class period. In the first (Figure 5.1, panel a)
an image of each item was placed next to a figure that detailed the distribution of student responses, by class period, which were then color coded to correspond to the levels of the learning progression. The second (Figure 5.1, panel b) displayed student responses to all items graphically by class period and were color coded to correspond to the learning progression. For both score report types, unique reports were generated for each teacher. The score reports were accompanied by two cover pages; page one had a half page version of our adapted learning progression followed by a half page table detailing how the items were grouped in the report. The second page was a full page display of our adapted learning progression.

**Rationale.** The rationale for the first design decision, to generate score reports as described above, included several factors. First, although we were informed by Alonzo and Elby (2019), we did not have a psychometric model and could not create the kinds of predictive score reports they had shared with teachers, illustrating the irreducible tension between the score report tools (Wertsch, 1997). The fact that we used Alonzo and Elby (2019) as our starting point was indicative of the power and authority it carried as these tools had been used previously by respected members of the research community. We also drew on the developmental pathway of score reports and their use. While there were few published records of studies using score reports in conjunction with learning progressions available, there was a larger history of score report use in educational settings (e.g. Zenisky & Hambleton, 2012).

In the end, we produced descriptive reports that did not require a psychometric model. In addition, Erin requested that we provide “simple” reports that would be easy to understand in the short amount of time we had to meet with teachers. Derek emphasized that it was crucial to display the student answer options as related to the learning progression, evidenced when he eliminated a score report from consideration that did not visually relate answer options to the
learning progression. These two points signaled the importance of the materiality of the tools; namely that the reports included the learning progression and visually displayed the connection between the responses and the levels of the learning progression. We also decided to include the two different versions of the score report, by item and by class period, to generate teacher feedback about which display was most useful to teachers to inform our future work. This was a result of the multiple goals the research team had for the design activity, to provide score reports that would help teachers see “what were the ways students were thinking” and to get feedback from teachers on the format of the score reports to inform our future work.

**Design decision II**

The second design decision, to loosely structure the facilitation guide for the teacher work group meeting, was based on a number of factors as well. The facilitation guide began with an introduction to the reports, interpretation time, and whole group discussion. Next, we planned to discuss instructional next steps with teachers, focusing on areas of growth for students and alignment with their curricula. Finally, we ended with a discussion of potential score report formats with the goal of capturing teacher feedback about their usefulness.

**Rationale.** This decision was partly informed by the limited time we had between the second research team meeting and the meeting with the physics teacher workgroup at Carver (2 days). Two previous research studies also informed our work. In co-PI Furtak’s previous research, the Elevate project, her team used a structured five-page protocol (See Appendix I) for facilitation of a workgroup meeting that included interpreting score reports (Furtak et al., 2014). The Elevate score report meeting was the first meeting of the school year and served as an introduction to the research project and included reviewing assessment data from the previous year as well as pre-test data from teachers’ current students. In Alonzo and Elby’s (2019) study,
they used a “think aloud” structure where teachers described their thinking as they interpreted score reports from students that were not their own, but they were asked to treat as their own for the purpose of the study. As with the first design decision, both the power and authority of this previous work and its developmental pathway mediated our action, informing our decisions.

As our context was different from each of those described by Alonzo and Elby (2019) and Furtak et al., 2014, we chose a middle-of-the-road-approach taking cues from both to inform our design. We considered the teachers’ history, which included very little prior experience with learning progressions and ordered multiple choice questions and built in opportunities for teachers to review the reports and share their thinking. However, the planned structure of the meeting was fairly open. Like the first design decision, this decision was also informed by our desire to capture teacher reactions to and feedback from the score reports in an organic way, leading us to keep the structure open (Table 5.2).

Summary of Teacher Conversations About Student Responses, Carver

Erin and I facilitated the first teacher workgroup meeting at Carver in early February. At this meeting, after greeting the teachers, I handed out folders containing packets of score reports (Fig. 5.1) and briefly described the learning progression and its levels as a way to interpret the assessment data. I mentioned that not all of the questions had answer choices that aligned to each of the four levels of the learning progression. The teachers opened their folders and flipped past the learning progression to look at their individual reports. We suggested teachers take some time to review the reports individually, encouraging them to mark up their copies before we began a whole group discussion; however, the teachers began talking right away. The conversation proceeded as follows:
Teacher: So we can’t tell which misconceptions students have on number one, response a or d?

Alex: How do you know which one is correct?

Kate: Question one, period one, 75% of students answered in level 2, and 25% answered in level 3.

Alex: So what’s the right answer?

Kate: 25% of the students got the right answer, 75% got level 2, no one picked level 1.

Alex: So then how do I tell what the answer is?

Kate: The correct answer corresponds with the highest level.

The remainder of the workgroup meeting was dominated by Alex and a strong negative reaction to the researcher designed tools presented to the teachers; what I described in my field note as “openly hostile” and what Erin described as “visceral”. The meeting proceeded with the teachers discussing both the structure of the items and the content they were assessing. They related this to the curriculum the students had experienced in their classes. For example, Chris stated that “[students] got the questions that were freshest in their minds”. As they attempted to interpret and make sense of the results, Kelly wondered, “…it seems like there’s six or seven questions they do well on. How do we make sense of that in terms of if they’re understanding the concepts?”

As the teachers looked over the rest of the items, Alex and some of the other teachers wondered about the value of questions that only had levels three and four from the learning progression as answer options, predicting that students who held level one or two understandings

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3 In the field notes the researcher occasionally captured a quote without attributing it to a specific teacher.
would be guessing on those questions; therefore, the items would not yield useful information. I reiterated the purpose of using the OMC items in conjunction with a learning progression, saying “this is the advantage...we don’t have to think about them as right or wrong, we didn’t grade it for a score...we can think about where they are on a continuum...level one isn’t wrong...they’re not like totally off.”

Alex declared that the assessment was a test of reading level rather than content knowledge noting that data for students who were in lower tracked classes displayed the same patterns as those in higher tracked classes. Alex further stated that it was “asinine” and could not be possible. Chris brought up other contexts that were familiar to the teachers’ work such as the International Baccalaureate curriculum and Bloom’s Taxonomy as a way of making sense of the data. Alex continued to react to the tools in a negative way saying for example, “I don’t see what I can get from this information”.

As the time allotted for our meeting came to an end, Erin showed the teachers the hypothetical student level score report and asked for teacher feedback. The teachers shared their thoughts on this score report and the other versions we had provided to them. Their feedback about the student level report was general; they thought it might be helpful to share with students. Additional feedback included suggestions such as bolding the correct answer, including each learning progression level as an option for each item and breaking down the items by sub-standard (i.e. friction).

**How Tools Mediated Teacher Activity at Carver**

The outcome of our first two design decisions, to create descriptive teacher level reports and to loosely structure the facilitation of the meeting, impacted the activity at the teacher
workgroup meeting in particular ways. The following analysis focuses on the tools the teachers
drew on and the activity the tools supported based on the application of my coding approach.

Tools

The majority of the conversation centered around the researcher-designed tools that we
brought to the meeting including the force and motion items, the learning progression, and the
score reports. Teachers’ recorded comments mostly either mentioned or were in direct response
to these tools. In addition to the researcher designed tools, the teachers occasionally drew on
some of the tools familiar to them in their work including the standards they were responsible for
and the curriculum that they followed. While the activity that the teachers engaged in centered
around the tools, the tools did not enable activity as aligned with our goals. We had designed the
tools to mediate activity related to student thinking to inform instruction; however, the activity
was more aligned with historical frameworks teachers were familiar with for classifying
students.

Activity

Interpreting, problematizing and rejecting. My first level of coding illuminates how
the researcher designed tools mediated teacher activity as teachers engaged in interpreting,
problematizing, and rejecting the tools. When teachers were interpreting, they were saying
things such as, “I gave it to my IB kids just to see where they were at, you see the exact same
thing in their data (Chris)”. Chris noticed that the pattern across different levels of physics
classes was similar. Kelly problematized the force and motion items, saying, “How do we make
sense of that in terms of it they’re understanding the concepts? Are the ones they’re doing well
on a reflection of the limited choice?” Kelly wondered if, on the items where students’ answer
choices corresponded with higher levels of the learning progression, students choose those levels
because those were the only options. Rejecting the tools happened when teachers, such as Alex said, “As a classroom teacher, I would tear this up and throw it away. This doesn’t tell me anything.”

Each of the three activity types, interpreting, problematizing and rejecting illustrated the tension between the agent and the tools. While I view both interpreting and problematizing as potentially productive activity in line with our goals, the rejection of the tools was unexpected. For one, it seemed to draw others away from more productive forms of activity. When Alex made frequent comments that were coded as rejecting, it left less room for other teachers to interpret and/or problematize the tools. Two, following Alex’s rejection, Chris also rejected the tools saying, “…I could care less about this stuff (holding up the item-by-item score reports)”. While I can’t know how Chris would have responded if Alex hadn’t rejected the tools, it is possible that there would have been more opportunity for extensive interpretation and problematizing had Alex not dominated with rejecting.

The rejection that both Alex and Chris engaged in was a result of what Wertsch (1997) described as the constraint and affordances of the tools. While we designed the tools to enable activity related to student thinking to inform instruction, the inherent constraints in the tools were not visible until we used them. The material nature of the teacher level score reports focused teacher attention on their individual classes and the similar response pattern across class types (e.g. sheltered, regular or honors physics). As this was unexpected for teachers, and potentially in conflict with their own frameworks for student thinking, this caused a conflict for some teachers which ultimately resulted in their rejection. As Wertsch pointed out, activity is not mediated by tools alone and “…is often based on other factors having to do with historical precedent and with cultural or institutional power and authority” (pg. 42).
**Frameworks for student thinking.** In part one of our facilitation guide, we had planned for teachers to “mark up their copies and note questions” in preparation for a whole group discussion. We had then planned for the tools to support teachers in a new form of activity that oriented them towards a resource-based view of student thinking, linking the data from the score report with the ideas in the learning progression and identifying areas of growth for their students. As soon as the meeting began, it was clear that there was tension between the teachers and the tools. None of the teachers talked about student ideas in a resource-based way or as aligned with the learning progression. Kelly was the only teacher who talked about student ideas saying, “...I noticed a lot of the ones kids did well on had to do with friction, as opposed to forces, maybe they understood friction better than forces.”, but this reference was to general rather than specific ideas. The majority of teacher conversation tended to draw on old or familiar routines and frameworks for thinking about student ideas. These included misconceptions, dichotomous thinking, Bloom’s Taxonomy, proficiency, and prior notions of what students are capable of (Table 5.3).
Table 5.3 Frameworks for student thinking and excerpt from teacher workgroup meeting at Carver.

<table>
<thead>
<tr>
<th>Frameworks for Student Thinking</th>
<th>Example from Carver</th>
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<tbody>
<tr>
<td>Misconceptions</td>
<td>“So we can’t tell which misconceptions students have on number one, response a) or d)” (unattributed teacher, Carver)</td>
</tr>
<tr>
<td>Dichotomous Thinking</td>
<td>“How do you know which one is correct?” (Alex, Carver)</td>
</tr>
<tr>
<td>Bloom’s Taxonomy</td>
<td>“Matching levels of the test to Bloom’s taxonomy. Kelly’s class able to get all of these and they’re at synthesis. So we know that if we ever need, if we’re planning again, we know that all of our students are at Bloom’s knowledge. So we don’t need to refocus that, we know that’s baseline and we can move up from there.” (Chris, Carver)</td>
</tr>
<tr>
<td>Proficiency</td>
<td>“Desegregate the students based on the items, so the items are matched to levels of proficiency.” (Alex, Carver)</td>
</tr>
<tr>
<td>Prior notions of what students are capable of</td>
<td>“...if you look at this, my two ELL classes are...that’s asinine...there’s no possible physical way the kids...do you know what I am saying? How can we say this is a valid assessment? 80% of my students have very limited language skills. That doesn’t make any sense.” (Alex, Carver)</td>
</tr>
</tbody>
</table>

**Misconceptions.** A misconceptions framework was noted just once during the workgroup meeting. Misconceptions came up at the beginning of the meeting when one teacher said “So we can’t tell which misconceptions students have on number one, response a or d?” This was in reference to an item where both responses a and d correspond to level two of the learning progression. The score report indicated the percentage of students that chose level two rather than indicating which specific answer option, a or d, the student had chosen. This comment indicated that the teacher was making two assumptions about the learning progression. One, that two different answers aligned to the same learning progression level would be associated with two different misconceptions; that knowing the level would not be enough to understand
students’ ideas. The second assumption was that all of the options that corresponded with levels one through three represented misconceptions rather than productive ideas. While the misconceptions framework did not come up often, it did provide evidence of the historical framework that the activity was situated within.

**Dichotomous thinking.** Dichotomous thinking came up more often and involved teachers talking about the correct or incorrect answers as detailed in the summary of the workgroup meeting. While most of the dichotomous thinking was generated by the teachers, I also voiced dichotomous thinking. When Alex repeatedly asked about “the right answer”, I reverted to a dichotomous view as well, talking about the right or correct answer when pressed. It is also important to note here that at the January 24th research team meeting, the first meeting where the score reports were discussed, I asked if the team could “bold the right answer” and this comment was not challenged. Erin also made a note in her fieldnote from the workgroup meeting about “bolding the right answer” and neither of us challenged this idea when teachers brought it up during the meeting. It is possible that even though we were trying to support new forms of activity around the nature of student ideas as nuanced and resource-based, the dichotomous view was part of both the lived histories of teachers and researcher alike.

**Bloom’s taxonomy.** Bloom’s Taxonomy (Bloom et al., 1956) is a hierarchical ordering of cognition that many teachers have learned to used to guide the creation of learning objectives, curriculum and assessment. During the workgroup meeting, Chris related the the learning progression to Bloom’s taxonomy. This was an attempt to make an unfamiliar tool more familiar by relating it to something that was part of Chris’ framework for categorizing student ideas. Additional evidence that this was part of Chris’ framework came up in the end-of-year interview, “What I tend to use when I make my own assessment is a tiered assessment. I start with Bloom’s
taxonomy, the knowledge, memorizing, do they know what these terms mean, can they apply them, put them in a sentence—all the way to synthesizing.” This suggests that Chris wasn’t only relating the learning progression to Bloom’s Taxonomy in the context of a single workgroup meeting. Bloom’s Taxonomy was a familiar framework used throughout the school year. While Chris was drawing on a history of practice informed by Bloom’s taxonomy, this framework may have been evoked as a way of drawing on the power and authority of a known other in a situation where the tools were designed to enable activity he was uncomfortable with.

**Proficiency.** Towards the beginning of the workgroup meeting, when teachers were sharing their initial reactions to the score reports, Alex said we should “Desegregate [sic] the students based on the items, so the items are matched to levels of proficiency”. Our interpretation was that Alex meant disaggregate. Like Chris did with Bloom’s Taxonomy, Alex was trying to relate the unfamiliar learning progression to something more recognizable and, through this, sharing evidence not only of the the historical but also the institutional precedent of the proficiency framework.

