Maine Physical Sciences Curriculum Partnership (MainePSP) Seventh Year Research Report

Compiled from Contributions by RiSE Center Faculty, Graduate and Undergraduate Students, Staff, and Partners

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I. Introduction and Summary of Results

There were two original goals of MainePSP research. The first was to investigate student knowledge of content, teacher knowledge of content, and teacher knowledge of student ideas. The second was to investigate the ways in which the community of teachers changed over time through their interactions within the MainePSP. Naturally, as new faculty were hired as part of the MainePSP, as new infrastructure for carrying out research emerged, and as new researchers participated in the project, new research studies were started.

Though the MainePSP was not conceived as a research project, it provided the opportunity for a great many projects. Some of these focused on content understanding (especially in the physical sciences) of both students and teachers, while others focused on scientific practices, the non-content knowledge for teaching that teachers bring to the classroom, teacher leadership, effective ways of discourse and how they can be promoted by teachers, and much more. In this report, we summarize some of the major themes of this work.

To summarize several major results of our project, we found evidence of:

- Improved student performance when teachers were better able to predict their students' incorrect ideas, consistent with the original goals of the proposal
- Growth in teacher knowledge of content, knowledge of their students' ideas, and appropriate pedagogical strategies to address these ideas, consistent with the professional development activities of the project
- Problems in teachers' use of mathematical reasoning in physical science, in a way that affected assessments written by students that only measured partial understanding of student knowledge
- Growth of student knowledge of argumentation as well as using evidence to back up claims in their reasoning, based on the use of targeted teaching materials
- Increased use of productive discourse moves by teachers, encouraging the use of scientific talk in the classroom
- Differences in teaching styles at the middle school, high school, and college level, as measured by observation protocols created in part by members of our project and now disseminated nationally
- Problems in recruiting STEM undergraduates into teaching, when they do not have adequate interaction with the classrooms and instead work with teachers only in the context of summer course planning and revisions
- Growth in community structure, facilitated by the project, as well as changes to this community as teacher networks changed from cross-district to intra-district connections, consistent with the cross-district early implementation of the project and intra-district policy choices that followed

More details about these results, and several more, are provided in the following document.

II. Research on Content Knowledge and Knowledge for Teaching

A great amount of work was done to work with teachers to develop their own content understanding as well as help their students develop a deeper understanding of the content. Three broad areas in the physical sciences, on energy, force and motion, and chemistry, and several topics in the earth sciences, were studied.

A. Teaching and Learning of Physics Topics: Energy

This broad area of research was perhaps the most active throughout the full project. In total, 16 researchers (including faculty (1), post docs (2), graduate students (10), and undergraduates (3)) worked on this project over the 7 years, completing 1 PhD and 1 Masters thesis, and publishing 5 major journal articles (with 3 more in preparation) and 8 peer reviewed conference proceedings papers (with 1 more in preparation).

Energy was studied from multiple perspectives. The focus was consistently on studying professional development activities and teacher knowledge, with findings showing that teachers are often doing very well (they know their students' ideas, they show growth in knowledge, they develop self-efficacy regarding their energy content knowledge). We applied a knowledge-in-pieces approach to model energy, we used discourse and modeling in an embodied learning activity with both students and teachers, and we looked deeply into content knowledge, knowledge of student ideas, and the use of various pedagogical strategies. At times, our work in energy moved beyond the physical sciences and included the earth sciences, and a new project with the biological sciences has just begun as an outgrowth of the MainePSP work.

Throughout the "Energy Project," as broadly defined, one activity has played a guiding role. A survey was designed in the early part of the project to help study both student knowledge and teacher knowledge of student ideas. This survey has been modified several times throughout the project, in a kind of qualitative action research project, to meet the needs of our ongoing investigations. Various iterations of the survey have been used in professional development settings to look at teacher content knowledge, and a masters thesis project is in progress, looking at teacher self-efficacy about their content knowledge, as a result. Teachers' comments about each others survey results were part of different professional development, leading to multiple publications and internationally invited presentations. Further, after studying differences between student responses to similar questions, we began a new research project on a particular kind of reasoning (namely, the flow of "coldness" rather than "heat") that is used by 99% of our students – far higher than is discussed in the research literature. So, this survey played a role in guiding professional development, generating new research activities, and helping develop the careers of multiple undergraduate and graduate researchers.

In the sections below, we describe the specific projects from which this summary is taken. A brief summary of participants and areas studied is shown in the table below:

		Did you study…				
Student	**Year**	**Students?**	**Teachers?**	**Survey?**	**PD?**	**Classroom?**
PhD student	2010-13	X		X		X
MST student	2011-13	X	X	X		
MST student	2011-17	X	X	X	X	
MST student	2012-13	X				X
Post doc	2013-14	X				X
MST student	2013-14		X	X	X	
SURA	2014 summer		X		X	
Post doc	2014-16		X	X		
PhD student	2013-15	X		X		
MST student	2015-16	X		X		
MST student	2016-17		X	X	X	
MST student	2016-17	X		X		
USEP	2017 summer	X		X		
MST student	2017-?	X	X			

1. Correlations between students' performance on assessments and teachers' knowledge of students and energy (K-12, PBIS Students and Teachers)

The project looked at teachers' knowledge of both content and student ideas using written assessments. A survey was developed around the topic of mechanical energy, largely using questions taken from the AAAS Assessment web-bank. Some questions (shown below) were locally created. Teacher responses on these assessments were used as a proxy for teachers' knowledge, and correlations between this knowledge and student performance on a written assessment about energy were made.

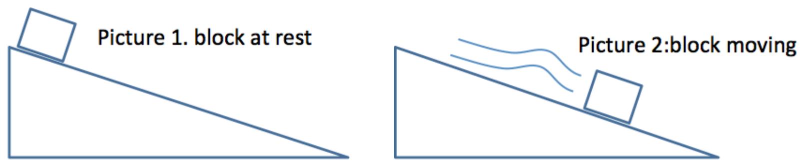
Researchers
Levi Lucy, Michael Wittmann

Project Dates
January 2011 until December 2013

Data collected
Written assessments for both teachers and students, and audio data for the validation study on both teacher and student assessments. An early version of a free response question that played a major role in future research is shown below.

In this question, the assumption that this system is in an Earth-bound system allows this question to be answered in terms of gravitational potential energy rather than work, consistent with the way gravitational potential energy is discussed in many middle school materials. When answering questions such as these, teachers and students were expected to talk about gravitational potential, kinetic, and thermal energy. Teachers were also expected to know what the most common incorrect student responses might be.