In workgroup meetings at Carver, I had observed an administrator facilitating teachers’ meetings around what they referred to as formative data. In this context, teachers would administer a common assessment, typically an end-of-section quiz, and come together to discuss their data. Prior to the meeting, teachers would populate a spreadsheet that used a proficiency scale including the following categories: advanced, proficient, partially proficient and unsatisfactory. The teachers would define a range of total scores on the assessment that corresponded with each of the proficiency categories. Here, Alex’s activity was mediated by the historical and institutional factors associated with test scores and proficiency used at Carver.
Prior notions of what students are capable of. The overall student response patterns in the score reports suggested that there was little variation between classes; that is, independent of which type of physics class students were enrolled in, their response pattern was similar. Chris expressed surprise that the pattern was similar for advanced IB students, saying, “I gave it to my IB kids just to see where they were at, you see the exact same thing in their data.” Alex expressed disbelief that students in a lower-track class could have the same response pattern as the students in a higher-tracked class saying,

..if you look at this, my two ELL classes are...that's asinine...there’s no possible physical way the kids...do you know what I am saying? How can we say this is a valid assessment? 80% of my students have very limited language skills. That doesn’t make any sense.

While the common response pattern for all students was anticipated by the research team, familiar with the theory behind learning progressions, the activity at this workgroup meeting suggested that thinking about student ideas in this way was not aligned with teachers’ daily work and internal frameworks. Chris and Alex both expressed views more aligned with the practice Carver used of tracking students by ability into differentially leveled classes based on test scores.

Outcomes

As we designed tools, we focused on how to overcome a problem related to frameworks of student thinking such as dichotomous or misconceptions frameworks, using the learning progression, OMC assessment items, score reports and facilitation as a way to do that. We proposed that these tools would free teachers from a more limited view of student thinking, but in doing so we introduced new limitations. The material nature of the tools constrained teachers, shifting their attention to the performance of particular subsets of students for whom they had
preconceived ideas about ability. While teachers drew on resources from their cultural, social or institutional contexts to make sense of the tools some found the differences between the resources and the tools to be too big, leading to rejection of the tools.

Second Iteration of the of Tools

Following the score report meeting with teachers at Carver, the research team reconvened to debrief. At this meeting, on February 7th, Erin and I summarized the takeaways, revisited goals, and discussed possible adjustments for the score report format and facilitation guide. I shared a general summary about the features of the tools the teachers found useful and Erin shared her perceptions of how teachers related learning progressions to other ways of classifying student thinking (e.g. Bloom’s Taxonomy). She also noted that learning progressions push on the assumptions we make about kids and how we sort them into classes. Looking toward the score report meeting at Mayfield, I suggested framing the conversation around the learning progression more explicitly to help teachers think about what it can offer as a way to view student thinking; to do this by drawing more specifically on the Elevate facilitation guide (Furtak et al., 2014).

At the subsequent meetings on February 14th and 21st we discussed the possible benefits of drawing more closely on Alonzo and Elby (2019) and presenting teachers with hypothetical data “because it makes it less personal”. Erin proposed a tentative plan for the teacher workgroup meeting, to begin with the learning progression and how it works, review mock data, review class level data and then finally review personal data. Eventually the plan to use mock data was eliminated because we weren’t able to produce the kinds of reports Alonzo and Elby (2019) had and we didn’t want to introduce another format into the meeting.

Derek brought up the idea of calculating a mean and providing that to teachers. That would be done by computing a maximum possible score based on choosing the answer option
associated with the highest level of the learning progression for each question and comparing
class means to that. I commented that “we don’t want to reduce to a mean” because I was afraid
it would reinforce some of the less productive frameworks about student thinking; here, Erin
expressed being against “showing [the] mean when it’s not as instructionally valuable”. Derek
countered that “a mean may still be valuable” because we would be using it “with [the] item by
item [report], getting at those ideas of thinking about student ideas differently”. Ultimately no
one pursued calculating the mean for the purposes of the teacher workgroup meeting.

Additional topics that were discussed in relation to iterating on the tools included the
context dependent nature of learning progressions, the significance of migrating learning
progressions out of their intended use, and thinking more about how the learning progression is
or could be used in regular teacher workgroup meetings. We referred back to Alex from Carver
and discussed how the tools could support teachers with different frameworks of student thinking
toward taking up a learning progression view to support teachers.

When we met again on April 4th, members of the team shared newly developed score
reports (Figure 5.3.). These reports were similar in design to those we used at Carver but
reported only on class level data; that is, how students in different levels of physics classes (e.g.
Physics I, Pre-AP, etc.) responded to the items.
Figure 5.3. Score reports for Mayfield
A subset of the research team planned to meet to walk through the score reports and develop the facilitation guide at a meeting on April 6th (Figure 5.4).

Figure 5.4. Facilitation guide from teacher workgroup meeting at Mayfield.
We were all in agreement that it was critical to start the meeting by walking through the learning progression. We developed a detailed facilitation guide designed to be used with teachers on April 10th.

**Design Decisions**

There were just over two months between the initial teacher workgroup meeting at Carver and the second teacher workgroup meeting at Mayfield. During this time a number of decisions were made. I identified two design decisions (Table 5.4) that, according to my analytic framework, had significant, noticeable consequences, about which the team deliberated on and redirected our work (Penuel et al., 2014).

*Table 5.4. Design decisions associated with the iteration of the tools in preparation for the teacher workgroup meeting at Mayfield.*

<table>
<thead>
<tr>
<th>Design Decision</th>
<th>Rationale</th>
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| Create class level reports, where all of the enrolled in a common course would be grouped together, teachers all receive identical reports. | -Depersonalizing the data for teachers may make a personal reaction less likely  
-Support a collective sense making discussion                                      |
| Adapt the facilitation guide to focus more explicitly on the learning progression. Create additional tools, such as item analysis Extend prompts for sensemaking | -Support teacher sensemaking of learning progression.  
-Open up space for teachers to spend more time engaging with student ideas.          |

**Design Decision III**

As soon as Erin and I returned from Carver, we advocated for depersonalizing the data presented in the score reports. The decision was made early on in the redesign to eliminate teacher level data from the score reports. Instead, we planned to present the teachers with class level data, where all of the students enrolled in a common course would be grouped together.
(e.g. Physics I, Pre-AP and AP Physics). Each teacher would now receive identical reports representing the collective data of the group rather than personalized data. We decided to keep the formats from both previously used score reports the same, the first displaying data by item and the second displaying data by class.

**Rationale.** This change was made, in part, as a response to Alex’s reactions to the tools. We hoped that if we depersonalized the data for teachers, their activity would be less focused on a personal reaction based on their own expectations of what their classes could or couldn’t do. We wanted to support a collective sensemaking discussion focused on overall patterns of student ideas rather than personal reactions. The combination of individuals and tools at Carver did not mediate the type of activity we had designed the tools to enable. Changing the interactions of the elements was a necessary next step and as Wertsch (1997) suggested, “…a change in cultural tools may often be a more powerful force of development than the enhancement of individual’s skills” (p. 41).

**Design decision IV**

The research team had collectively decided to revise the facilitation guide to better support teacher understanding of the tools we planned to introduce at the score report meeting. Through discussion, we adapted the facilitation guide to focus more explicitly on the learning progression by 1) Reviewing what a learning progression is, how it is structured and how it might be helpful to teachers 2) Discussing the development of the Force and Motion learning progression 3) Discussing the levels of the Force and Motion learning progression and 4) Discussing OMC items and their relationship to the learning progression. Following this, we planned for time to review and discuss the score reports, their patterns, meaning and curricular significance. In this iteration of the facilitation guide, we added a series of prompting questions
to help facilitate discussion of the score reports. We also developed additional tools to support teachers as they interpreted the tools. This included a handout of item five of the force and motion items which visually mapped the answer options to the learning progression (Figure 5.5).

![Figure 5.5. Force and motion assessment item 5 mapped to the learning progression.](image)

**Rationale.** The decision to restructure the facilitation guide was made in response to several of the observations we made at Carver. The first was that they skipped over the learning progression to look at the score reports first. Our plan to review the learning progression at the beginning of the meeting included handing out a single page copy of the learning progression first, without the data, to help facilitate the discussion without the distraction of the data on the table.

The amount of detail we put into the plan to discuss the structure of the tools was in response to the kinds of questions that came up at Carver when teachers were interpreting and problematizing the tools. We hoped that answering these questions up front might open up space for teachers to spend more time engaging with student ideas. By changing this tool to provide...
additional sensemaking opportunities that seemed to be lacking at Carver, we hoped to enable activity related to student thinking to inform instruction.

Summary of Teacher Conversations about Student Responses at Mayfield

I facilitated the teacher workgroup meeting at Mayfield and was accompanied by another research team member. We met with physics teachers Pat, Jamie and Taylor on their April 10th teacher work day. I began the meeting by introducing learning progressions in general; discussing how they are structured, what they afford, and then handed out the single page version of the adapted Force and Motion learning progression (Figure 5.3, panel a). Following the introduction, I explained the learning progression’s utility as a tool to locate students at levels and think about what instruction would be helpful in moving them forward. I also summarized the development of the Force and Motion learning progression to give teachers a little more context for understanding its development. Together, the group looked at a handout that mapped a single item to the learning progression (Figure 5.5) and I explained that instead of just one right answer and three wrong answers, each of the options is linked to the learning progression and provides information about what students might be thinking.

We looked together at the answer options and I asked teachers to think about what a student who chose each option might be thinking. The teachers responded as follows:

Pat: [a student who chose (a) thinks the ball is] not touching anything, force requires contact.

Teacher: [Option b represents] the biggest misconception. The timeframe of the question and the answer. Students revert to where does the force start. The force is still in there.
Jamie:  If they chose option (b) they would be thinking about residual forces. Leftover.

Pat:  A student who chose (c) understands earth is pulling, understands gravity

Teacher:  A student who chose (d) has the misconception plus reality, plus (b), plus (c).

After the teachers shared their ideas about student thinking, I reiterated the way the OMC items linked to the learning progression. Jamie took some time to carefully study the item and noted that a student might think that the hands could still be touching the ball based on the picture. Taylor added that students “won’t read a ton” and will notice one ball is shaded in and will assume that’s the one being talked about and suggested some edits to the drawing.

As I transitioned to the score reports I talked again about OMC items and how they can help differentiate between what students actually know rather than just if they are right or wrong. I handed out the score reports and asked the teachers to look them over pointing out that, unlike item 5, not all of the items have answer options that correspond to all of the levels of the learning progression. After spending a few minutes looking at the reports, Jamie asked if “you could actually grade [the items] on a proficiency scale?” Neither Pat nor Taylor thought this would be possible.

After teachers had time to review the score reports, I asked them to share what they noticed. Their responses follow:

Jamie:  A lot of level 2s.

Taylor:  A lot of level 3s.

Kate:  Any other patterns?

Pat:  Makes sense that when there’s a level four it’s the lowest percentage.
After the teachers finished sharing their initial impressions, I asked if anything surprised them. Pat was surprised that more students hadn’t chosen level one responses. When no other teachers shared, I asked about the format of the score reports and if there was anything confusing in terms of readability. Pat said no, but asked, “what’s the value of putting two [answer options] for the same level answers on there?” Pat wondered if the answer options could be reworded to include all of the levels and explained that “It starts skewing the data. It’s hard to look at the percentages. It would be easier to delineate if you had four questions with four answers” that corresponded with the four levels of the learning progression. Taylor noted that it would be helpful to have the questions grouped by types, such as boulder questions, throwing questions, questions where there’s actual motion. In response to the grouping suggestion, I explained how Alonzo and Steedle (2008) had broken down the items into four categories: force, no force, motion, and no motion. Taylor said it would be nice to see it broken down according to those categories with all of the items from a single category displayed together in the score report.

Noticing that there was an item on which the majority of students chose a level 1 response option, I asked the teachers to, “Tell me what you think is going on with number 15.” (Figure 5.6).
15. Maria pushes on a heavy rock, but the rock does not move. Why not?
   a. Nothing is moving, so there are no forces acting.
   b. Maria is exerting a force on the rock, but the force from the rock is stronger.
   c. There must be another force on the rock, opposing Maria's push.
   d. The rock is heavier than Maria.

Figure 5.6. Force and motion assessment item 15.

The question stated: Maria pushes on a heavy rock, but the rock does not move. Why not?

Most students chose option (d) the rock is heavier than Maria.

Jamie: Kids know forces are equal and opposite and Maria can change her force, the kids are thinking Maria isn’t pushing hard enough.

Taylor: The kids are forgetting about the normal force.

Next, the group discussed the best ways to display data and I asked what additional information the teachers would need for the data to be actionable. Pat referred back to organizing the questions by type to better understand the ideas students had. Taylor added that it would be nice to know how the levels of the learning progression correlate with the number of conceptual add-ons; that is, the additional ideas students need to demonstrate understanding as they increase in sophistication, further suggesting ranking the questions themselves in terms of difficulty.

Jamie and Taylor both asked for teacher level reports. Additional suggestions included disaggregating Pre-AP and Physics (Pat) and highlighting misconceptions so they could be specifically addressed (Jamie).
When I asked the teachers if it would be useful to use the force and motion items as a pretest for physics students. They said yes, and Pat explained that it could help teachers understand “What am I doing right, wrong, where am I going to improve,” adding that, “We always talk about re-teaching and we never do” acknowledging that the information would be actionable in the following school year rather than in the present. Although originally in agreement that a pre-test would be useful, Jamie added that they “might not get much on a pre-test. Everything might be red (level 1)”. Jamie also suggested that later, midway through the unit, it might be more helpful to use the items to help indicate “where I’d have to go back in again.” I shared that the overall vision for using the learning progression in conjunction with the items would be to use the tools to figure out what kinds of things kids need to know; then, intentionally design activities based on moving students up to the next level on the learning progression.

After studying the score reports again, Pat said that it was interesting that a student “can still answer a question wrong and still be proficient.” I said that “even the wrong answers can still give you useful information.” I wrapped up the meeting and let teachers know I would email the teacher level reports. Jamie’s last thought was “I’m questioning grading on proficiency. I was never really trained on standards-based proficiency grading. It makes me question myself as a grader.”

**How Tools Mediated Teacher Activity at Mayfield**

Design decisions III and IV, to depersonalize the score reports and build in additional structure to the facilitation guide for grounding the learning progression, mediated the activity at Mayfield in important ways. Similar to the analysis of the Carver teacher workgroup meeting, the following analysis will focus on the tools and the activity the teachers engaged with and in.

**Tools**
All of the conversation at the Mayfield physics teacher workgroup meeting was related to the researcher-designed tools. Unlike the teachers at Carver, Mayfield teachers did not mention the standards or their curriculum during the meeting. In addition, they spent more time interacting with material aspects of the tools. For example, they looked carefully at both questions five and fifteen from the force and motion items. The redesigned tools supported teachers in activity oriented toward the tools; in addition, teachers spent more time in conversation about student thinking.

**Activity**

**Providing feedback, interpreting, and problematizing.** At Mayfield teachers engaged in providing feedback, interpreting, and problematizing, but not rejecting as teachers had at Carver. *Feedback* was mostly provided in response to questions I posed to teachers. For example, I asked teachers, “How do you want the actual breakdown of scores?” and Jamie said, “[I] want it to be with a comparison against Pat’s students for example, to know what Pat is doing well and learn from [Pat]”. Here Jamie provided feedback that made a case for the relevance of teacher level reports, the desire to look at the data from their own classes.

When the teachers at Mayfield were *interpreting*, their focus was on the data rather than on the tools and how they worked. As described in the meeting summary, teachers interpreted the data when I asked them “Overall what do you notice?” and they replied, “A lot of level 2s” and “A lot of level 3s”. They also interpreted student thinking. For example, when we were discussing item 15 Jamie said, “Kids know forces are equal and opposite and Maria can change her forces. Kids [are] thinking Maria isn’t pushing hard enough.” Here Jamie tried to make sense of why a student would have chosen a particular answer option. Here the materiality of the score reports mediated activity in two ways. Providing a handout of a particular item, mapped to the
learning progression, influenced what teachers paid attention to. When they paid attention to specific answer options I probed them to tell me what they thought their students might be thinking. During this meeting, the bulk of the discussion of student ideas happened when we focused on a particular item as we did with item five.

When the teachers at Mayfield were problematizing the tools, much like the teachers at Carver, they were questioning why each item didn’t have answer options that corresponded to all four learning progression levels. They also problematized the way the items were grouped in the score report, and Taylor wondered if they could be grouped “...by similar types of questions. Boulder questions, throwing questions, things where there’s actual motion.” Similarly, activity at Carver centered on aspects of the items. The material nature of the tools and the way they displayed the items linked to the learning progression focused teachers on some of the constraints of the tools such as the fact that not all items had answer options that corresponded to all four levels of the learning progression. The teachers at Mayfield engaged with the force and motion items more deeply than the teachers at Carver. They problematized specific items, getting to the level of the way a ball was shaded in in a figure and what that might indicate to students.

**Frameworks for student thinking.** The goal of the design decisions that affected the iteration of the tools were to better support teachers in participating in activity that engaged them in a resource-based discussion of student thinking mediated by the tools. Foregrounding the learning progression did seem to mediate more productive forms of activity; that is, there was more interpretation related to student ideas and no instances of rejection. Unsurprisingly, teachers continued to draw on their own frameworks for thinking about student ideas. At Mayfield these included misconceptions, dichotomous thinking, proficiency and prior notions of what students are capable of.
**Misconceptions.** At least one teacher mentioned misconceptions in relation to interpreting the responses to question five. In this example one of the teachers noted that the biggest misconception was contained in choice (b) when students think the force is still acting on an object (like a hand on a basketball) even when the hand is no longer touching the ball. Later, when I asked teachers what information they would need in the score reports to make the information actionable, Pat said “Highlighting some kind of misconception. Addressing specifically those misconceptions instead of glossing over.” Here, Pat indicated an approach to instruction that involved identifying and addressing misconceptions with students, suggesting a historical framework that influenced Pat’s thinking about student ideas.

**Dichotomous thinking.** Dichotomous thinking came up less frequently at Mayfield than it had at Carver. It wasn’t until the end of the meeting that Pat noted “[a student] can still answer a question wrong and still be proficient”. This particular example will be discussed below, but it suggested that Pat’s view was that any option other than the one corresponding with the highest level of the learning progression was incorrect. When Pat made that comment about the “wrong” answer, I replied “…even the wrong answers can still give you useful information.” reinforcing the dichotomous view even though we were talking about OMC items. Here the tool supported activity that placed the two frameworks in tension with each other.

**Proficiency.** As it did at Carver, proficiency came up several times at Mayfield. Right after I handed out the score reports, Jamie asked “with these could you actually grade them on a proficiency scale?” This was another attempt to make sense of the unfamiliar learning progression in the context of the familiar proficiency framework. Mayfield focused on proficiency based grading school wide. They used the same categories as the teachers did at Carver but their practice was to grade students on a four-point scale with each point
corresponding with one of the proficiency categories: unsatisfactory, partially-proficient, proficient, and advanced. In retrospect, due to the institutional context and noting that the learning progression also was organized into four levels, it is unsurprising that the tool would mediate activity related to a proficiency scale. Pat’s comment discussed above “[students] can still answer a question wrong and still be proficient” was evidence of this. Pat was considering both the dichotomous and the proficiency view. In the dichotomous view level three would be incorrect, on the proficiency scale it would be rated as proficient.

Towards the end of the meeting Jamie shared, “I’m questioning grading [on] proficiency. Never really trained on standard-based proficiency...It makes me question myself as a grader.” This comment suggested that Jamie experienced tension through interaction with the tools and that tension was related to the way the tools suggested viewing student ideas. This may have been in conflict with Jamie’s about prior beliefs and/or practices.

Prior notions of what students are capable of. At Mayfield, evidence of this framework came up several times, but in a different way than it had at Carver where teachers expressed ideas about their expectations for what certain groups of students (e.g. English language learners or advanced students) were capable of. At Mayfield several comments suggested that teachers held deficit views of all students. This was especially true for Pat who made comments that included, “[it] makes sense that when there’s a level four option it’s the lowest percentage”, “I thought there’d be more level 1s” and “Putting Pre-APs with regulars wouldn’t be useful”. Pat’s expectations were that students wouldn’t chose answers that corresponded with the most sophisticated understanding and was surprised that more of them hadn’t chosen answers that corresponded with level one. Considering that this assessment was
given after students had experienced instruction related to force and motion, Pat’s expectations remained low.

Jamie also made a comment that was suggestive of a deficit view saying “[you] might not get much on a pre-test. Everything might be red (level 1).” This comment was made in response to my asking about the usefulness of the force and motion items at the beginning of the unit. Jamie’s expectation was that students would come to physics class with a level one understanding, even though they experience instruction related to force and motion in middle school. The comments Pat and Jamie made are suggestive of features of the social, cultural, historical and institutional context in which worked. Both Pat and Jamie identified as White and the majority of their students were non-White. Students from underrepresented groups in the STEM fields are often subjected to deficit framing in school where their difficulty with school learning is attributed to traits inherent to individuals, families and communities (Jackson, Gibbons, Sharpe, 2017).

**Actionability.** An additional category of activity was recorded at Mayfield, actionability. Early in the meeting I asked teachers what information they would need in the score report to make it actionable. Their replies were mainly related to the format of the tools. Later in the meeting, in response to a question I posed about how using the items as a pre-test might be beneficial Pat noted that it could be helpful to have the information from the assessment to know, “what am I doing right, wrong, where am I going to improve. We always talk about re-teaching but never do.” Jamie indicated that “Using the items midway through the unit might help to indicate where I’d have to go back in again.”
While the activity related to actionability only scratched the surface of what could be possible, the redesign of the tools created an opportunity to start a conversation which didn’t happen at Carver.

**Outcomes**

Teacher activity at Mayfield was more aligned with our goals. Teachers focused on the researcher designed tools, providing feedback, interpreting and problematizing. They also engaged in activity related to student thinking, and began to discuss the idea of instructional action. While both individuals and tools are responsible for mediated action and must be considered, focusing on the tools for the purposes of understand isolating elements can “bring their insights to bear” (Wertsch, 1997, p. 26). As such, the design decisions we made when we iterated on the tools following the workgroup meeting at Carver included depersonalizing the data to provide school level score reports to teachers and building more structure into the facilitation guide including foregrounding the learning progression.

The first four discussion points on the facilitation guide were designed to explain learning progressions generally, the development of the Force and Motion learning progression specifically, the levels of the learning progression, and the significance of the OMC items. This scaffolding provided clarity on many of the points that resulted in unproductive tension at the Carver meeting. It also helped to build the basis of a shared understanding among the workgroup and opened up space to discuss student thinking. Specific additions to the facilitation guide, such as collectively looking at an assessment item, also supported teachers in activity around student thinking.

While the newly designed tools enabled activity more aligned with our goals, it also introduced new constraints. These included not specifically leaning on the ideas detailed in the
learning progression to make sense of student thinking. For example, when the teachers described what ideas they though a student had if they chose a particular answer option, as they did for items five and fifteen, I did not relate their interpretations back to the learning progression. On item fifteen, the question that stated *Maria pushes on a heavy rock, but the rock does not move, why not?* the majority of students chose option (a) *nothing is moving, so there are no forces acting* which was associated with level one of the learning progression. The teachers discussed why they thought students chose that option. Jamie stated “Kids know forces are equal and opposite and Maria can change her force. Kids [are] thinking Maria isn’t pushing hard enough.” The next step for me, as the facilitator, would have been to relate Jamie’s interpretation to level one of the learning progression which indicates that a *student understands force as a push or pull that may not involve motion*. From there we could have had a conversation about whether or not teachers agreed that choosing a level one response should be associated with that understanding and why. Only then could we begin to talk about the instructional responses that would help students move to a level two understanding.

**Case 1, Summary**

The preceding case study, Tools to Support Teacher Activity in the Context of Force and Motion, was designed to respond to both research question one *How can researchers design tools to support teacher activity that privileges student thinking to inform instruction?* and research question two *How do the tools of the activity system mediate activity oriented around using student thinking to inform instruction?*. This case followed researcher designed tools through two iterations. In the first iteration, the tools were designed hastily, in just ten days’ time. The research team attempted to balance the tension of providing quality tools necessary to support teacher activity with the need to honor our commitment to producing timely results. The
teachers engaged in activity mediated by the tools but were defensive. They drew more often on alternative frameworks of student ideas rather than the new form of activity the tools were designed to enable. We learned important lessons from the physics teacher workgroup at Carver and incorporated those lessons into our next iteration.

The teachers at Mayfield engaged in activity mediated by the tools, and were more open to both the tools and the ideas they contained. The teachers did engage in activity related to student thinking and scratched the surface of a conversation about instructional action. While we made progress in the design of tools to support teachers in privileging student thinking, we missed opportunities too, and those missed opportunities informed our future work.
Chapter 6. Results: Tools to Support Teacher Activity in the Context of Energy

In the following chapter, I will present the results from Case 2, Tools to Support Teacher Activity in the Context of Energy. To answer research question one, *How can researchers design tools to support teacher activity that privileges student thinking to inform instruction?*, I focus on the tools designed by the research team to facilitate two specific workgroup meetings, as well as the audio recordings of the activity that took place at those enacted meetings. To answer research question two, *How do the tools of the activity system mediate activity oriented around using student thinking to inform instruction?*, I draw on the coded transcripts of those same teacher workgroup meetings to analyze the specific activity in which teachers engaged. In my analysis, I found that when used together in combination a well structured facilitation guide, student work and a framework of student ideas seemed to mediated teacher activity related to student thinking to inform instruction.
Context

The two physics teacher workgroup meetings at the center of this case took place during the 2017-2018 and 2018-2019 school years (Table 6.1).

*Table 6.1. Timeline of physics teacher workgroup meeting activity, Case 2.*

<table>
<thead>
<tr>
<th>Activity</th>
<th>2017-2018</th>
<th>2018-2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explore Student Ideas</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Design Tasks</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Practice Using Tasks</td>
<td></td>
<td></td>
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<tr>
<td>Enact Tasks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reflect on Enactment</td>
<td></td>
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</tr>
</tbody>
</table>

Chris, Andy and Alex, participants from Case 1, were all part of the physics teacher workgroup during the focal meetings in Case 2. Avery joined the workgroup in the 2017-2018 school year and Blair was part of the workgroup for one year only, during the 2017-2018 school year.
The first meeting took place in January 2018. The workgroup was completing the final stage of the FADC, *reflect on enactment*. The focus of our work together during the fall of 2017 was the collaborative design of a formative assessment task referred to as *the skateboarder*.

The teachers decided to enact the formative assessment task twice during their unit on energy, both as a pre and post-assessment. Following the post-assessment enactment in January, I had expected that teachers would collect student work samples to bring to the workgroup meeting on January 25, 2018.

The second meeting took place during the fall of 2018. The plan was to enact the *explore student ideas* stage of the FADC. In this meeting, teachers would be exploring the student ideas that had come up in the previous year’s enactment of *the skateboarder* to support them in the future re-design of that task for enactment in the new school year.

I chose to focus on these two meetings because the research team had designed a new tool to support teacher activity related to student thinking, the Modeling Energy Flows learning progression between the first and second meetings. In both meetings, the goal was to support teacher activity related to student thinking to inform instruction centered on the same formative assessment task, the skateboarder. The addition of this new tool provided an opportunity to investigate how it might enable teacher activity toward student thinking to inform instruction.

**Reflect on Enactment, January 2018**

As I described above, the teachers had focused their work during the fall of 2017 on the collaborative design of the skateboarder formative assessment task. Beginning in August 2017 the teachers explored student ideas related to energy, developed learning goals, and designed a formative assessment task. In January 2018, teachers planned to enact the task as a post-
assessment. This was followed by the reflect on enactment stage of the FADC at the January 25th, 2018 meeting.

**Design of Tools to Support Teacher Activity**

The facilitation guide for this meeting (Figure 6.1) was designed through a collaborative process by members of the research team and on the basis of prior research (Furtak, 2018).

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**Meeting 5: Sample Facilitation Guide for Making Inferences and Identifying Next Steps**

<table>
<thead>
<tr>
<th>School</th>
<th>Date</th>
<th>Time</th>
<th>Lead Facilitator/s</th>
</tr>
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</table>

**Goal:** Make inferences about the tool and student thinking.

**Materials:**
- Student work
- Representations of student learning created or used in Explore phase.

1. **Reminder about norms for looking at student work**
   a. Our focus here is on student thinking and we should try to refrain from making judgements.
   b. We should be looking for a range of student ideas not just those that are right or wrong.

2. **Looking at student data**
   a. Clustering activity
      i. In this activity we will group student ideas into multiple piles (at least 2, 4-6 are ideal)
      ii. The group should make a plan for what criteria they will use for each pile before they start sorting
      iii. After the student work is sorted, teachers can talk about the differences between each of the pile focusing on what students understand in each pile.

**Coach’s Note:** In the sorting activity, if there are too few piles, it may mean teachers are not attending to meaningful differences in student responses and may be focusing too much on correct vs. incorrect. Too many piles may mean teachers are attending to minor differences that may not be related to the learning goals. It is often helpful to have post-it notes or index cards handy to label the piles. It can also be helpful to start with the upper anchor and lower anchor ideas as the first piles to make it easier to fill in the middle.

3. **Instructional action and tool revision**
   a. Consider the following:
      - How did this tool meet your goals?
      - How did it fall short?
      - How could it be re-designed?
      - What general principles can they use going forward?
   b. How did the enactment work with students? Make time to reflect on it here.
      - How might the enactment or the structure of giving the FA have had an impact?
   c. Identifying instructional action and feedback
Coaching note: It can be difficult for teachers to determine instructional next steps. While feedback is important, we try to discourage re-telling as the default plan. If the clusters of student ideas are arranged in a progression, it can be helpful to ask what teachers would do to move students to the next cluster. Interesting patterns can emerge here. For example, one group of teachers decided to sort through the lowest anchor pile. At first glance, it was hard to glean any meaningful information from the answers themselves as they were so scattered and often blank or only a few words. The teachers realized that this pile was disproportionately made up of their emerging bilingual students. This led them to the realization that this group of students would need more language support. For the next activity, they decided to build in time for students to first discuss the question and then provide optional sentence frames on the board.

4. Setting goals for the next cycle
   a. What other goals have we identified for the next cycle?

Coaching note: In addition to content goals, at this point, teachers may have also identified specific teaching practices they want to work on in the next cycle, such as in the language supports example above. It may also be a non-content specific goal, such as a cross-cutting concept or scientific practice, that teachers want to carry through and build upon.

5. Looking ahead

Coaching note: After the first cycle, we have a better idea of how long it will take to go through the whole process. Some groups like to spend a lot of time sensemaking around the content, others like to design and revise tools. Sometimes the reflective process requires multiple sessions. When selecting the next topic, the sense of time will be important as it will often be the case that we need to skip a unit or two ahead. On the other hand, if the topic is one that stretches across the year, the sensemaking and exploring student ideas may go quickly and teachers can get into design almost immediately.

Figure 6.1. Facilitation guide from physics workgroup meeting on January 25, 2018.

A subset of the team involved in the facilitation of professional development, including PI Furtak and research team members, met weekly to reflect on and revise professional development tools, including facilitation guides. This particular facilitation guide included the addition of coach's notes which were designed to guide facilitators through each step. While the details of the development of the facilitation guide are beyond the scope of this case analysis, we drew heavily on prior research from the Elevate project and the FADC (Furtak & Heredia, 2014;
Furtak et al., 2016; Furtak, 2018) where the facilitation guides were originally developed and revised based on research findings, to inform this work.