The two pictures below show a block on a ramp. There is friction between the block and the ramp. In the first picture the block has not started moving yet. In the second picture the same block is sliding down the ramp.

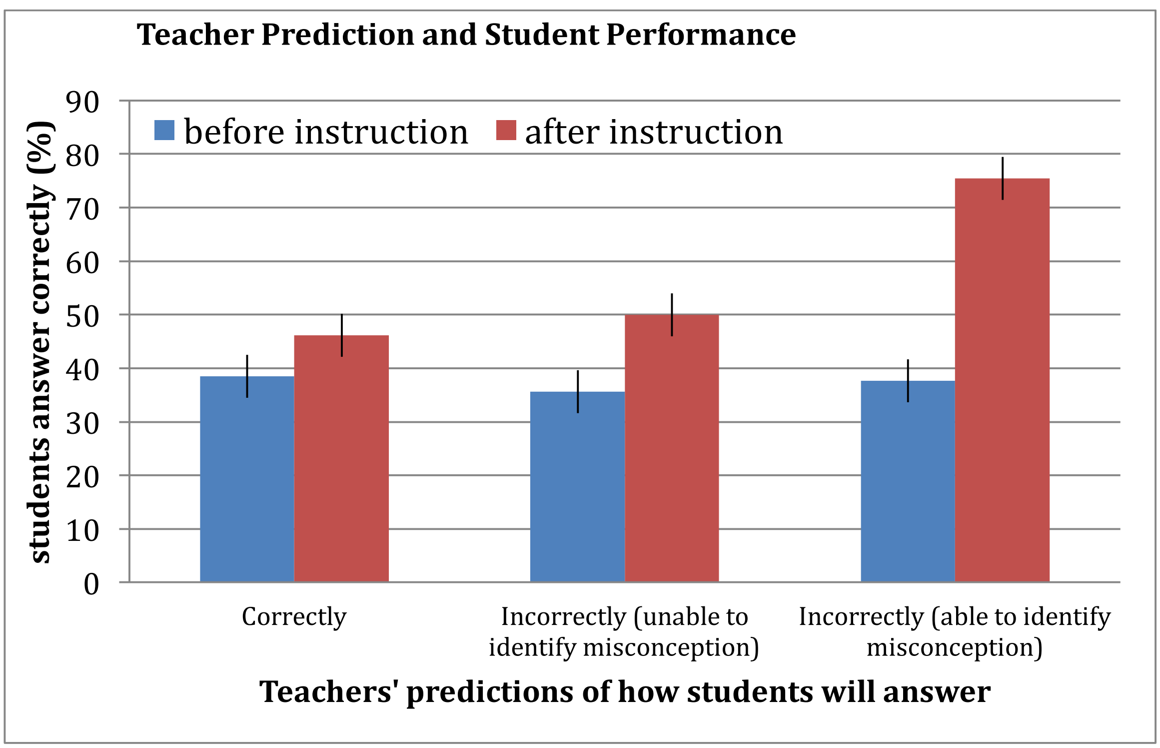


What types of energy are in picture 1?________________________________

What types of energy are in picture 2?________________________________

Findings

For limited circumstances in the data (where it was possible), correlations were found between teachers' knowledge of student ideas on a given question and student performance on that particular question. Teachers who gave a more detailed response on a free response question had students who also gave more detailed responses. Teachers who gave more detailed responses also had students who performed better on the multiple choice portion of the written assessment. Furthermore, teachers who could better explain a wrong student answer to a particular question, had students who performed better on that questions. This last result is summarized in the chart below.



In this chart, we have data from 3 groups of teachers answering a question about energy transfer in the closed system of a spring being compressed by a cart and being released so that the cart shoots (with some kinetic energy) across the floor. For the teachers who predicted that their students would answer correctly, student gains on the question (from before any to after all instruction) were approximately 8%. For those who predicted that students would *not* answer correctly, but gave no explanation for what the most common incorrect answer might be, student gains were approximately 16%. For those teachers who explained the most common incorrect answer (namely, that the spring would continue to have a potential energy, even as the cart now had kinetic energy), student gains were approximately 36%, substantially larger than for all other students.

This preliminary result was an important finding for our overall project, suggesting that we needed to make more efforts to understand how teachers thought about their students' ideas.

Next Steps

See below on further results of the use of the energy survey, both with teachers and with students.

Publications and Presentations

Lucy, L. (2013) Correlations Between Students Performance on Assessments and Teachers' Knowledge of Students and Energy. Unpublished Masters Thesis, Michael C. Wittmann advisor. Available online at http://digitalcommons.library.umaine.edu/etd/2010/

Lucy L. & Wittmann, M.C. (2012) Validating a Survey of Students' and Teachers' Understanding of Energy, contributed presentation at the AAPT Summer Meeting 2012, Philadelphia, PA.

Several publications making use of these results in subsequent studies are listed below.

2. Analysis of teachers' energy understanding and refinement over time

Given the work done by Lucy and Wittmann, several new opportunities for further research presented themselves. Levi Lucy, Greg Kranich, and Michael Wittmann revised the teacher survey to focus on just one question (shown above), the block starting from rest on an incline plane, and then sliding down the frictional surface. Teachers were asked to (1) describe the energy before the block has started sliding and at another location near the bottom, but still before coming off the incline plane, (2) imagine the answer that would most commonly be given by students answering incorrectly, and (3) suggest pedagogical strategies for addressing the most common incorrect response, namely that there is no energy before the block starts moving. Teachers were asked these questions on an annual basis, allowing for year-by-year observation of changes to their answers.

Researchers

Carolina Alvarado and Michael Wittmann

Research Subjects

PBIS Cohort teachers

Focus of the project
Analyzed how the teachers' understanding of energy as well as teaching/learning energy changed while being involved in the MainePSP activities. We looked for an individualized assessment of teachers' growth in their content knowledge, recognition of students' ideas and pedagogical strategies regarding energy while participating in the PD designed by the MainePSP.

Project Dates
September 2014, ongoing process

Data collected
Teacher Energy survey and video of a cohort meeting

Findings
By using the data of those teachers who had responded to the Teacher Energy survey in more than one year, we were able to make comparisons of their understanding of energy concepts, how they recognize their students' ideas, and the type of pedagogical intervention they would do if they find those ideas in their classroom. We interpreted their responses in terms of the NGSS, both in terms of content knowledge and scientific practices.

We observed that teachers evolved in the way they consider energy; they valued the details of the energy transformation and transference more than in the earlier stages. In Table 1, we show the responses of one particular teacher in two years of answering the question. Teachers' responses have a more detailed story regarding the energy involved in the scenario analyzed. Teachers tend to include the indicators of energy as part of a complete answer in their later stage responses, rather than just considering the recognition of the different energy types as a complete answer.