As it was designed, the facilitation guide was divided into five parts. It began with norms to remind teachers that we should focus on student thinking and refrain from making judgments when looking at student work (e.g. van Es, et al., 2014). In addition, we planned to support teachers as they looked for a range of ideas rather than just those that are right or wrong. This structure was built to help teachers move away from general claims like “my students didn’t get it” in favor of drawing on evidence from their student work such as, “my students don’t understand that potential energy is related to position, and I know that because they said the skateboarder has no energy when not moving.” Following this reminder, our intention was to guide teachers through a process of looking at student work through the piling activity, described in Chapter 3, where teachers would arrange a stack of student work into at least three piles based on evidence of student thinking. Our routine of using at least three piles was intended to require that teachers create categories beyond right and wrong to attend to the substance of student thinking.

Next, we planned to ask teachers to think specifically about whether the formative assessment task did or did not meet goals, how the enactment worked with students, and what instructional action or student feedback they would plan for. Finally, the planned meeting would end with goal setting for the next cycle of the FADC.

**As designed: Opportunities for activity related to student thinking.** As it was designed, the first three parts of the facilitation guide provided opportunities for activity related to student thinking. The first part reviewed norms for a resource-based framework of student ideas, the second part supported identification and categorization of particular student ideas, and
the third part created an opportunity to reflect on the task and its enactment. It also provided space to discuss instructional action and feedback.

**Enactment of Tools**

I arrived at Carver to facilitate the meeting, having communicated with teachers previously that they would be bringing student work; however, when I arrived, only Chris had student work samples. As described, the structure of the facilitation guide called for a focus on student thinking via the piling activity, which I did not enact. Instead, I asked teachers general questions such as “So where’s everybody else at?” and “What’s useful in terms of talking about the data?” I did this because only Chris had brought student work to the meeting and most of the teachers had not yet enacted the skateboarder as a post-assessment task. As designed, he planned the piling activity as designed asked teachers to make piles from their own student work, and we had not discussed variations of that routine if student work was not available. Here, my activity was mediated by the tool, the material facilitation guide, as well as the context. I had planned to enact the piling activity; however, the context mediated my action in a different direction.

I followed this by enacting part three of the facilitation guide, which focused on instructional action and tool revision. I asked the teachers, “What generated good information and what generated not useful [information]?” While not all of the teachers had enacted the post-assessment, they had all enacted the pre-assessment. As these two versions were quite similar, I proceeded with this portion of the facilitation guide as designed assuming teachers could draw upon either or both of these enactments.

**As enacted: opportunities for activity related to student thinking.** My choice to skip the piling activity resulted in missed opportunities for the workgroup to engage in activity related to student thinking. The enactment of the third part of the facilitation guide did provide
opportunities for activity related to student thinking; however, as I did not draw on ideas from
the student work that Chris had brought to the meeting as part of this activity, teachers’ main
focus was the task rather than student ideas. While teachers did discuss student ideas as part of
their activity, there were only four isolated instances where this occurred.

**Teacher Activity**

The four instances where teachers discussed student responses were stand alone examples
where a student response was mentioned, but no sustained conversation followed. I coded each
of these instances as examples of restating and interpreting student ideas. In two of the examples,
the activity ended with the interpretation of the student idea. In the other two examples, the
interpretation informed potential revisions to the task.

**Restating and interpreting.** Blair and Andy each referred to student ideas in the context
of the skateboarder formative assessment task. One of the questions asked students, “Without an
applied force, will the skateboarder ever exceed their original height? Explain.”

Blair: I asked them would the skater just keep going and they’re like, no, why would he
stop.

Alex: Friction’s one of those...

Blair: It took a while, they came up with friction, what happens, trying to get them to
think about the heat it creates with the bearings, a couple skaters they’re like, a
couple of them had first hand experience.

In this example, Blair replayed a classroom interaction, as a general recollection of the
class’ understanding that friction will eventually cause the skateboarder to slow down and stop if
no additional force is applied. Blair asserted that, although friction wasn’t explicitly addressed
through instruction, students understood it and some student understanding was based on real
world experience. While Blair did reference students’ general understanding of friction, there is no specific interpretation of what students understood about it. The question was designed to elicit understanding of energy transformation. From Blair’s retelling it is impossible to know if students understood that it was through the mechanism of friction that energy was transformed from kinetic to thermal. Without specific examples of student ideas and a framework in which to locate them, this idea was not discussed any further and was not used to inform any instructional decisions.

In the second instance, Andy added an additional example of student thinking related to friction,

No, I used that to talk about conservation of energy. Even though we didn’t talk about friction necessarily, they understood that unless you add a force, that’s adding energy to the system, and so without and force the energy stays the same.

Here, Andy made an inference that students had an understanding of the conservation of energy; that even if the skateboarder slows down and has less kinetic energy, the total energy in the system stays the same if no additional force is applied. Again, as Andy referred to a general recollection and not a specific student idea, it was difficult to know what exactly students understood about the conservation of energy. For example, what did it mean that students understood that “the energy stays the same?” Did they understand that it is being transformed within the system? These are the kinds of questions a framework of student ideas and artifacts of classroom practice such as student work (e.g. Kazemi & Franke, 2004) or video of classroom interactions (e.g. van Es & Sherin, 2002) could have helped the workgroup explore in greater depth.
Blair and Andy both restated and interpreted their students’ ideas; however, these examples were not pursued or used to inform further discussion in the workgroup. Without the routines of the FADC to organize the workgroup and tools, such as a resource based frameworks of student ideas (i.e. learning progressions), to support understanding about where the kinds of student ideas Blair and Andy were sharing were located, the activity related to student thinking stopped at the level of interpretation. As the teachers were not drawing on material examples of student work, they did not have specific student ideas to attend to. The workgroup conversation did not draw on either example, raised by Andy or Blair, to inform task redesign or instructional decisions.

**Restating and interpreting to inform instruction.** In two examples, Alex and Avery restated and interpreted student responses that were used to support instructional decisions in the context of task redesign. In the first example, the workgroup activity centered around the first portion of the skateboarder task (Figure 6.2).
In panel (a) of the pre-assessment, the task asked students to label a model with the points where kinetic and potential energy were at their minimum and maximum values. In panel (b), the post-assessment, students were asked to label a new model and describe the differences between their initial and final models.

In reference to these two versions of the task Alex said, “I had one kid that just put max and min, so now your comparison would be that you understood maximum and minimum, but you didn't understand where potential and kinetic went.” This reference to a student response described how a student labeled the diagram with the abbreviations “max” and “min” as the task had instructed them; however, they did not attach those terms to the type of energy (kinetic or potential). Alex interpreted this to mean that the student did not understand where to put those forms of energy. In the context of the larger conversation, this student response provided evidence to Alex that the question “was not the best” and “it doesn’t have any content and I don’t think that it’s relevant to the test, to be honest.” In addition, in terms of comparing an initial and
final model Alex said, “Honestly, they shouldn’t be able to compare, the first one was crap, the second one was good, how else would you compare them?”

In this example, Alex drew on historical and institutional resources related to the purposes of assessment. Stating that the modeling item on the assessment “doesn’t have any content” and is not “relevant to the test” suggested that Alex viewed the purpose of assessment as a tool for measuring content knowledge alone, not useful for assessing student skill related to scientific practice. This view was more in line with historical frameworks of science education rather than the new vision laid out in the Framework and detailed in the NGSS and helped locate both the tools and Alex on their developmental paths (Wertsch, 1997) Rather than redesigning the task to create alternative opportunities for students to share their thinking, Alex wanted to eliminate the question all together. Redesigning the task in this way would serve to close off rather than open up opportunities for students to share their thinking on the task.

The last instance where a teacher discussed a student response was toward the end of the meeting, when the redesign of the task was being discussed. Avery said,

Ok, true, whenever he’s in the middle and he’s just sitting there, I think we need little lines showing movement ‘cause my kids got stuck, they’re like ‘that’s when his motion is going to happen, he’s going to have zero kinetic, ok he is moving, ok, hold up’, so if we had little lines behind him when he’s down there, that would be nice.

Here Avery restated and interpreted student ideas and connected those ideas to the redesign of the task. Avery’s interpretation was that students did not understand when and where the skateboarder in the model was moving. The suggestion put forth was to edit the picture to indicate motion so the task could better elicit student ideas about the energy of the skateboarder at different positions on the halfpipe. This example was the only one in this meeting where a
teacher used evidence of their students’ thinking to inform a decision toward increasing opportunities for students to share their ideas.

Summary, January 2018

While the tools were designed to support activity related to student thinking, they did not enable me to enact them as they were designed. In addition, I did not draw on the student work that was available at the workgroup meeting. This constrained the amount of attention paid to student thinking during this workgroup meeting. The examples I described provide evidence that the tools did mediate some activity related to student thinking. The specifics of that activity; however, focused more on recalling students’ general responses and less on the specific substance of their ideas. Without tools such as artifacts of student work and a framework to interpret the ideas found in that work, the activity was constrained to the level of general interpretation. In two of the examples, those shared by Alex and Avery, the student responses or ideas discussed by teachers were used to inform the potential redesign of the skateboarder task; however, particularly in the case of Alex, this was not necessarily in ways that increased opportunities for students to share their ideas through the task. Here, a framework of student ideas could have enabled teachers to provide more opportunities for students to share their ideas because they would have had a reference point for what more sophisticated student responses might look like.

Development of the Modeling Energy Flows Learning Progression

Between the January 2018 and September 2019 workgroup meetings at Carver, the research team developed the Modeling Energy Flows learning progression, as described in Chapter 3. This learning progression integrated all three dimensions of science learning: science practices, crosscutting concepts, and disciplinary core ideas, that are outlined in the Framework
for K-12 Science Education (NRC, 2012). It focused on tracking the flow of energy in, out, and within a system through the use of the practice of modeling. As a tool for teacher professional development, the Modeling Energy Flows learning progression has the potential to support teachers as they begin to explore the instructional shifts required to support students in reasoning about phenomena in the ways described by the NGSS. It does this by providing a hypothesized trajectory of the kinds of ideas we would expect students reasoning at the level of the NGSS to provide. As such, it serves as a tool for designing instruction and assessment opportunities that makes space for students to share those ideas. Teachers can use the ideas in the learning progression as they design instructional opportunities by considering the types of experiences students would need to participate in to be able to share the ideas detailed in the learning progression. Later, when evaluating responses to assessment items, teachers can use the learning progression to locate their students’ ideas and consider the instructional next steps that will help them reason at higher levels.

Explore Student Thinking, September 2018

The September 2018 physics teacher workgroup meeting was the second Aspire meeting of the school year. The workgroup had begun to explore student thinking related to energy in the previous meeting and planned to continue that work on September 25th in the context of the skateboarder formative assessment task.

Design of Tools to Support Teacher Activity

In addition to the facilitation guide to support the explore student thinking stage of the FADC, the research team designed tools to mediate teacher activity in the context of the September 25, 2018 workgroup meeting. The facilitation guide for the FADC stage explore student thinking (Figure 6.3) was designed through the same collaborative process by members
of the research team as described above. While the two facilitation guides were similar in format, the depth of detail in the September 2018 version was much greater.

<table>
<thead>
<tr>
<th>FG 02 - Exploring Student Ideas</th>
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<tbody>
<tr>
<td>School</td>
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**Materials**

*Modeling Energy Flows Learning Progression*

Modeling Energy Flows LP-Look Fors

Student work

NGSS Performance Expectations (in color for binder)

**Goals**

Teachers are introduced to PE specific learning progressions

Teachers use student work to explore PE specific learning progressions

1. **Identifying PE in yearly plan**
   i. For (your discipline), we have identified two NGSS Performance Expectations, aligned with district priority standards, that we will focus on in our work this year. Based on what you’ve told us, these are the energy relevant performance expectations we have aligned with your curriculum:
      1. Bio
         a. **HS-LS1-7** - cellular respiration
         b. **HS-LS2-5** - PS and CR in Carbon Cycle
      2. Chem
         a. **HS-PS3-4** - transfer of thermal energy
         b. **HS-PS1-4** - bond energy and chemical reactions
      3. Physics
         a. **HS-PS3-2** - PE/KE
         b. **HS-ESS2-3** - Convection currents
   ii. We have a pretty good sense of when we think you’ll be teaching units aligned with these PEs, and we just wanted to check these timelines with you to be sure we’re on the same page [insert timeframes here]:
      1. Bio
      2. Chem
      3. Physics
   iii. If this timing changes, we’d appreciate a heads-up as soon as you know so we can be sure the assessments are ready when you need them.

2. **PE specific learning progressions**
   a. At our last meeting we unpacked the Modeling Energy Flows learning progression. Let’s discuss any questions that have surfaced since the last time we met.
b. In addition to the Modeling Energy Flows learning progression, we have developed performance expectation specific learning progressions to help us work specifically with ideas students have as related to the PEs. As a reminder, performance expectations are learning goals that include all three dimensions of the NGSS (DCIs, SEP, CCC). You might have multiple PEs in a single unit or an entire unit devoted to one PE.
   
   i. Let's take look now at the PE specific LP with specific attention to what we are calling "look fors;"
   
   1. Let's talk about what we mean by "Look-Fors" - these are the kinds of things we might expect to see in student work or hear students say at that performance level.

   ii. We have populated this column with some ideas and hope to get your input on what evidence you would look for in student work to identify student ideas at each level. Our plan is to generate ideas with multiple groups of teachers so that we can create a version that incorporates all of your ideas.

   iii. Take some time to review the "look fors" before we dive into student work.

c. Last year, you may have developed formative assessments that aligned with the performance expectations. Although these formative assessments were not designed to align with the learning progression it's helpful to look at student responses and the task itself to see how they do (or do not) align with the learning progression.
   
   i. Read through each of the student work samples, and highlight evidence you can use to help locate these student ideas on the learning progression, knowing that each student work sample may have characteristics of multiple levels.

   ii. Once you have determined where you would locate each piece of student work we will discuss our thinking as a group.
   
   1. What evidence did you highlight to locate students at each level?
   
   a. This evidence will be used to populate our "look fors".

   2. What additional evidence, not elicited by the task, would help us locate students at each level?

d. Now that we have populated the "look fors" we can turn our attention to the task.
   
   i. We will focus on this more in our next meeting but let's think about our initial ideas around task design.

   ii. If we were to re-design the task, how might we provide opportunities for students to provide the types of evidence we are looking for in each of the levels.

   iii. In future visits, we will talk about how we can map instruction to the performance expectation specific learning progression and how we can use the learning progression to provide students with instructional opportunities that will help them progress toward more sophisticated understandings.

Figure 6.3. Facilitation guide from September 25, 2018, physics teacher workgroup at Carver.
In our design, we divided the facilitation guide into three main parts: locating the energy performance expectations in yearly plans, exploring the performance expectation specific learning progressions, and logistics. We began by asking teachers to identify the performance expectations in their yearly plan. The purpose of this activity was to help the research team set planning goals for the year based on where in the curriculum teachers felt those focal performance expectations might fall. Next, we planned to introduce teachers to a new tool, the performance expectation specific learning progression (Figure 6.4).
Figure 6.4. Performance expectation specific learning progression.

This tool was designed to support teacher use of the Modeling Energy Flows learning progression that teachers had been introduced to at the previous meeting. It combined the...
Modeling Energy Flows learning progression with space for identifying *look fors*; defined as the evidence a teacher might find in student work related to a performance expectation at each level of the learning progression. This tool had the potential to address the fact that learning progressions on their own are not necessarily ready for use in classrooms with teachers (Gotwals, 2012). One of the goals of the teacher workgroup meeting was to populate the list of look fors. The research team had generated a preliminary list, and we planned to ask teachers to review a preselected set of student work in order to help identify some of those specific look fors. In addition to mediating teacher activity related to student thinking, one of the goals for this work was to help teachers connect the less familiar learning progression to the more familiar NGSS performance expectation their previous work with the project had focused on. The materiality of the learning progression with look fors was designed to focus teacher attention on specific aspects of student ideas that could align with the learning progression (Wertsch, 1997).

Following the introduction to the performance expectation specific learning progression, the facilitation guide called for teachers to read through the student work samples and highlight evidence that could be useful to help locate student ideas on the learning progression. In this way, we designed for teachers to interact directly with student ideas. Next, we planned for the teachers to participate in a group discussion to link highlighted student ideas to the learning progression, identifying look fors along the way. In addition, we planned for teachers to identify any additional evidence they would want the task to elicit if it were redesigned with the learning progression in mind. Here, we planned for the teachers to move back and forth between the student work samples and the learning progression; to mediate activity that linked the two. The final portion of part two asked teachers to consider the ways they might redesign the task to provide opportunities for students to share evidence of their thinking as described by the learning
progression. The design of the tools was intended to help support teachers in a conversation about the kinds of instructional action this information might lead them to take.

**As designed: opportunities for activity related to student thinking.** As it was designed, the second part of the facilitation guide provided opportunities for activity related to student thinking to inform instruction. The performance expectation specific learning progression was designed to mediate teacher activity including the identification of evidence of student thinking in student work samples. Once the student ideas were identified, the tools were intended to support teachers as they identified the specific ideas they would look for with relation to the learning progression, making a link between the levels of the learning progression and the ideas teachers would look for in student work. The activity would then focus on thinking about instruction through task redesign.

**Enactment of Tools**

As I began the meeting, I skipped over the first part of the facilitation guide as I had already collected information about where the focal performance expectations were located in the teachers’ curricula at a previous meeting. Instead, I started by handing out the performance expectation specific learning progression and the student work samples. I deviated slightly from the design in response to a teacher request that we go through a work sample together instead of look at them individually. Together, the teachers and I discussed specific aspects of two of the student work samples in great detail. The conversation included teacher discussion of task redesign.

**As enacted: opportunities for activity related to student thinking.** I enacted the September 25, 2018 teacher workgroup meeting with greater fidelity to the design than I had at the January 25, 2018 meeting. Two factors made it possible for me to enact the facilitation guide
as designed: first, pre-selecting the student work guaranteed that we would have student ideas to anchor our activity. Second, the performance expectation specific learning progression provided a framework to locate student ideas, providing a way to structure the activity. The plan to bring several pre-selected student work samples, afforded the workgroup with the opportunity to discuss artifacts of student work which can be a productive way to focus teacher attention on student ideas (Kazemi & Franke, 2004). Enacting the facilitation guide as designed, relying on this material tool, enabled teachers to engage in activity around student thinking.

**Teacher Activity**

Unlike the January 2018 workgroup meeting, where there were four isolated instances where student ideas were mentioned, at the September 2018 meeting there was sustained activity centered on multiple student ideas from the student work samples. Due to the difference in the way the activity flowed, I will present the following sections organized by the two central episodes where teacher activity related to student thinking. Each episode was defined as having a clear beginning and end, a focus on a single student work sample and occurred consecutively.

**Episode 1: “Because once they hit the middle of the ramp, then they become equal”**.

As described above, I had handed out the student work samples and in response to a teacher request we looked at a single artifact together (Figure 6.5).
Figure 6.5. Student work sample supporting teacher activity at the September 25, 2018 workgroup meeting as described in episode 1.

The workgroup reviewed the entire task and the conversation proceeded as follows:

Chris: ..if we’re just looking at the KE and PE stuff, they’re spot on.

Andy: What was it that you called…?

Chris: So I would give that a level three.”

Kate: The mechanisms?

Andy: Yeah, the mechanisms. I don’t see anything about mechanism on her, but we also didn’t ask them

Kate: Right, that’s…

Chris: We didn’t ask them
Avery: Yeah. That’s a problem.

Kate: That’s the other thing we can talk about. How does this tool give opportunities for kids…

Chris: However, they do talk about a mechanism at the bottom where they are going through total energy being the sum of potential and kinetic.

Here, Chris referred to the specific student response “Because once they hit the middle of the ramp, then they become equal (PE and KE) to total energy.” as evidence of the students’ understanding of the mechanism. The workgroup engaged in an extended conversation in an attempt to make sense of and interpret this particular student response. The result of that interpretation was that the student response suggested an understanding of kinetic and potential energy not being equal to each other but together being equal to total energy.

Following the interpretation, Avery said “I’d give this person a two.” This statement was a revision of Chris’s previous assignment of the student’s idea as a level three response. To follow up I read the characteristics of a level two response out loud and asked, “So, what evidence does this student show that they understand an increase in one form and a decrease in another form? Where, tell me what you’re seeing there.” Andy pointed back to the model where the student had identified where the maximum and minimum amounts of kinetic and potential energy would be measured with arrows and some written explanations.

Chris and Avery’s use of the learning progression to categorize student responses was a reflection of how the materiality of the tool influenced which aspects of the tool they attended to; in this case, the numerical representation of the levels (Wertsch, 1997). This also aligned with the historical practice of assigning numerical grades to students in schools. I responded to Avery by reading the characteristics of a level two response, indicating that my focus was on student
ideas, and prompted the teachers to provide evidence for that classification a move that turned their attention back to the student work sample, which Andy did. The conversation continued:

Andy: That last question, I would really like, I would be really curious how they would explain how KE and PE and total energy are related to each other.

Chris: At any other point.

Andy: At any other point. Because I feel like they have this conception that it’s only at the bottom of the ramp where that’s true.

Chris: Or the middle.

Andy: Or the middle, whatever they mean is the middle of the ramp

Here, Andy articulated what additional follow up information would be helpful to fully assess student understanding because it remained unclear if the student believed that was only true at a single point, what they referred to as “the middle”. Andy used the learning progression as a guide to look for evidence of student understanding; in this way, the material tool enabled teacher activity related to student thinking. Together, Chris and Andy suggested that it would be helpful to know what that student thought about the relationship between kinetic, potential and total energy at another point in the model. Alex followed up and said,

Didn’t we talk about connecting this with the graphs last time with the, didn’t we, bar graphs and they have to draw the bar graphs at specific...cause then that’s clear...Explains the total energy throughout the whole system not just them interpreting and then us having to interpret what they mean, ‘cause that’s the problem is that you have to interpret what they mean.

Alex’s comment expressed her view that the question elicited student ideas that were ambiguous and difficult to interpret and followed up with a suggestion for a task revision that
could eliminate the ambiguity. Alex’s suggestion was to ask the students to draw bar graphs representing kinetic, potential and total energy at different points. The graphs would be easy for the teachers to interpret and would also provide students with the opportunity to demonstrate level two ideas of energy transfer. In this example, the workgroup activity moved back and forth between the student work sample and the learning progression. These tools mediated an interpretation of student thinking, an interpretation of the levels of the learning progression and instructional next steps.

The presence of the student work samples, the facilitation of the workgroup meeting and the learning progression mediated teacher activity related to interpreting student responses. The workgroup not only looked to the written response to part (d) to make sense of the student ideas, they also looked to the information in the model to inform their interpretations. Chris, Andy and Avery all moved back and forth between the student work and the learning progression to first, the learning progression and later to interpret the student response in reference to the learning progression. As the workgroup came to a collective understanding of both, the student idea moved from Chris’ original level three categorization to Avery’s level two categorization as described above. Throughout the episode, the learning progression and/or the ideas it contained were referenced a total of ten times. While the teachers made some of those references, I made most of them. For example, I prompted teachers to provide more information about why they thought a particular student idea might align with an idea in the learning progression. In this way, the learning progression was a tool that provided me with additional opportunities to press teachers to explain the ideas they noticed in particular student responses. Here, the material nature of the tool not only focused teacher attention on a particular student response, it also provided me with the appropriate prompts to probe teachers in their thinking.
The instructional action the teachers landed on - to ask students to use graphs to explain how energy transferred between potential and kinetic as the skateboarder moved back and forth on the ramp - was consistent with level two of the learning progression. It was also consistent with instructional opportunities the students would be participating in; the PhET activity the teachers used in this unit depicted energy transfer using similar graphical representations.

Episode 2: “Creates less kinds.” At the beginning of the next episode, I pointed the teachers to the next student work sample in the pile (Figure 6.6) and the workgroup reviewed it as follows:

![Initial Model](image)

**Figure 6.6.** Student work sample supporting teacher activity at the September 25, 2018 workgroup meeting as described in episode 2.
Alex: ‘creates less kinds’, I don’t like that word. ‘And more potential. It creates less kinds and more potential.’ That word shouldn’t be in there, it should be transfers...that’s a bad word.

Andy: Although did you notice down at (d) they mentioned the chart, ‘potential and kinetic energy are the same because if we have a pie chart and both energies are equal it shows that total of both energies’ so they get that part, at least from (d) I see that they get that.

Kate: OK (reading). When the skater is at the top it shows that there is more potential energy, so they’re just like saying it but not really saying why so much.

Alex: I don’t thinking we give them a spot to say what, like there’s not, all of this is says, label, label, label,. I mean and explain your choices for maximum and minimum, which they did.

Andy: (d) gets to the heart of what we want them to know, but it’s not very specific, it’s just how are these two things related to each other.

Kate: So what would you ask them to get them to talk about the indicators?

Alex: So I would change, for (d) I would be more, I would say “in the system, in the total system’ and we have to use that vocab ‘in the system, how are PE and KE related to total energy and then give them so bullet points on that like…

Andy: So they have to relate back to the model.”

Alex: Yea discuss that so number, to get to a higher level three is to use that model and relating it to the phenomenon, right, so, them talking about the transfer and transformations through those indicators. So he gets the overall picture, but to like specifically break it down into those specific indicators, I don’t think we could
ever get to a four with this assignment to be honest because they would have to
develop their own model and we’re giving them a model.

In the student work sample, the teachers indicated a similar issue as they had in episode
1, that while the student demonstrated the points in the model where kinetic and potential energy
would be at their minimum and maximum, they did not have an opportunity to demonstrate their
ideas about the relationship between the increase in one form and the decrease in another as
detailed in level two of the learning progression. Here, the teachers recognized the constraints
inherent in the formative assessment task; however, unlike at the January 2018 meeting, this did
not result in teachers recommending that the question be eliminated.

I asked the teachers about ways students might demonstrate a level three understanding
by asking about the indicators. Alex detailed some ideas pointing out that the task limited
students’ opportunities to demonstrate a level four understanding. Additional tools relevant to the
teachers’ context were referenced at this point. Alex indicated that the curriculum, *Active
Physics*, was limiting because it did not talk about conservation. I referenced the teachers’ prior
instruction relative to force as a resource that students could use in the context of the task. I
prompted the teachers as follows:

Kate: It’s starting to ask them to predict even though they’re not making a model, so what
would, for them to start to get at conservation and dissipation what kinds of
questions would you have to ask them?

Chris: to get to dissipation, another model where the skater doesn’t go all the way back
up to the top and then why.

Alex: And what happens to the energy. So this word creates I think that misconception
needs to be discussed in that specific model.
The episode ended here after the teachers briefly explored the kinds of questions they would need to pose to students to get them to share their ideas about conservation and dissipation. This included providing students with a new model that would give them an opportunity to explain why the skateboarder could never reach the original starting height as described in part (c).

**Summary, September 2018**

Like episode 1, in this example, the activity moved between the learning progression and the task. The learning progression was referenced a total of eight times, and I made half of those references. Here, the teachers were drawing on the language contained in the learning progression such as conservation and dissipation, system and surroundings and indicators to make sense of student ideas and propose task revisions. The learning progression not only mediated activity toward student thinking, it also supported teachers in using new terminology to describe student ideas, terminology that not only aligned with the learning progression, but aligned with the performance expectation of the NGSS as well. In this way, the learning progression was a tool that enabled teacher activity related to student think in ways that aligned with the goals of the *Framework*.

Alex, Andy and Chris, all made suggestions related to task redesign which included, rewording questions and asking new kinds of questions they hadn’t considered before. This is consistent with findings from Furtak et al. (2016), who found that when teachers participated in professional development that used a learning progression in the context of the FADC the quality of the formative assessment tasks and the eliciting questions that teachers asked both improved in quality. In this episode, Alex also brought up the district curriculum suggesting that it was a limiting factor as it did not mention the conservation of energy. While this constraint was not
discussed at length, it represented a sentiment that teachers often shared related to their frustration with the district adopted curriculum, signaling the historical and institutional context (Wertsch, 1997). Finally, Alex made the only reference to an alternative framework of student thinking, that the misconception associated with the student idea “creates less kinds” needed to be addressed. While Alex did not expand this statement, my interpretation was that Alex meant that idea that energy can be created was the misconception that needed to be addressed.

Case 2, Summary

At the January 2018 workgroup meeting, I did not enact the facilitation guide as designed nor did I utilize the student work that was available at the meeting. These factors, combined with the absence of a learning progression, constrained teacher activity. The development of the Modeling Energy Flows learning progression, prior to the September 2019 meeting, enabled teacher activity in important ways. First, by providing student work samples, teachers were able to reference specific student responses. Then, they were able to use the leaning progression to interpret them. Finally, they considered the types of re-design the task would need to undergo to provide students and opportunity to share the kinds of ideas in the learning progression.

In response to my first research question, *How can researchers design tools to support teacher activity that privileges student thinking to inform instruction?* It is clear that the design of the learning progression had important implications for enabling teacher activity. Also of note, is the design of the facilitation which in this case was adapted to included a pre-selected set of student work. As discussed earlier, this choice had tradeoffs (Horn et al., 2015). While teachers’ ability to reason about particular students was constrained, we enabled a more resource-based conversation, avoiding deficit thinking, and also created an opportunity for collective inquiry. Learning progression combined with student work enabled activity related to student thinking in
ways that were not possible when these tools were not available or not utilized in the workgroup meeting.

In response to my second research question, *How do the tools mediate activity oriented around student thinking to inform instruction?*, the outcomes from the September 2018 meeting suggest that both the materiality and the developmental path of the tools (Wertsch, 1997) were important factors in mediating activity. The Modeling Energy Flows learning progression mediated workgroup activity both by providing a framework to within which to view student ideas from the work samples. The materiality of the performance expectation specific learning progression enabled participants to move between the work samples and the learning progression. As the facilitator, I relied on the learning progression as a source of potential student ideas and then pressed teachers to turn to the student work for evidence when they made claims related to what level students responses might have been associated with. The developmental path of the Modeling Energy Flows learning included attention not only to the performance expectations of the NGSS, but also to the teachers’ contexts as it was developed during the Aspire project. The student work was from the teachers’ own students and the formative assessment task was co-designed by the teachers. These factors enabled activity because the tools had power and authority in the context of teachers’ work. In contrast to the isolated examples discussed at the January 2018 meeting, the tools mediated sustained activity related to student thinking to inform instruction in September 2018.
Chapter 7. Discussion

In this dissertation my goal was to answer the following questions, *How can researchers design tools to support activity that privileges student thinking to inform instruction?* and *How do the tools of the activity system mediate activity oriented around using student thinking to inform instruction?* I conducted two embedded case studies in the context of the larger Aspire project, nested within the Aspire research-practice partnership between researchers at the University of Colorado, Boulder and science instructional coordinators at the Sunshine Public School District. In this concluding chapter I will summarize my findings as related to Wertsch’s (1997) claims of mediated action, connect those findings to the larger literature base, and discuss both the significance and limitations of these findings. I will end with suggestions for future research.