Teachers also showed a positive change regarding the identification of students' ideas prior to instruction, observed in Table 2. By being able to identify the intuitive ideas students bring to the classroom before a formal instruction, a teacher is better equipped to identify the ideas that need to be changed during instruction and what possible strategies to use.

Table 1. Teacher's response regarding a complete answer in two different years while participating in the MainePSP program.

2012-2013	**2013-2014**
In pic 1 there is **GPE** and **thermal**. In pic 2 there is **kinetic** (mechanical) energy, **thermal** and **light**.	In picture there is **potential** energy due to the position of the block and some **thermal** due to the friction. In picture 2 there is still **potential** as well as **kinetic** (mechanical) as well as some **thermal** due to the friction between the block and the surface. The total amount of energy does not change. The energy types only changes form. Energy is not created or destroyed.

Table 2. Teacher's response regarding their students' ideas prior instruction in two different years while participating in the MainePSP program.

2012-2013	2013-2014
Because they **do not have an idea of energy** other than it is something that they here in the news and costs money. Energy makes things warm or move.	The student would equate **energy with movement**. If there is no movement then there must be no energy. the amount of energy will decrease as the object comes to the end of it's journey [...]

Finally, we observed teachers including more active learning strategies while planning an intervention with their students. They valued active learning in earlier stages but showed a more aligned plan in the later stages, indicating that teachers had more resources to implement an actual active learning experience in their classrooms. In Table 3 we can observe the changes in the type of verb usage in two different years. While the earlier response implied a passive role for the student and the teacher as the provider of the knowledge, the later response painted the student in an active role facilitated by the teacher.

Table 3. Teacher's response regarding what would they do if their students still holds an alternative idea in two different years while participating in the MainePSP program.

2012-2013	2013-2014
I would begin by **offering** the scientific definition of energy, then **introduce** the concept of potential energy by stretching rubber bands [...] I would then **explain** how any kinetic energy, the energy of motion, has to result from the presence of potential energy to begin with.	I tend to use **group discussion** a lot and I'm sure we would hammer out a lot of the details in that format. For **demonstrations** I would use the coaster cars to demonstrate how starting higher on the ramp gives the car the potential to travel further

Across this study, we found teacher growth in:

- their causal explanations, like when thermal energy exists in Picture 2 because of friction between the block and ramp.
- their understanding of gravitational potential energy, describing it as arising due to the arrangement of the system, e.g., the height above the ground.
- their description of conservation of energy within a system, focusing not on forms but on the elements of the system, and including thermal energy in their description.
- how they value student ideas, looking at what they know and how they know it rather than what they don't know.
- their awareness of student difficulties.
- how they attend to content ideas as they relate to student learning, for example, their attention to motion as an indicator of kinetic energy (rather than a result of having energy).
- their desire to use knowledge of student ideas to guide what will happen in the classroom.

- their sophisticated reasoning about the system (how it was set up, how it evolved) and awareness that students need to think similarly.
- their attention to a student-centered classroom, in which students' ideas develop through student activity rather than through a teacher's intervention.

Given the population analyzed (namely, experienced science teachers), we considered that the changes observed were most likely due to their participation in the MainePSP program.

We designed a cohort meeting where teachers discussed four responses given by their colleagues in earlier years. This exercise allowed us to observe in a larger population what they consider relevant or valuable in the areas of our study (energy content and pedagogical strategies). The video of the session showed that teachers did not separate between the three dimensions, as was also clear in our analysis of their written work. This suggests that the choice of pedagogical strategies relies on both knowledge of content and of students, while knowledge of students' ideas and difficulties depends to some measure on having a deep enough content knowledge to recognize the strengths and weaknesses of student reasoning.

Further analysis of the teachers' discussions showed additional elements worth further explanation. Teachers passed from evaluating how correct an idea was into recognizing the pieces from each response (rather than evaluating it as a whole). There was an interesting distinction between misconception and omission, which demonstrates an empathy towards the ideas of others, recognizing that missing pieces don't necessarily mean holding a wrong conception. Finally, teachers generated their own version of a complete answer mixing different pieces of the responses given after engaging in productive conversations as a group.

<u>Next Steps</u>

We found these changes in all of the teachers who answered to the Teacher Energy Survey more than once, which is the only population that allowed us to assess changes while participating in the MainePSP program. Given the useful analysis on teachers' growth found with this type of assessment format, we plan to use this format for further exploration of teachers' changes in the three areas discussed. We would like to be able to observe if the responses given in the survey actually reflect the teachers' practices in their classroom. We are working on the publication of two papers, one addressing the methodology of the set of questions regarding one particular physical phenomenon and the changes observed in the teachers' responses, while the second paper will address the use of given data for a pedagogical development session with teachers who are familiar with the item.

<u>Publications/Presentations</u>

Alvarado, C., Wittmann, M.C., and Millay, L. (to be submitted 2017) A tool to measure teacher growth in understanding multiple dimensions of energy, Journal of Research in Science Teaching.

Wittmann, M.C. (2017) Turtles all the way down: How models of knowledge help us think about teachers' understanding of student knowledge, invited talk, Physics Professor Edward "Joe" Redish 75th Birthday Celebration and Golden Jubilee, College Park, MD.

Wittmann, M.C. (2017) Seeking Different Kinds of Understanding: Research with Middle School Teachers, invited talk, AAPT National Meeting 2017, Atlanta, GA.

Wittmann, M.C. (2017) What do we mean by knowledge when teaching physics?, invited talk, APS April Meeting 2017, Washington, DC.

Wittmann, M.C. (2016) Listening to Teachers: Understanding knowledge of energy from multiple perspectives, invited talk, Reunión Anual de la AAPT-MX 2016, "La Física en nuestro entorno," Cancun, MX.

Wittmann, M.C., Alvarado, C., Millay, L. (2016) Teacher Knowledge of Student Difficulties: 'Collectively, We're a Genius!', contributed poster at the Physics Education Research Conference 2016 in Sacramento, CA.

Wittmann, M.C., Alvarado, C., Millay, L. (2016) Teacher Knowledge of Student Difficulties: 'Collectively, We're a Genius!', contributed presentation at the AAPT Summer Meeting 2016, Sacramento, CA.

Alvarado, C. (2016) K-12 pedagogical development courses based on the teachers' survey data. Invited Oral presentation at the American Association of Physics Teachers Winter Meeting, New Orleans, LA.

Wittmann, M.C. & Alvarado, C. (2016) A Model for Data-Centered Teacher Professional Development. Workshop at the Physics Teacher Education Coalition Conference, Baltimore, MD.