Taken together, the findings from Case 1: and Case 2: suggest that certain combinations of tools have greater potential for mediating teacher activity related to student thinking to inform instruction. In Case 1, the combination of score reports with the Force and Motion learning progression had limited potential to enable activity related to our goals. One explanation for this finding is that the materiality of the tools constrained teacher activity by focusing attention on discrepancies between the data in research designed score reports and teachers’ prior beliefs of what students are capable of. In Case 2, the combination of the Modeling Energy Flows learning progression with student work from teachers’ own classes had greater potential to enable activity related to student thinking to inform instruction. A possible explanation for this is that the developmental path of this configuration of tools was more aligned with features of teachers’ contexts. The following sections will explore these findings in greater detail.
Summary of Findings

As Wertsch (1997) noted, the irreducible tension between the individual and the tools they interact with results in activity; through that activity, individuals acquire skills and those skills are evidence of learning. One of the goals of the research team in the Aspire project was to design tools that would help support teachers build facility with viewing student ideas as resources for instruction and then using those student ideas to inform instruction.

The Materiality of the Tools Enabled and Constrained Activity

Score Reports

In Case 1, the score reports designed for teachers at Carver were personalized, which focused teachers’ attention on how groups of students in their tracked classes responded to the OMC items. Some of the teachers expressed disbelief that the pattern of responses they saw in the score reports was similar for students in high and low tracks which suggested a deficit view of students. In this case, when the response pattern in the score report did not align with their expectations some teachers rejected the tools.

Although the score reports were depersonalized for the teachers at Mayfield, the reports still aggregated students according their class type (e.g. regular, pre-AP, AP) and teachers still expressed views about what their students were capable of; however, in a slightly different way. Here, teachers didn’t express disbelief about particular groups of students (i.e. lower tracked students) not being capable; rather, they seemed to hold the view that all of the students were incapable of having an understanding related to more sophisticated responses about force and motion. While there was a difference in how the view manifested at the two different schools, it remained clear that teachers at both schools held deficit views of their students. This limited view of what students are capable of is not uncommon (Battey & Franke, 2015). In studies of
mathematics teachers, Jackson and colleagues (2017) found that teachers often attributed students’ difficulty with mathematics to personal, family or community traits rather than as a problem of instruction; particularly when students were from non-dominant groups.

Although the teachers at Mayfield, didn’t reject the tools as the teachers at Carver had, neither group engaged in robust activity related to student thinking to inform instruction. The materiality of the tools uncovered a deficit view that constrained teacher activity by focusing attention on teacher views of deficits rather than assets. A deficit view may be an obstacle to realizing the vision of the Framework and implementing the NGSS because it often results in instructional decisions that limit students’ opportunities to share their thinking in meaningful ways (Jackson et al., 2017).

Learning Progressions and Student Work Samples

Looking across the two workgroup meetings in Case 2, the importance of the materiality of the tools was also apparent. Without the material pieces of student work and the learning progression, during the January 2018 workgroup meeting, it was not possible to enable robust activity related to student thinking to inform instruction. Without the tools, the activity was mainly related to general interpretations and recollections of student ideas which led to minimal conversation about instruction.

The tools utilized at the September 2019 meeting focused teacher attention on student ideas from work samples that were generated in the teachers’ own classes. The learning progression provided, not only a framework for interpretation of the student ideas found in the work samples, but also a framework for task redesign. This framework was critical as it mediated activity related to how changes in the task could provide opportunities for students to share their thinking in more sophisticated ways. Well designed tasks, that afford opportunities for students
to share their thinking, enable teachers to interact with student ideas in more responsive ways (Kang & Anderson, 2015).

Following the January 2018 meeting, the research team decided that rather than rely on the teachers to bring student work to the meeting, we would preselect a common set of student work. This decision was made, in part, out of concern that if all teachers didn’t bring work samples with them to meetings it could limit activity as it had at the January 2018 meeting. However, it is important to consider the affordances and constraints associated with student work from either source. When teachers use a common set of student work, they are able to interrogate student thinking collectively and when they use work from their own classrooms they can bring their understanding of specific students and the context under which the student work was generated to the conversation (Horn et al., 2015). While both sources of student work have associated affordances, in Case 1, I uncovered the potential constraint that drawing on what teachers know about their students could bring less productive views, such as deficit views, that limit opportunities to discuss student thinking. This prompted us to decide that a common set of student work would be the best fit for this particular context.

Summary

The materiality of the score reports and the learning progressions constrained and enabled activity in meaningful ways. In Case 1, although the redesign of the score reports and the associated tools enabled more activity that was related to our goals, deficit views continued to constrain workgroup activity. In Case 2, the combination of the learning progression with the pre-selected sample of student work supported more productive activity related to student thinking to inform instruction. Attending to the materiality of the tools illuminated important elements of the tool mediated action in teacher workgroup meetings. Investigating additional
elements, such as the developmental path that both tools and individuals are on can help clarify the role of the sociocultural, historical and institutional factors that impacted teacher activity.

**Developmental Paths**

**Score Reports**

As Wertsch (1997) pointed out, individuals and tools have a history, a present and a future; the history an individual has with a particular type of tool can inform the activity they will engage in with that tool in the present. In Case 1, score reports were the focal tool of the workgroup meetings. The research team’s activity related to score reports was based on prior research done with score reports for use with learning progressions (e.g. Alonzo & Elby, 2019; Furtak et al., 2014); however, that literature base remains limited. There is more abundant literature on score reports in general (e.g. Zenisky & Hambleton, 2012) which details best practices for how to communicate results from state level standardized assessments with students, parents and teachers. As standardized test scores have been used historically in schools as a factor in teacher evaluation and merit based pay (e.g. Shifrer, Turley & Heard, 2017) the use of score reports to communicate this information is complicated. The history of score report use reveals the purposes for which these tools have been designed and used for in the past and the ways it may impact activity in teacher workgroups.

In schools like Carver, which has historically had a strong accountability climate, practices that involved identifying focal groups of students (e.g. Black males, English language learners) for targeted intervention is a common practice (Horn et al., 2015). Typically, this targeting occurs with the goal of devoting resources to improving the outcomes for groups who traditionally underperform. However, the interventions that follow often include remedial or procedural work rather than rigorous learning opportunities that could support more
sophisticated thinking. In conjunction with these types of interventions, when teachers use score reports, such as those described above, to mediate workgroup activity, that activity is often narrow and limits deeper reflections and potential opportunities for teacher learning (Horn et al., 2015). Given the history of the institutional use of score reports, it is unsurprising that teachers at Carver, and to a lesser extent at Mayfield, would have difficulty using them to support a resource-based view of student ideas for all of their students. In essence, we were asking teachers to reappropriate a tool used to serve accountability needs for new purposes that may have been in conflict with the historical use of the tool.

**Learning Progressions**

Like the score reports, the learning progressions (Force and Motion, Modeling Energy Flows) also existed in their own developmental pathways. As described earlier, the Force and Motion learning progression (Alonzo & Steedle, 2008) was utilized as a tool by the research team because it held power and authority as a result of it having been published in a peer reviewed journal and used by respected colleagues. While these factors served to afford research team activity, they may have constrained teacher activity because the learning progression was an unfamiliar tool, from an unknown source, and not connected to their curriculum. In addition, the context dependence nature of student ideas and learning progressions (Alonzo & Elby, 2019) may also have constrained activity. Further, while our goal was to design tools to mediate teacher activity related to student thinking, the Force and Motion learning progression was designed based, in part, on a misconceptions framework, one of the frameworks we hoped to move teachers away from (Alonzo & Steedle, 2008).

Although the Modeling Energy Flows learning progression was designed by the research team, it was developed in the context of the Aspire project and was informed by the teachers
with whom we worked (Buell et al., 2019). The development of this learning progression also took a resource-based approach and drew heavily on tools from the NGSS, increasing its relevance to teachers. As the teachers had been working with the performance expectations of the NGSS as part of their work in the Aspire project, and as part of their work with district instructional coordinators, this tool was more closely aligned with their practice. For this reason, the Modeling Energy Flows learning progression was better suited to enable activity related to student thinking, particularly when it was used in conjunction with student work from teachers’ own context. This is consistent with findings from Furtak and Hereida (2014) who noted that teachers who were not involved with the development of a learning progression had difficulty making sense of it and incorporating its use into their practice.

Summary

The developmental pathway of tools, such as the score reports and learning progressions described here, hold important information about the context in which the tools were developed. Understand the history of the tools may help predict how they might be used in both the present and the future. In Case 1, the history of the externally developed learning progression and score reports may have constrained teacher activity. In Case 2, the development of the learning progression occurred within the context of the Aspire project and was aligned with tools that were familiar to the teachers. Additional tools, such as student work from teachers’ own students and a co-designed formative assessment task were also aligned with teachers’ experiences and were closer to their practice. The proximity of the tools to teachers’ practice may have enabled activity related to our goals.
Significance

The findings from this dissertation carry significance for practicing teachers and instructional leaders interested in designing professional learning opportunities aligned with the goals of the *Framework* as well as researchers interested in studying how teachers learn to do this work.

Evidence from the two cases presented here suggests that we may be able to mediate teacher activity related to student thinking with the right configuration of tools. In the cases described here, a resource-based framework of student ideas, such as a learning progression, in conjunction with student work from teachers’ own classrooms seemed to hold the greatest potential for mediating activity related to student thinking. Given this finding, professional development designers can build on work from scholars who have studied how teachers use student work (e.g. Kazemi & Franke, 2004) and learning to notice (e.g. van Es & Sherin, 2002) and incorporate the use of a framework of student thinking, like a learning progression, to focus teacher attention on student ideas, interpret them and make decisions about instructions next steps (Alonzo, 2018). The use of a learning progression can help teachers identify the key components of student ideas that will be useful to further investigate (Alonzo & von Aufschnaiter, 2018) and this might be of particular significance for teachers less familiar with the content; including, new teachers and teachers working out of their content area of expertise.

When teachers engage in activity related to student thinking to inform instruction in their collaborative workgroups they are building the skills they need to began to enact the practices required by the science education reforms laid out in the *Framework*. Better understanding the design and use of the tools that support teachers as they build the skills they need will help
professional development providers create meaningful teacher learning opportunities, the kind that can effect change.

For researchers interested in studying how teachers learn about reform oriented instruction, it will be especially important to attend to the sociocultural, historical and institutional contexts where this work takes place, in addition to the teachers and the tools that mediate their activity (Coburn, 2006; Jackson et al., 2017; Windschitl et al., 2012). Without attending to these contexts, it may be difficult to understand for instance, why teachers might reject the tools they interact with in a profession context. Additional tools, such as interview protocols, designed to assess teachers’ views of their students’ abilities (Jackson et al., 2017) may be necessary in supporting this work.

Understanding these contexts is also critical at a time when many teachers are faced with accountability pressures in their schools. Accountability measures such as teacher evaluation may constrain teachers and the practices they are willing to engage in (Bradford & Braaten, 2018). The tools that we design must be responsive to or compatible with the institutional settings, or again, teachers may turn away from the tools, or worse the profession itself.

**Limitations**

It is important to acknowledge that this dissertation research focused on two individual case studies that included limited examples of teacher activity in two teacher workgroups. While these case studies were in depth inquiries, they likely are not representative of all science teachers in the district. Several factors limit the generalizability of these findings, including field notes as the primary source of data in Case 1, the nature of my monthly participation in workgroup meetings and the lack of member checks conducted in either case.
In Case 1, the primary source of data was fieldnotes from both research team and teacher workgroup meetings. Research team meeting field notes were created by a rotation of graduate research assistants. The fieldnotes recorded at the teacher workgroup meetings were created by two researchers present at each meeting. In comparison to an audio or video recording, the fieldnotes could not possibly capture every detail. As the note taker was also a participant in the meeting, at times it would have been difficult to both record notes and actively engage in the meeting creating gaps in the record. In addition, it is likely that researcher bias resulted in research assistants paying greater attention to the conversation at different points in the meeting resulting in a different level of detail at certain points.

In fulfilling my role as a workgroup facilitator as part of the Aspire project, I attended teacher workgroup meetings one or two times each month. The teachers often met with their workgroups multiple times each week. I have no knowledge of how the meetings that I did not attend proceeded or how they may have been different from the meetings I did attend. While I have worked with the teachers at both schools for almost four years, I can only speak to the workgroup meetings that I have observed and participated in. This limited my ability to make global claims about norms, habits or regular activity of the workgroups. It also limited my ability to make claims about the impact of my facilitation on workgroup activity, as I had no comparison point.

Finally, in these cases, I did not conduct member checks with participating teachers. Member checks are an important part of establishing validity in qualitative research. I chose not to conduct member checks because too much time elapsed between workgroup meetings and the creation of the cases. For this reason, it seemed unrealistic to ask teachers to recall a single meeting so far in the past. As a former teacher and a researcher committed to improving learning
opportunities for teachers, I value the teacher perspective in the context of research and regret that I did not plan to make teacher member checks a priority in my study.

**Future Research**

The goals of the research described in this dissertation related to the design and use of tools to mediate teacher activity related to student thinking to inform instruction. While the findings suggest that certain combinations of tools may be better suited than others to mediate teacher activity related to student thinking, how exactly the activity can be leveraged toward informing instruction is less clear. The teachers in Case 2 engaged in activity related to tool design, an important first step in taking instructional action. However, determining instructional next steps remains difficult to address (Heritage et al., 2009). Researchers and professional development providers will need additional tools that can support teachers as they move beyond formative assessment task design toward informing instruction.

One focus of research then, should be on the kinds of tools that might support teachers in deciding what type of instructional opportunities to provide to their students once they uncover their ideas. While some tools (e.g. Diagnoser, dianoser.com) offer prescriptive feedback to students and their teachers related to their ideas about science, it is unclear how engaging with a tool like this mediates teacher activity related to student thinking. Is this the sort of tool that supports teachers in selecting instructional opportunities for their students based on their ideas or are other tools better suited for this role?

Rather than just focusing on supporting teachers in selecting instructional next steps, other tools support teachers in taking on the kinds of classroom practices have the potential to reframe science teaching toward student thinking (e.g. Windschitl et al., 2013). Tools associated with “Ambitious Science Teaching” (Windschitl, Thompson & Braaten, 2018) such as “back
pocket questions” prompt students to share their thinking as a teacher walks around the room and interacts with groups of students engaged in an activity. The next step in understanding how focusing on student thinking can inform instruction is to study how tools like these mediate teacher activity in the classroom, including interactions between teachers and students such as feedback.

The next steps for researcher related to student thinking to inform instruction will need to broaden the nexus of activity related to student thinking from the workgroup to the classroom. Teachers will need to take the skills they learn with their colleagues to their students and will need to interact with their students as they engage with their ideas.

**Conclusion**

Teacher activity related to student thinking was and remains worthy of continued investigation if we hope to realize the vision of science teaching documented by the Framework (NRC, 2012). A focus on student ideas can be viewed as an entry point for teachers taking on reform oriented instruction related to the NGSS because activity related to student ideas as informing instruction can lead to the kind of instruction that elicits student ideas. This shift, described as reframing science teaching to “work on and with students’ ideas” (Stroupe & Windschitl, 2015, p. 181) will require considerable effort. Science teachers are inundated with endless information throughout the course of their day about how they should allocate their time and why type of information they should attend to in their classrooms. The most important information, in the context of the science classroom, remains the content of students’ ideas. Paying attention to those ideas and building practice that puts those ideas at the center of the science classroom is not easy work. Participation in professional learning opportunities like the ones described here are key to making this vision a reality.
References


Coherence from the Classroom to the District Office. Cambridge: Harvard Education Press.


Appendix A: Planning tool used in FADC
<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Force</th>
<th>No Force</th>
<th>Motion</th>
<th>No Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Common Errors:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- If there is no motion, there are no forces acting.</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>- When an object is moving, there is a force in the direction of its motion.</td>
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<tr>
<td></td>
<td>o 2A: This motion could be the force that put the object into motion initially.</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>o 2A: The object may come to rest because the force it carries with it has been used up.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Student understands force as a push or pull that may or may not involve motion.</td>
<td>If a force is acting on an object, it is moving unless the object is immovable.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Common Errors:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Forces are caused by living things.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>- Force is an internal property of objects related to their weight. (There is a force on all objects that is not due to gravity or because of their motion.)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>- Forces prevent the natural movement of objects (i.e., gravity prevents objects from flying off into space).</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>- Objects cannot move in the absence of friction.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Way off-track</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Level</td>
<td>Description</td>
<td>Force</td>
<td>No Force</td>
<td>Motion</td>
<td>No Motion</td>
</tr>
<tr>
<td>-------</td>
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</tr>
</tbody>
</table>
| 1     | Student believes that the object's speed (rather than its acceleration) is proportional to the net force in the direction of its motion. Common Errors:  
- An object's speed and direction are proportional to the nonzero net force acting on it.  
  - 3A: An object may come to rest when opposing forces (e.g., the force which put the object into motion initially and gravity) come into balance.  
- A constant force causes constant speed.  
- Without an applied force, all objects will slow down and eventually come to rest. | If a force is acting upon an object, it is moving.  
2A: The force acting on an object could be the initial force (which is carried with the object and may dissipate over time). | If no force is acting upon an object, it is not moving. | If an object is moving, a force is acting upon it. | If an object is not moving, no force is acting upon it. |

(Continued)
Appendix C: Force and motion assessment items.

Directions: Before you begin, please write the number from your index card in the section marked ‘STUDENT ID’ on your purple bubble sheet, and then fill in the bubbles below. DO NOT write your name or your school ID number anywhere on the top of the bubble sheet.
This is an assessment of your understanding of force and motion.

Fill in your answer choices for questions 1 to 16 on your bubble sheet. You should end on question 16.
1. The box sitting on the table above is not moving because
   a. no forces are acting on the box.
   b. the table pushes up with the same force that gravity pulls down.
   c. gravity is keeping the box down on the table.
   d. gravity is pulling down, but the table is in the way.

2. Amelia hits a puck on a flat frictionless surface. She then observes the speed of the puck. Which of the following observations is most likely?
   a. The speed is constant because the force from Amelia's hit is still acting on the puck.
   b. The speed is constant because there is no force acting on the side of the puck.
   c. The speed is decreasing because there is no force acting on the side of the puck.
   d. The speed is zero because there is no force acting on the side of the puck.

3. 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?
   a. It will move faster and faster across the ice.
   b. It will keep moving until Jeff stops pushing.
   c. It will move at a constant speed across the ice.
   d. It will speed up and then move at its maximum speed.
4. 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. If Jeff stops pushing, what will happen to his car?
   a. It will gradually slow down because there is no force to keep it going.
   b. It will gradually slow down as the force of Jeff's push decreases.
   c. It will keep moving at the same speed because there is no force to slow it down.
   d. It will stop moving as soon as Jeff stops pushing because there is no force to keep it going.

5. Use the figure above to answer the question. When the ball is on its way down through point A, what force(s) are acting on it?
   a. There are no forces acting on the ball.
   b. Only the force from Lisa's push is acting on the ball.
   c. Only gravity is acting on the ball.
   d. Both gravity and the force from Lisa's push are acting on the ball
6. Use the figure above to answer this question. When the ball is on its way back up through point B, what force(s) are acting on it?
   a. Only gravity is acting on the ball.
   b. Only the force from the floor is acting on the ball.
   c. Only the force from Lisa's push is acting on the ball.
   d. Both gravity and the force from the floor are acting on the ball.
   e. There are no forces acting on the ball.

7. The boulder in the picture is not moving because
   a. the boulder is too heavy for other forces to affect it.
   b. no forces are acting on the boulder.
   c. gravity is holding it down to the ground.
   d. the ground pushes up with the same force that gravity pulls down.
8. 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. 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 it reaches its maximum speed.
   d. The rocket will move only while the engines are on.

9. 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. 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.

10. 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.
11. On a visit to a science lab, Madison observes a blob of shiny material, which appears to be floating in the air. The blob isn't moving. What can she conclude about the force(s) acting on the blob?
   a. Gravity cannot be acting on the blob because it isn't falling down.
   b. Gravity must be acting on the blob or it would float away.
   c. There are no forces acting on the blob because it isn't moving.
   d. Each force acting on the blob has another one to cancel it out.

12. 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?
   a. Only gravity is acting on the stone.
   b. Only the force that Derek put on the stone is acting on it.
   c. Both gravity and the force that Derek put on the stone are acting on it.
   d. There are no forces acting on the stone.
13. 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?
   a. There are no forces acting on the stone at point B.
   b. The force of gravity is now equal to the force from Derek's throw.
   c. There is no more force left from Derek's throw.
   d. Gravity has slowed the stone until it stops.

14. A rocket sled is traveling on a very long frictionless track. The sled travels faster and faster when the engine is on. What is true about the force exerted by the engine?
   a. The force exerted by the engine is constant as the sled travels faster and faster.
   b. The force exerted by the engine increases as the sled travels faster and faster.
15. Maria pushes on a heavy rock, but the rock does not move. Why not?
   a. Nothing is moving, so there are no forces acting.
   b. Maria is exerting a force on the rock, but the force from the rock is stronger.
   c. There must be another force on the rock, opposing Maria's push.
   d. The rock is heavier than Maria.

16. A spacecraft moves at a constant speed in outer space. If there is no friction or gravity, what force(s) are acting on the spacecraft?
   a. There is an unbalanced force acting on the spacecraft.
   b. The spacecraft must have an engine which is exerting a constant force on it.
   c. There are no forces acting on the spacecraft.
   d. The force that launched the spacecraft into outer space is still acting on it.
### Description of energy conceptions and complexity levels of the hypothesized learning progression

<table>
<thead>
<tr>
<th>Energy Forms</th>
<th>Energy Transformation</th>
<th>Energy Degradation</th>
<th>Energy Conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students are expected to...</td>
<td>Students are expected to...</td>
<td>Students are expected to...</td>
<td>Students are expected to...</td>
</tr>
<tr>
<td>...understand that the amount of energy in a particular form depends on indicators and factors</td>
<td>...understand that each transformation process includes the reduction of energy in one form and increase of energy in another form</td>
<td>...understand that the degradation of energy means that all processes will stop in the long run if no additional energy is provided to keep them running</td>
<td>...understand that whenever it seems that energy is not conserved, energy was transformed into a form that is not considered in the equation</td>
</tr>
<tr>
<td>Level 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...know how the amount of energy in a particular form depends on other physical measures</td>
<td>...know for a given how one form of energy is transformed into one another</td>
<td>...know how the process of energy degradation depends on a particular mechanism</td>
<td>...know how all forms of energy of a given system add up to a conserved quantity</td>
</tr>
<tr>
<td>Level 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...know that the amount of energy in a particular form depends on other physical measures</td>
<td>...know for a given process which forms of energy are transformed into one another</td>
<td>...know the reason for the degradation of energy</td>
<td>...know that the total amount of different forms of energy involved in a process may be conserved</td>
</tr>
<tr>
<td>Level 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...know one of more energy forms</td>
<td>...know that energy can be transferred from one place to another, or transformed from one form into another</td>
<td>...know that when energy is transferred or transformed some energy is degraded</td>
<td>...know the principle of energy conservation</td>
</tr>
</tbody>
</table>
Appendix E: Phenomenon based item cluster

Please write your full name in the box to the right:

**How does a skydiver get enough energy to reach maximum speed?**

*Felix Baumgartner holds the world record for the fastest speed achieved by a human without an engine. Felix broke the sound barrier by reaching a top speed of 377 m/s (faster than the speed of sound). Felix used a very large balloon to fly approximately 39,000 meters above the Earth and, wearing a special suit, descended to the Earth.*

In physics, a system is the part of the world that is under investigation and the surroundings are anything outside of the investigation. Use the figure above to circle the best answer.

1. Which of the following is included in the system under investigation?
   (a) the balloon and the air around Felix’s body
   (b) Felix’s body
   (c) the Earth
   (d) Felix’s body and the Earth

2. Which of the following is part of the surroundings?
   (a) the balloon and the air around Felix’s body
   (b) Felix’s body
   (c) the Earth
   (d) Felix’s body and the Earth

Select whether or not the following forms of energy are relevant within the system used to answer the question: “How does a skydiver get enough energy to reach his maximum speed?”

<table>
<thead>
<tr>
<th>Form of Energy</th>
<th>Definition</th>
<th>Relevant</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Kinetic</td>
<td>energy associated with motion</td>
<td>Y</td>
</tr>
<tr>
<td>4. Thermal</td>
<td>energy associated with temperature</td>
<td>Y</td>
</tr>
<tr>
<td>5. Gravitational Potential</td>
<td>energy associated with distance from the center of the Earth</td>
<td>Y</td>
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<tr>
<td>---</td>
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</tr>
<tr>
<td><strong>6. Elastic Potential</strong></td>
<td>energy associated with the stretching, twisting, and bending of an elastic object</td>
<td>Y</td>
</tr>
<tr>
<td><strong>7. Chemical</strong></td>
<td>energy associated with arrangements of atoms in a chemical reaction system</td>
<td>Y</td>
</tr>
<tr>
<td><strong>8. Radiation</strong></td>
<td>electromagnetic energy (examples: light, radio waves, X-rays)</td>
<td>Y</td>
</tr>
</tbody>
</table>
Use the following information about Felix’s height, velocity, and energy while in freefall to answer the following questions. The time and measurements begin the moment Felix leaves the balloon.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Height (meters)</th>
<th>Velocity (m/s)</th>
<th>GPE (kJ)</th>
<th>KE (kJ)</th>
<th>GPE + KE = TE (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>38,969</td>
<td>0</td>
<td>42,000</td>
<td>0</td>
<td>42,000</td>
</tr>
<tr>
<td>34</td>
<td>33,446</td>
<td>310</td>
<td>36,000</td>
<td>5,000</td>
<td>41,000</td>
</tr>
<tr>
<td>50</td>
<td>27,833</td>
<td>377</td>
<td>30,000</td>
<td>8,000</td>
<td>38,000</td>
</tr>
</tbody>
</table>

9. While in freefall, the distance between Felix’s body and Earth _____.
   (a) increased  
   (b) decreased  
   (c) decreased then increased

10. Felix’s gravitational potential energy (GPE) ______.
    (a) increased  
    (b) decreased  
    (c) stayed the same

11. This was because _____.
    (a) GPE was mostly transformed to KE within the system  
    (b) GPE was mostly transferred to radiation out of the system  
    (c) GPE did not change

12. As Felix got closer to Earth, his body moved _____.
    (a) faster  
    (b) slower  
    (c) slower and then speed up

13. Felix’s kinetic energy (KE) ______.
    (a) increased  
    (b) decreased  
    (c) stayed the same

14. This was because _____.
    (a) GPE was mostly transformed to KE within the system  
    (b) KE was mostly transferred to radiation out of the system  
    (c) KE did not change

15. Using the table, calculate the change in total energy (TE) from 0 to 50 s.
    (a) -4,000 kJ  
    (b) -3,000 kJ  
    (c) -1,000 kJ

16. The TE in the system ______.
    (a) increased  
    (b) decreased  
    (c) stayed the same

17. This was because _____.
    (a) energy was transferred into the system as heat  
    (b) energy was transferred out of the system as heat  
    (c) energy does not change
18. The initial model of the system and surroundings was incomplete because it did not show how energy flows. Draw a model that shows how Felix gets enough energy to reach maximum speed. Using labels, arrows, and/or lines, include the following in your model:

- Components of the System and Surroundings
- Forms of Energy
- Flows of Energy
19. Use your model (from Question #18) to describe in words how Felix gets enough energy to reach maximum speed.
20. An arrow is shot into the air using a bow.

What can be stated about the arrow?

a. The arrow has gravitational energy because the arrow is flying quickly.
b. The arrow has kinetic energy because the arrow is moving.
c. The arrow has no energy because the arrow has no drive system.
d. The arrow has no energy because the arrow is not a living thing.

21. On a table one glass is filled with cold milk and one glass is filled with hot milk. There is the same amount of milk in each glass.

Which statement about the energy of the cold and hot milk is correct?

a. The cold and the hot milk possess the same amount of thermal energy but the hot milk has a higher temperature than the cold milk.
b. Only the hot milk possesses thermal energy. The cold milk does not possess any thermal energy at all.
c. The cold and the hot milk possess thermal energy but the cold milk possesses less thermal energy than the hot milk.
d. Neither the hot nor the cold milk possess thermal energy. Only moving things possess energy.

22. A skater goes back and forth in a half-pipe without pushing.

Which statement is correct?

a. Due to friction, the kinetic energy of the skater is transformed into thermal energy. Thus, the kinetic energy of the skater decreases until he stops.
b. While moving down the walls of the half-pipe, the gravitational energy of the skater is transformed into thermal energy due to friction. This is because he is not pushing until he finally stops.
c. The skater needs to push at least once to overcome friction. But, since he is not pushing, his kinetic energy is transformed into thermal energy until he stops.
d. The kinetic energy of the skater is transformed into thermal energy due to friction. Because energy cannot be destroyed, the skater continues to move until he brakes.
23. A student wants to develop a light that uses 100% of the electricity it receives to emit visible light. What would you say about this idea from a scientific perspective?

a. Such lights already exist and are in use now.
b. Such lights are possible to build if he uses different conductive materials (e.g., Carbon Nanotube) not copper wires.
c. Such lights are possible to build if he attaches solar cells on the light to convert light to electricity again.
d. Such a light is impossible to build in the real world.


What can you tell about the energy forms involved?

a. The skater’s kinetic energy is transformed into thermal energy because of friction, and as a result, the skater slows down. Nevertheless, the total sum of all energy remains constant because of energy conservation.
b. The skater loses kinetic energy due to friction and slows down. Because of slowing down, the total sum of all energy forms decreases.
c. The skater does not lose any kinetic energy since there is energy conservation, even in the case of friction. Thus, the skater keeps on moving.
d. The skater slows down because kinetic energy is transformed into thermal energy by friction. Even though this is true, the skater never completely stops because there is conservation of energy.

25. Imagine you are riding a bike.

What happens when you are cycling?

a. Chemical energy from food is transformed into kinetic energy of your muscles. Afterwards, pedals and chain transform kinetic energy into speed.
b. Your muscles transform chemical energy from food into kinetic energy of your legs. Afterwards, pedals and chain transfer kinetic energy to you and your bike.
c. Kinetic energy from food is burned up in your muscles. Afterwards, pedals and chain transfer kinetic energy to you and your bike.
d. Chemical energy is produced by combustion of food in your muscles. Afterwards, pedals and chain transform chemical energy into kinetic energy.
26. A gymnast can use a trampoline to jump higher than she could jump without one.