Wittmann, M.C., Alvarado, C., & Millay, L. (2016). Teacher responses to their multiple goals for teaching energy. Conference proceeding from the Physics Education Research Conference 2015. College Park, MD.

Alvarado, C. (2015) Desarrollo de cursos para profesores de nivel medio basado en investigación (Development of middle school teacher pedagogical development courses based on research). Invited Oral presentation at the III Coloquio Internacional en la Enseñanza-aprendizaje de las Ciencias, Universidad de Guanajuato, Mexico.

Wittmann, M.C., Alvarado, C., & Kranich, G. (2015) Data-centered teacher professional development. Workshop at the Physics Education Research Conference, College Park, MD.

Alvarado, C., & Kranich, G. (2015) Using data to talk about assessment. Workshop at the No Question Left Behind: Bringing Guided-Inquiry Curricula into Science and Mathematics Classrooms, Orono, ME.

Wittmann, M.C., Alvarado, C., & Kranich, G. (2015) Using data to talk about teaching. Workshop at the High School Physics and Physical Science Teachers meeting, Orono, ME.

Alvarado, C., Wittmann, M.C., & Millay, L. (2015) Professional development promotes deeper understanding by teachers analyzing teacher responses. Poster presentation at the American Association of Physics Teachers Summer Meeting. College Park, MD.

Wittmann, M.C., Alvarado, C., & Millay, L. (2015) Teacher growth in pedagogical knowledge of energy in the MainePSP. Poster presented at the American Association of Physics Teachers Summer Meeting. College Park, MD.

Alvarado, C., Wittmann, M.C., & Millay, L. (2015) Change in Teachers' Views about Energy in the MainePSP. Poster presentation at the Foundations and Frontiers of Physics Education Research. Bar Harbor, ME.

Wittmann, M., & Alvarado, C. (2015) Measuring Change in Teachers Views about Energy in the MainePSP. Poster presentation at the Physics Teacher Excellence Coalition (PhysTEC) Conference 2015, Seattle, WA.

Alvarado, C., & Wittmann, M.C. (2015) Change in Teachers' Views about Energy in the MainePSP. Oral presentation at the 2015 American Association of Physics Teachers Winter Meeting, San Diego, CA.

Alvarado, C. (2014) Reconociendo las ideas de energía en estudiantes (Recognizing energy ideas in students). II Coloquio Internacional en la Enseñanza-aprendizaje de las Ciencias, Universidad de Guanajuato, Guanajuato, Mexico. November 2014.

Alvarado, C., & Wittmann, M.C. (2014) Entendimiento de Energía en profesores de nivel secundaria (K-12 teachers' understanding of energy). Oral presentation 2014 Annual Reunion of the American Association of Physics Teachers – México Chapter, Universidad de Guanajuato, Guanajuato, Mexico.

3. Learning about Modeling and Energy Through an Embodied Modeling Activity (K-12, PSP Teachers and Earth Science Students)

This study investigates learning about science content through participating in an embodied modeling activity (Energy Theater or ET). The researchers conceptualize ET as an activity in which participants engage in the practice of modeling and the research is focused on the kinds of learning about science content that is supported through this practice. For the analysis the Knowledge in Pieces perspective on conceptual change and learning is being utilized.

<u>Researchers</u>
Lauren Barth-Cohen & Michael Wittmann

Project Dates
Data collection began in Spring 2014 and analysis is ongoing.

Data collected
Video and audio of PSP teachers participating in ET through a Wednesday collaborative, and video and audio of the 9th grade students participating in the same ET activities in their classrooms. Also, in this data the participants were doing ET about both topics in earth science and topics in physics.

Findings
The new science education standards foster interest in understanding how scientific practices contribute to learning science content. Here we contribute to this discussion in the context of an embodied modeling environment. Four classrooms of high school science students each self-organized themselves to use their bodies to represent the dynamic equilibrium of the earth's energy, as energy joins and leaves the earth at relatively equal rates. Through qualitative data analysis using coordination class theory we show that the students used their conceptual understanding of dynamic equilibrium to generate and then to revise their models. We show that there were mismatches between what content students represented within their model and what other students expected to be represented within their peer's model. These mismatches led students to modifying the conceptual content that was being represented in the model and to modifying how they represented that content. We argue that these mismatches function as a mechanism to drive model revision and this result affirms the synergistic importance of both the conceptual content and the particular representation of that content in the modeling process.

Publications
Barth-Cohen, L. A. & Wittmann, M. C. (2017) Aligning Coordination Class Theory with a New Context: Applying a Theory of Individual Learning to Group Learning. Science Education, 101(2), 333-363. http://onlinelibrary.wiley.com/doi/10.1002/sce.21264/full doi:10.1002/sce.21264

Barth-Cohen, L. & Wittmann, M. C. (2016). Expanding Coordination Class Theory to Capture Conceptual Learning in a Classroom Environment. In Looi, C. K., Polman, J. L., Cress, U., and Reimann, P. (Eds.), *Transforming Learning, Empowering Learners: The International Conference of the Learning Sciences (ICLS) 2016, Volume 1* (pp. 386-393) Singapore: International Society of the Learning Sciences.

Barth-Cohen, L. & Wittmann, M. C. (2015). Mismatches between Represented Science Content and Unmet Expectations as a Mechanism of Model Revision. *National Association of Research in Science Teaching 2015*.

4. Content Knowledge for Teaching Energy (PBIS teachers)

As an outgrowth of the work on teacher knowledge, begun in the MainePSP, co-PI Wittmann was also a local PI on a project to study Content Knowledge for Teaching Energy.

This study investigated teachers' knowledge of energy and of their students' ideas. The goal of this work was to better understand the role of teacher knowledge (of content, of students, and of content as focused on teaching and learning) on classroom actions and student learning. Much of this work, done locally, is described above, in the section on the analysis of teachers' energy understanding.

<u>Researchers</u>
Michael C. Wittmann, Lauren Barth-Cohen, Alex Axthelm. Primary outside collaborators are from Rutgers University (PI: Drew Gitomer, also Eugenia Etkina), Seattle Pacific University (PI: Stamatis Vokos), Facet Innovations (PI: Jim Minstrell), ETS (PI: Geoffrey Phelps, also Courtney Bell), and Horizon Research, Inc. (evaluator: Sean Smith)

<u>Project Dates</u>
The project began September 2012 and ended in the form described below in 2014.

<u>Data Collected</u>
The project collected artifacts from several teachers who volunteered to participate in the study. From these teachers' students, we also gathered classroom data on student work, collected by teachers from homework and in-class assignments and tests. Finally, we surveyed students in this class with a specially designed survey that was independent of other surveys on energy that have been used in the project in the past.

<u>Findings</u>
The design with collaborators at Rutgers, SPU, ETS, Facet Innovations, and Horizon was focused on high school teachers, and the concepts used to design the teacher assessment and student knowledge assessment were very often beyond the knowledge that is needed to work in middle school physical science classrooms. As a result, the major involvement in this project ended, and the emphasis on middle school teaching and learning, as well as middle school teachers, was continued as described above.

<u>Next Steps</u>
Based on our preliminary findings about survey and assessment design, we needed to make more efforts to recruit high school teachers to participate in the study. This would have provided an excellent opportunity for the MainePSP to extend the question of vertical alignment to the high schools, much like the MaineESP has extended the question of STEM learning into the elementary schools. For middle school teachers, the concepts of energy used in Earth science and physics courses in high school seem as horizon content knowledge – what needs to be known next – suggesting a valuable interplay between teachers at different grade levels. Given limitations in personnel at the time of this project work, these attempts at extended vertical integration were not pursued further.

5. Energy: Differentiation between Thermal Energy and Coldness

When we examined survey data gathered over time in the MainePSP, we consistently found that students, and also many teachers, had great difficulties when responding to survey questions about thermal energy transfer. In particular, many thermal energy questions are about the flow of energy from hot to cold objects, consistent with the NGSS. In many ways, this flow suggests the metaphor of energy as a substance, as if a substance were flowing from location to location or object to object. We noticed that one popular answer to a question allowed students to answer as if the substance were not "heat" or "thermal energy" but was instead "coldness." We brought the data forward to teachers at the 2015 MainePSP Fall Summit, and based on discussions with teachers and an examination of existing research in this area, we developed a Collaborative in 2016 and a research project focused on this topic. This project was then expanded to include an MST thesis project as well as a 2017 USEP student project.

The original assessment, designed by Lucy and described above, had been modified to include questions about thermal physics, not just mechanical physics. As before, the survey questions were used as assessments of conceptual understanding of students prior to and after instruction to measure the changes due to instruction. Students explored the conceptual understanding of Energy, identifying the different forms of energy, its transformation into other energy forms, the transfer of energy among the objects in the system, and the conservation of the energy within the system. In the new survey, with additional thermal physics questions compared to before, three questions were of interest.

The survey was designed to assess the topics covered in the Energy unit, using mostly multiple-choice items. It allowed us to give feedback within a reasonable time to teachers regarding the performance of their class. A report of the results prior to instruction allowed teachers to be aware of the ideas held by their students to be considered in their instruction. A comparison of the pre and post instruction responses allowed the teachers to observe the students' conceptual change.

We explored the understanding of thermal energy using multiple items in the survey to see if there is a coherent understanding of thermal energy when the item implies *warm*/*hot* items compared to when it uses *cold* items in the scenario studied.

<u>Researchers</u>
Michael Wittmann, Laura Millay, Adam Rogers, and Carolina Alvarado.

<u>Project Dates</u>
Collection of survey data and modification of the items Summer 2015
Collection and analysis of survey data Fall 2015 and Spring 2016
Collection of modified survey data Fall 2016 and Spring 2017, and interviews with middle school students, Spring 2017.

<u>Data collected</u>
We used the 2015-2016 data in order to inform our analysis of conceptual understanding, as well as data from the 2014-2015 for comparison in the response patterns. We modified the existing survey questions to include answer items that included coldness (in questions that had not had them before) and both coldness and thermal energy, and used these survey responses in 2016-17. Finally, we used open-ended versions of these survey

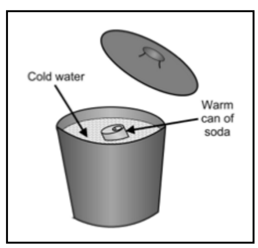
questions in interviews with middle school students (N=17, so far) to further explore their thinking about coldness.

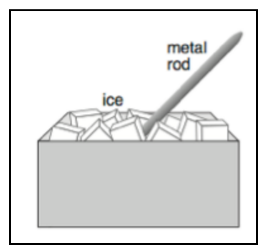
In 2016, we hosted two collaborative sessions with teachers to discuss the conflict observed in the data. We collected energy models from the teachers exploring particular scenarios in order to track the different interpretations of thermal energy in a scenario that works with cold objects (i.e. snow in a bucket interacting with room temperature rods).

<u>Findings</u>

Students' Survey Responses
The survey has two items using similar objects submerged in ice or cold water. Both items are designed to assess the conceptual understanding of thermal energy being transferred as the submerged object lowers its temperature (Figure 1). There are some differences in the type of wording used as well as the details of the scenario itself that makes them different to each other.

Figure 1. Scenarios used in the two items analyzed. They both includes objects at room temperature interacting with a colder substance, cold water or ice.

(a) 

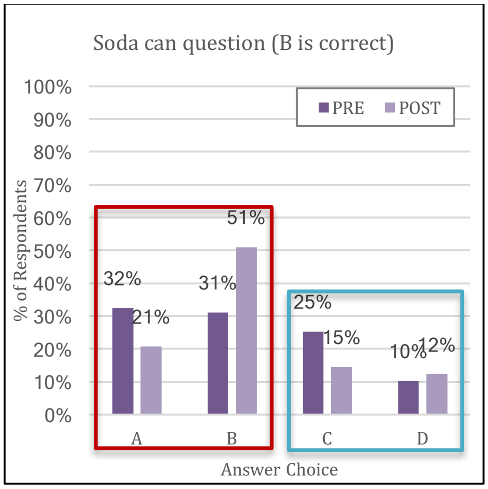
(b) 

The items have multiple choice answers that includes the idea of thermal energy or heat being transferred as well as coldness or cold being transferred. Students' responses show that the responses using coldness as an entity is attractive to students. There is a different tendency to use thermal vs. coldness to explain the two scenarios (Figure 2). Students use the idea of cold as an entity with a higher frequency to explain the thermal interaction between the rod and the ice (scenario b), even after instruction. In contrast, the use of coldness to explain the interaction of the soda and cold water decreases after instruction not being as popular as using thermal energy to explain the scenario.