How would you explain the physics of jumping on a trampoline?

a. The stretched trampoline creates elastic energy and transforms it into kinetic energy. This additional energy is transferred to the gymnast.
b. There is no energy stored in the stretched trampoline. In order to jump higher, the gymnast needs to transform power into energy.
c. The elastic energy stored in the stretched trampoline is transformed into additional kinetic energy of the gymnast. As a result, the gymnast can jump higher than she could jump without a trampoline.
d. The elastic energy stored in the stretched trampoline is transferred to the gymnast. In order to jump, the gymnast transforms this energy into kinetic energy.

27. What is the relationship between rock formations and Earth’s surface?

a. Most rocks form underground and reach the Earth’s surface as molten rock moves.
b. Most rocks form underground and reach the Earth’s surface as other rocks are destroyed.
c. Most rocks form underground and never reach the Earth’s surface.
d. Most rocks form at the Earth’s surface and stay there for a long time.

28. Below the outermost rocky shell of the Earth, it becomes:

a. Hotter, molten, and gravity increases
b. Hotter, gaseous, and magnetism increases
c. Colder, solid, and pressure increases
d. Hotter, denser, and pressure increases
e. Colder, denser, and pressure increases
f. 

29. Which of the following figures do you believe is most closely related to what you might see if you could cut the Earth in half?

![Figures A, B, C, D, E]
30. Scientists often talk about the Earth’s tectonic plates and their role in mountain formation, volcanism, and earthquake occurrence. Which of the following figures most closely represents the location of the Earth’s tectonic plates?

![Diagram of tectonic plates]

31. On continents, where does most volcanic material come from?

![Diagram of volcanic sources]

32. Since the initial formation of the Earth:
   a. The rocks at the Earth’s surface have generally decreased in temperature.
   b. The rocks at the Earth’s surface have generally increased in temperature.
   c. The rocks at the Earth’s surface have generally stayed the same temperature.
Appendix F: Modeling Energy Flows learning progression.

<table>
<thead>
<tr>
<th>Level</th>
<th>A Learning Progression for Modeling Energy Flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>● Students are able to <em>generalize their model</em> to unknown or multiple phenomena, and can <em>explain limitations of applying the model</em> to a new phenomenon.</td>
</tr>
</tbody>
</table>
| 4     | ● Students *develop a model* that illustrates a mechanism that can explain or predict the phenomenon, AND *use* the model to make predictions about how changing one part of the model would influence energy flows elsewhere in the system.  
● Students can explain how the total energy of the *system* constrains the magnitude of change possible.  
● Students can *describe limitations of the model* in explaining or predicting the phenomenon |
| 3     | ● Students *use* or *develop* a model that relates changes in the phenomenon directly to changes in energy through transfers/transformations by identifying specific indicators.  
● Students begin to show evidence that their model is accounting for conservation and dissipation.  
● Model includes energy flows into, within, and out of the *system* |
| 2     | ● Students *use* or *develop* a model to illustrate a relationship or pattern between the increase in one form of energy and the decrease in another form, or transferred from one location or object to another.  
● Students identify the most relevant components and relationships in the model and distinguish between the *system* and surroundings  
● Model focuses on energy flows within the *system* only. |
| 1     | ● Students *use* or *develop* a model that shows, through drawings or labels, the components involved in a *phenomenon*, some (but not necessarily all relevant) energy forms, transfers, or transformations. |
Appendix G: Score reports.

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student understands</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✔ force as a push or pull that may not involve motion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✔ motion implies a force in the direction of motion that acceleration implies no force. Conversely, an object believes that force implies motion in the direction of the force.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✔ an object is stationary either because there are no forces acting on it or because there is no net force acting on it.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✔ objects may be moving even when no forces are being applied. However, he or she does not believe that objects can continue moving at a constant speed without an applied force.</td>
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<tr>
<td>✔ there may be forces acting on an object that are not in the direction of its motion. However, he or she believes that an object cannot be moving at a constant speed in a direction in which a force is not being applied.</td>
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</tr>
</tbody>
</table>

1. The box sitting on the table above is not moving because
   a. no forces are acting on the box. (Level 2)
   b. the table pushes up with the same force that gravity pulls down. (Level 3)
   c. gravity is keeping the box down on the table. (Level 1)
   d. gravity is pulling down, but the table is in the way. (Level 2)

7. The boulder in the picture is not moving because
   a. the boulder is too heavy for other forces to affect it. (Level 1)
   b. no forces are acting on the boulder. (Level 2)
   c. gravity is holding it down to the ground. (Level 1)
   d. the ground pushes up with the same force that gravity pulls down. (Level 3)
11. On a visit to a science lab, Madison observes a blob of shiny material, which appears to be floating in the air. The blob isn’t moving. What can she conclude about the force(s) acting on the blob? (Level 2)
   a. Gravity cannot be acting on the blob because it isn’t falling down.
   b. Gravity must be acting on the blob or it would float away.
   c. There are no forces acting on the blob because it isn’t moving.
   d. Each force acting on the blob has another one to cancel it out.

15. Maria pushes on a heavy rock, but the rock does not move. Why not? (Level 3)
   a. Nothing is moving, so there are no forces acting.
   b. Maria is exerting a force on the rock, but the force from the rock is stronger.
   c. There must be another force on the rock, opposing Maria’s push.
   d. The rock is heavier than Maria.

Questions with Response Options Representing Levels 2 through 4

2. Amelia hits a puck on a flat frictionless surface. She then observes the speed of the puck. Which of the following observations is most likely? (Level 2)
   a. The speed is constant because the force from Amelia’s hit is still acting on the puck.
   b. The speed is constant because there is no force acting on the side of the puck.
   c. The speed is decreasing because there is no force acting on the side of the puck.
   d. The speed is zero because there is no force acting on the side of the puck.
3. 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?
   a. It will move faster and faster across the ice. (Level 4)
   b. It will keep moving until Jeff stops pushing. (Level 2)
   c. It will move at a constant speed across the ice. (Level 3)
   d. It will speed up and then move at its maximum speed. (Level 3)

4. 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. If Jeff stops pushing, what will happen to his car?
   a. It will gradually slow down because there is no force to keep it going. (Level 3)
   b. It will gradually slow down as the force of Jeff’s push decreases. (Level 2)
   c. It will keep moving at the same speed because there is no force to slow it down. (Level 4)
   d. It will stop moving as soon as Jeff stops pushing because there is no force to keep it going. (Level 2)

8. 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. While the engines are on, how will the rocket move?
   a. The rocket will move at a constant speed. (Level 3)
   b. The rocket will move faster and faster as long as the engines are on. (Level 4)
   c. The rocket will move faster and faster it reaches its maximum speed. (Level 3)
   d. The rocket will move only while the engines are on. (Level 2)
9. 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. 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. (Level 2)
   b. It will steadily slow down because no forces are acting on it. (Level 3)
   c. It will continue moving with a constant speed because no forces are acting on it. (Level 4)
   d. It will continue moving with a constant speed because the force from the engines is still acting on it. (Level 2)
Appendix H: Elevate facilitation guide

September 2011
Learning Progressions and Results from 2010/2011 Pre-Post-Follow-up Tests

<table>
<thead>
<tr>
<th>School</th>
<th>Date</th>
<th>Time</th>
<th>Lead Facilitator</th>
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Purpose
To introduce learning progressions and look at reports of student understanding from pre-post-follow-up tests from 2010/2011 school year.

Objectives
- Discuss *Adaptive Schools* article and purposes of professional/teacher learning communities
- Introduce teachers to ELEVATE learning progression
- Problematize traditional approaches to assessment and contrast with design of ELEVATE
- Distribute and begin discussion of 2010-2011 assessment reports

Prerequisites
- Read *The Adaptive School*, Chapter 2: The Importance of Professional Community

Materials
- Learning Progression in T-format (Legal Size, color)
- Breakdown and description of learning progression levels booklets
- “How to read your assessment report” handout
- Assessment Reports 2010-2011

Design for Facilitation

1. **Greetings and introduction (5 minutes)**
   - We’ll be seeing you tomorrow for the pretesting
   - (Thanks for all your help in getting the pretesting finished. We plan to get that data processed so we can bring you the test results at the October meeting.
   - We’ll be starting with a more general discussion today but then will get pretty specific into natural selection. We want to keep the bulk of what we do at consistent with what we do at the other schools, so when we get to the natural selection and assessment report piece we’ll break into two groups, and will go with you to discuss the energy learning progression and constructing a pretest for your students.

2. **Talking about Adaptive Schools Chapter 2 (15 minutes)**
   - We asked you to read a chapter from *Adaptive Schools* last time. We wanted you to read this chapter because we think it frames the approach we will be taking in our research project very well, and helps to explain how schools and departments of
teachers can really change what they are doing by working collaboratively and focusing on effective science instruction.

- We know that [X]HS has been focusing on creating professional learning communities and collaborative planning.
  - How have these communities been structured? What are some of the organizing principles around them?
  - How does the structure of your communities compare with the picture that is presented in the Adaptive Schools chapter?
- In the course of our work together, we will work within a professional community. We know this is different from other professional developments where the outsiders come in and ‘train’ the teachers. Our project instead will focus on the expertise in this group.
- Just because we come together as a group doesn’t make us a community. We want to focus our professional community on these five elements
  - Shared norms and values
    - Discussed last time (meeting norms)
    - Take care of me, take care of us, take care of our values
    - “We are referring to sharing expertise and perspectives on teaching and learning processes, examining data about students, and developing a sense of mutual support and shared responsibility for effective instruction.” Ch2, p?
  - Collective focus on student learning
    - Will be starting this today when we view the assessment reports, and continue once we are developing, enacting, and revising formative assessments
    - Try to get away from ‘reasoning by anecdote’ and focus on actual evidence of teaching and learning
  - Collaboration
    - Accomplishing work together that would not be possible alone
    - Drawing on each other’s expertise to build our knowledge of the discipline and repertoire of teaching strategies
  - De-privatized practice
    - Sharing our teaching with each other and critically reflecting on how to improve
  - Reflective dialogue
    - Listening to each other, giving each other feedback, facilitating the group, coaching each other
- As we proceed with today’s meeting and through the semester, we will be referring back to these elements of professional community to highlight the way that we want to be working together.

3. Introduce Assessment Results and Learning Progression (20 minutes)
- We’d like to start today with a ‘Collective Focus on Student Learning’ by showing you the whole school results of the pre-post-follow up test from last year. This was a 22-
item multiple-choice assessment (we have not started working with the open response items yet).

- This graph breaks down the mean test scores by class type. You’ll see on the back the means, max and min scores, and the standard deviations.

- Keep in mind that this is an assessment that was not necessarily aligned with your instruction, so we wouldn’t expect your students to have really high scores. It’s also designed to be really hard, so we don’t want too many students getting perfect scores on it (this way we can trace growth across multiple years of the research project – that is, there’s room for growth).

- Let’s take a minute to talk about the data:
  - What trends do you notice in the data?
  - What differences do you notice from pre-post-follow up, and between the different types of biology classes?
  - What does this tell us about student understanding?

- Most of what you’ve been able to say about this data is focusing on this idea of the number of questions students got right. But it doesn’t tell you what they were thinking if they got it wrong.

- Usually tests are constructed so that there are right and wrong answers, but in our research, we are interested in learning more about the gray area. So we wrote a different type of multiple-choice item, where each of the ‘wrong’ answers is linked to a common student misunderstanding related to the ‘right’ answer (pass out ‘How to read your assessment report’)

- Here is a sample item with four response options. This item is not actually on the test, but it is a released item from a previous version of the test and is VERY similar to the items your students took.

- This item addresses the idea of limitations in the availability of natural resources, one element of the concept of natural selection.
  - How is this item similar to or different from the assessment questions you’ve used in the past?
  - What kinds of information would you anticipate getting from questions like this as compared to the questions you have used in the past?

- You’ll see that response ‘a’ is the correct answer, and the arrow there links it to the right idea. But below the right idea in that purple table are some common misunderstandings of the idea, and they correspond with different response options.

- At the bottom of the page you’ll see another way to report out assessment data that we’ll be using in this project. We’re not as interested in the total score as we are in the distribution of student responses among the ‘wrong’ choices.

- Presenting the information this way allows us to track movement in student responses to the distractor about this concept, and this sample data shows how students shifted toward the right answer from the pre- to posttest.

- Since the NSF will not allow us to show you the items until the end of the study, your assessment report will consist of a number of tables like this, one for each of the major concepts about natural selection that we are tracking in the study (pass out learning
progression and explanation booklet). So this way you’ll have the information about how students responded to individual items without seeing the actual items.

- The front page of this booklet shows you our learning progression, which consists of the different concepts about natural selection, lined up in order. They build on Mayr’s five facts and three inferences about natural selection. Just like in that sample report, you’ll see the ‘right’ answer in the darkest color at the top, and then the misunderstandings we’ve identified below.
  - Take a minute to look at the levels underneath some of the facts and inferences, and you can flip to a different page in the booklet for more of a description of that kind of idea

4. Exploring Assessment Reports (40 minutes)
- We have prepared an individual assessment report for each of you (Pass out assessment reports). You’ll see on each page a piece of the learning progression and then data on how students responded to items that are matched to the levels in that piece of the learning progression, just like the ‘How to read your assessment report’ example.
- For those of you who taught two multiple levels of biology last year, you will see we have prepared a separate report for each type of course
- We understand that this is a totally overwhelming amount of information – in some ways it’s easier just to look at overall scores!
- In our project, this is where our work starts – not just this year, but each year – by exploring student learning in depth, to help us start to think about what students understand, and what confuses them, and to delve into that gray area of student understanding, or the middle levels on the learning progression.
- We thought it would be helpful to look at one item or set of items with you today so that you can see how we assemble the test data. Then you can take the reports and look at them more in depth and look for interesting patterns in the data. Then the next time we meet we can discuss these results along with the new pretest data results.
- For an explanation of the levels for each item, look in the booklet.
- Take a few minutes to look at your report and pick one or two items you’d like to look at with the group. You might look for items where the pre-post-follow up results are surprising, or which confirm something you remember from teaching the unit.
  - (Give teachers several minutes to look at their reports and find an item or two of interest. Facilitators assist teachers in interpreting assessment reports, discussing ideas from the learning progression, and identifying interesting items to discuss.)
- Share out which items that teachers want to look at make a list.
- Go through items one-by-one (may have to prioritize depending on time).
  - Start by talking about what the item was testing and common naïve ideas students have about that concept. Use booklet as a guide. Look at how the students scored before and after the unit of instruction.
  - Are your results similar to other teachers’ results? Are they similar or different across class types?
For each item, ask teachers to do a replay of their teaching last year. What evidence did you see of these ideas in your classroom? How did they come up? What did you do about them?

5. Looking ahead to next time (5 minutes)
• We know that we’ve given you a lot of information this month; we ask you, between now and the next time we meet, to take a look through all of the sub-sections of your assessment reports. Maybe use a pen or highlighter to mark results that you think are interesting and that you’d like to talk about.
• Next time we will bring pretest reports from your students this year, and use those results to identify concepts from the learning progression that we’d like to focus on as we develop our common formative assessments.
  ➢ Review date/time for next meeting: (regular times)

Facilitators Areas of Focus
➢ Monitor teachers and be ready to help them read and interpret the assessment reports and learning progression
➢ Jot down areas of confusion and ways to improve the facilitation guide (for subsequent school meetings) and assessment report documents.

Notes