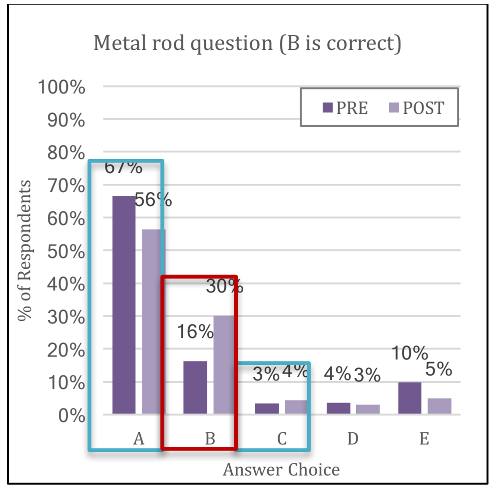
Given the results found, we decided to share this analysis with teachers and explore with them the different interpretations that could be made from both scenarios depending on the type of approach used, thermal versus coldness. As found in the literature, our students can hold both models simultaneously. While refining the understanding of thermal energy during the class, the idea of coldness hasn't been eliminated from the resources they use after instruction to answer the questions.

Figure 2. Students' responses prior and post instruction from the two explored items. Answers within the red rectangle use the idea of thermal energy, while answers within the blue rectangle use the idea of coldness as an energy form.

(a)



(b)

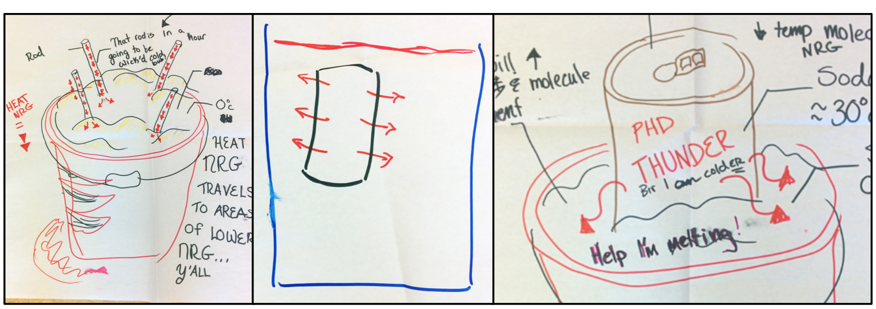


Teachers' Energy Diagrams

After presenting the data to the teachers participating in the collaborative sessions, we decided to engage them in an activity trying to model the energy interaction in the given scenarios (Figure 1), as well as a different scenario that uses a thermos with hot water. In small groups teachers worked on generating a diagram to explain the energy transference among the different objects involved in the scenarios. Three different categories were found from the diagrams used.

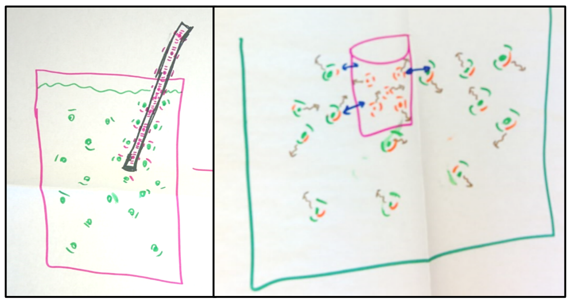
The first category of representations focuses on the thermal energy transfer direction, using thermal energy as a flow, see Figure 3. In the diagrams we can observe that the energy moves from the hotter object into the colder object. The representation doesn't allow us to know more details about the thermal interaction, is energy lost? Is the entire object (rod or can) changing its temperature at the same rate (same temperature on the top or bottom of the object)?

Figure 3. Representations focusing on thermal energy transfer as flow.



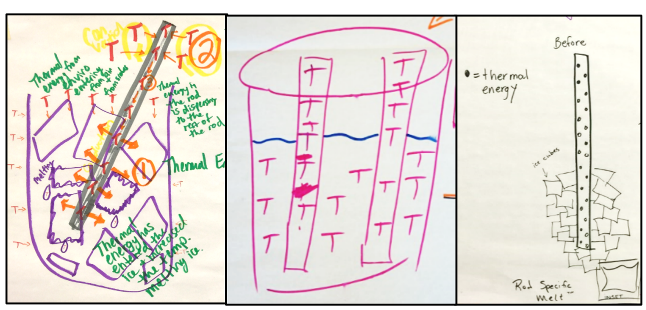
A second representation uses a molecular level to explore the thermal energy, using the vibration of the molecules as an indicator of thermal energy (Figure 4). The more vibration of a molecule the more thermal energy it has. By using a diagram to represent the scenario in two different moments we can observe the change in the thermal energy of the different objects involved. In some cases, colors are used to track the origin of the extra thermal energy. This representation may allow us to observe if the change in thermal energy is uniform in the objects or if it is gradual. The representation could indicate energy conservation if the number of lines used to represent the molecular vibration/thermal energy remains constant in both instances, or may indicate a lack of conservation if the number differs meaning energy was lost or added to the system.

Figure 4. Representations focusing on thermal energy as molecular vibration.



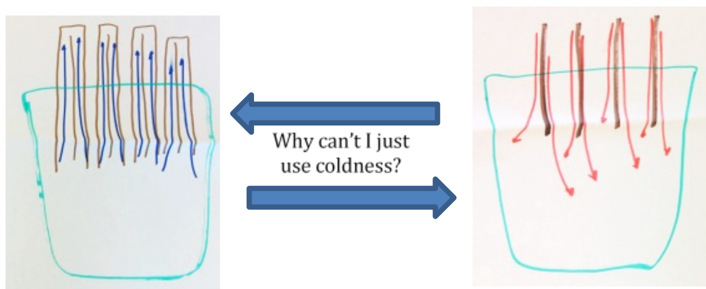
Finally, the third type of representation shows units of energy making an explicit reference to the type of energy involved in the scenario (Figure 5). This particular representation seems to share features with the previous two categories. Some of the teachers' representation of energy by units includes the transfer of those energy units individually, allowing to have a story among time of the energy. In other instances they use the relative amount of thermal unit energies in the objects to indicate whether one object is hotter than the other or if they reach thermal equilibrium.

Figure 5. Representations focusing on thermal energy as units.



These models allow us to understand the different approaches that can be used when talking about thermal energy in scenarios that use cold objects. The different categories emphasize different aspects of the energy interaction: direction of the transference, approaching thermal energy in a molecular level, and observing thermal energy as units to facilitate the idea of conservation of energy. Nevertheless, as one of the groups discussed it, this doesn't inform us how to discard the idea of coldness as something that is being transferred instead of thermal energy (Figure 6). While we know different ways to talk about this using thermal energy, it doesn't mean that the idea or tendency to use coldness as an entity if the options allow it will be eradicated.

Figure 6. Representation showing both models, thermal energy and coldness, can be held simultaneously.



<u>Next Steps</u>

In the literature we can observe an awareness of the misuse of *cold* as an energy entity rather than describing a "cold object" as something that has less thermal energy. This dual use of thermal energy can lead to complications when we try to keep the analysis of conservation of energy. Nevertheless, there is no follow up in the literature on how to address it, or a deeper understanding of this conflictive conceptual understanding.

We have begun a study to investigate the issue in greater detail. We are studying the implications of holding both thermal and coldness energy forms simultaneously, and will explore the complications of instructions when trying to address it. We would like to eventually be able to propose specific strategies to help modify the student perspective, allowing them to find the use of *cold* as an energy entity not useful and keep thermal energy as a model that works for both (warm and cold objects) scenarios.

We will also investigate the conversation among teachers while creating the diagrams in order to observe the features that were discussed while analyzing the scenario. This type of analysis would give us more detail on how they consider the thermal energy observed, how they define the story to tell, and whether or not they were including their students' perspectives while engaging in the activities.

<u>Presentations</u>

Alvarado, C., Wittmann, M. C., Rogers, A. Z., & Millay, L. A. (2016). Problematizing "cold" with K12 Science Teachers. In D. L. Jones, L. Ding, & A. Traxler (Eds.), 2016 Physics Education Research Conference Proceedings (pp. 32–35). https://doi.org/10.1119/perc.2016.pr.003

C. Alvarado, M.C. Wittmann, Adam Z. Rogers, L. Millay (2016) Problematizing 'cold' with K12 Science Teachers, contributed poster at the Physics Education Research Conference 2016, Sacramento, CA.

C. Alvarado, M.C. Wittmann, Adam Z. Rogers, L. Millay (2016) Who Let the Cold Out?, contributed presentation at the AAPT Summer Meeting 2016, Sacramento, CA, 2016 July.

Wittmann M.C, Alvarado C., Millay, L. & Kumpa R. (2015) Keeping out the cold? Finding a gap in students' learning about energy transfer. Presentation at the Maine Partnership Summit: Evidence-based strategies for excellence in teaching. Carrabassett Valley, ME.

Rogers, A. (2016) The Persistence of Coldness: Exploring Students' and Teachers' Thinking about Thermal Energy. Presentation at the University of Maine Graduate and Undergraduate Research Symposium. Bangor, Maine.

B. Teaching and Learning of Physics Topics: Force and Motion

The topic of Force and Motion has been studied throughout the MainePSP, beginning first with a project similar to the Lucy/Wittmann survey-driven work on student and teacher knowledge of content and teaching knowledge of student ideas, then branching out into several other projects as new results focused our attention on particular ideas. In total, 7 researchers (including faculty (3), graduate students (3), and undergraduates (1)) worked on this project over the 7 years, completing 2 Masters theses and 1 Honors thesis, and publishing 1 peer reviewed conference proceedings paper (with 1 more in preparation). Below, we describe the work in terms of three major strands of activity.

1. Knowledge in Force and Motion (PBIS Student and Teacher, K-12)

<u>Researchers</u>
Thompson, Stetzer, Laverty

<u>Focus</u>
Investigating relationships between teachers' content knowledge, pedagogical content knowledge, and student learning in the context of Force and Motion in PBIS classrooms

<u>Project Dates</u>
Ongoing; began Summer 2011

<u>Data Collected</u>
2013-2014: A revised student survey was administered both pre-and-post instruction of the *VIM* unit to all PBIS students. The survey measuring content knowledge (CK) and pedagogical content knowledge/knowledge of student ideas (KSI) was also administered to all PBIS teachers in Fall 2013.

<u>Findings from the student surveys</u>
2013-2014 student surveys did not find overall learning gains of force and motion concepts among the PBIS students. Further analysis of the data grouped the survey items into five content categories to look at more specific topics (Newton's first law, second law, third law, uniform motion, changes in motion). Little shift was found in student understanding pre-to-post across any of the five content categories. The analysis indicates that students tend

to relate net force with velocity, rather than net force with acceleration. Students infer that if an object is moving in a direction, then there must be a net force moving it in that direction, regardless of whether the object is speeding up, slowing down, or traveling at constant speed. Students additionally relate forces with motion rather than changes in motion, showing that they are lacking the connections between balanced forces and uniform motion. Survey items also show that students have difficulty in defining, and distinguishing between, different types of motion.

These findings from the student survey informed efforts to redesign the force and motion curriculum with a greater focus on achieving student understanding of force and motion concepts. A task force of teachers worked during the summer of 2014 to develop a set of student activities, with supporting teacher materials that would map a clear learning progression of Newtonian force and motion concepts while still maintaining the strong engineering design concepts present in the *VIM* curriculum. The task force, comprised of middle school teachers and researchers from the MainePSP, worked to identify the core force and motion concepts, align these concepts with national standards, and review research based curricula to develop a coherent progression that would support a learning progression towards an understanding of Newton's laws of motion. This revised set of materials was then piloted by the task force teachers in the fall of 2014. The task force reconvened in the early winter of 2015 to reflect and complete revisions to the curriculum. They then provided training and professional development to other PSP teachers for a second phase of piloting that occurred during the spring of 2015.

<u>Findings from the teacher survey</u>
Teacher surveys from 2013-14 showed some persistent gaps in content knowledge understanding, even after professional development. These misconceptions are congruent with findings from the literature base and previous studies measuring understanding of Newtonian force and motion concepts and have shown to be resistant to change.

<u>Posters and Presentations</u>
Laverty, D.P. (2016) *Investigating Teachers' Content Knowledge and Pedagogical Content Knowledge in a Middle School Physical Science Curriculum on Force and Motion*. Master's Thesis with advisors John R. Thompson and MacKenzie Stetzer, University of Maine, Orono, Maine.

D. P. Laverty, J. R. Thompson, and M. R. Stetzer (7/28/12). *Preliminary investigations of physical science teacher content knowledge and PCK*. American Association of Physics Teachers Summer Meeting. Philadelphia, PA.

2. Teacher-Generated Common Formative Assessments For 8th Grade Force and Motion

In the process of creating professional development activities for teachers, Greg Kranich worked closely with John Thompson, Mac Stetzer, and Dan Laverty to analyze the PBIS teaching materials that teachers were using in the classroom. Several serious errors were observed, including ones in an area where teachers and students both showed difficulty. Many said that an object speeding up has positive acceleration and an object slowing down has negative acceleration. This is only sometimes true, namely when the object is moving with a positive velocity.

To address these and other issues with the PBIS materials, a group of teachers came together to create a modified instructional unit. This would provide a platform in which to first learn about motion before moving on to the work on forces. As part of this curriculum modification, 4 teachers came together, with Greg Kranich leading their work, and developed a set of new classroom materials. They also created an assessment for investigating how well students had learned the material.

<u>Researchers</u>
Gregory Kranich, Michael Wittmann, Carolina Alvarado

<u>Research Subjects</u>
Four MainePSP teachers

<u>Focus of the project</u>
We examined a group of teachers in the process of creating common formative assessment items for an 8th grade unit on force and motion. In particular, we were interested in how the conceptual understanding of the individuals in the group shaped their interactions and informed the development of an assessment item.

<u>Project Dates</u>
October 2014-January 2015

<u>Data collected</u>
We collected video from six planning meetings and the four module assessments created by the group.

<u>Findings</u>
We studied a group of middle school teachers as they modified curriculum and developed common formative assessments on force and motion concepts. While discussing assessment goals for student understanding of acceleration, two of the teachers held opposing models about the implications of the sign of acceleration on the direction of an object's motion and whether it is speeding up or slowing down. Failing to resolve the inconsistency between their individual models, the resultant assessment item was such that both models would provide the same correct response, albeit for different reasons. The potential for correct answers for incorrect reasons perpetuated ambiguity into its classroom use as a formative measure of student understanding. More specifically, the item had limited ability both to accurately inform teacher instruction, interventions, and feedback that would support students in identifying their mistakes and refining their thinking.

<u>Contributed Publications/Presentations</u>

G. D. Kranich, M. C. Wittmann, and C. Alvarado, Teachers' conflicting conceptual models and the efficacy of formative assessments, 2015 PERC Proceedings [College Park, MD, July 29-30, 2015], edited by A. D. Churukian, D. L. Jones, and Lin Ding, doi:10.1119/perc.2015.pr.040.

G. D. Kranich, 2016, "Inconsistent conceptions of acceleration contributing to formative assessment limitations (Master's thesis)," University of Maine, Retreived from: http://digitalcommons.library.umaine.edu/etd/2438/

RiSE Conference 2015: Teaching, Learning, and Assessment in the Context of the Next Generation Science Standards and the Common Core State Standards in Mathematics, University of Maine, Orono, ME, June 2015, "Using Data to Talk about Assessment," Carolina Alvarado, Gregory Kranich (Workshop).

Kranich, G. D., Wittmann, M. C. & Alvarado, C. (2015) Formative Assessment Efficacy as Affected by Teachers' Conflicting Conceptual Models, contributed poster at the 2015 Summer AAPT meeting. (Presentation)

The Summer 2015 Meeting of the American Association of Physics Teachers (AAPT), University of Maryland, College Park, MD, July 2015, "Consequences of teachers' content difficulties on planned instruction and assessment," Gregory Kranich, Michael Wittmann, Carolina Alvarado (Presentation).

The Summer 2015 Meeting of the AAPT, University of Maryland, College Park, MD, July 2015, "Teachers' pedagogical decisions when facing gaps in content knowledge," Gregory Kranich, Michael Wittmann, Carolina Alvarado (Poster).

The Summer 2015 Physics Education Research Conference (PERC), University of Maryland, College Park, MD, July 2015, "Data-centered teacher professional development," Michael C. Wittmann, Carolina Alvarado, Gregory Kranich, Alex Axthelm (Workshop).

3. Force and Motion: Developing the Geometric Model of Vectors through Kinesthetically Engaging Activities with 8th Grade Physical Science Teachers and Students

Based on past results, growing out of the Laverty/Thompson/Stetzer study and the Kranich/Alvarado/Wittmann study, a new project was begun to help students and teachers with considering coordinate systems and the directionality of motion, force, and acceleration. This work involved curriculum development, research into teacher knowledge of coordinate systems and accelerated motion, and research into student knowledge of the same.

<u>Researchers</u>
Peter A. Colesworthy, Carolina Alvarado, Gregory Kranich, Elijah Tabachnick, & Michael C. Wittmann

Research Subjects
Maine PSP 8th Grade Teachers and Students

Focus
Research over the past 30 years has highlighted the struggles that students have with understanding vector quantities at all levels of education. Prior research has found that students are able to understand the vector nature of displacements, but fail to transfer that vector knowledge to quantities such as velocity and acceleration. To isolate issues about vectors from issues of algebra, I am studying this problem in 8th grade physical science students' conceptual understanding of vector quantities without the direct use of algebra. I am carrying out a design experiment around a modified course sequence; the proposed modification utilizes forces as an anticipatory model for which the students can begin to develop their sense of the properties of a vector in a kinesthetically engaging experience. This introduction of vectors, through the use of forces, provides students the ability to then reinforce their understanding of vectors in the environment of displacement vectors. This design should encourage students' abilities to transfer their understanding of vectors to the concepts of velocity and acceleration, and thus gain a deeper understanding of all vector quantities.

Project Dates
October 2015 - June 2017

Data Collected
Interviews with and surveys of teachers answering questions about accelerated motion, audiovisual recordings of teacher professional development activity, working through, usability testing, and providing feedback on student worksheets, samples of student work during piloting of the adapted curriculum, reflective student statements after completion of the adapted force and motion introductory lesson, and 20min. audio recording of debriefing meeting with piloting teacher, field notes of the implementation of the revised materials.

Findings:
Working with the piloting teacher indicated that the lessons were highly effective at developing the concept of a vector arrow. Students developed skills that many had not expected, were able to reason about direction of vectors beyond the predicted level, but still struggled to apply the correct signs to certain kinds of motion.

Due to major technological issues regarding the creation of materials for multiple classes, the project was modified during the 2016-17 academic year to focus less on the use of force probes and more on the use of vectors to describe motion. In the process, a series of professional development activities was planned. Several teachers were observed to have the same struggle with accelerated motion that students have. They were surprised to find that positive acceleration could mean slowing down (only true when traveling with a negative velocity) or that negative acceleration could mean speeding up (again, only true when traveling with a negative velocity). New materials were developed to help address theses issues. These materials were piloted during the spring of 2017.

One result of this work was an Honors thesis by Elijah Tabachnick:

Tabachnick, E. J. (2017). An Analysis of Inservice Physical Science Teachers' Understanding of Accelerated Motion. Honors Thesis (Physics), University of Maine.

<u>Contributed Publications/Presentations</u>

Tabachnick, E. J., Colesworthy, P., and Wittmann, M. C. (to be given July, 2017), Physical Science Teachers' Resources for Accelerated Motion, contributed presentation, Summer meeting of the American Association of Physics Teachers, Cincinnati, OH.

Tabachnick, E. J., Colesworthy, P., and Wittmann, M. C. (to be given July, 2017), Understanding the Origins of Teachers' Resources for Accelerated Motion, contributed poster, Summer meeting of the American Association of Physics Teachers, Cincinnati, OH.

Tabachnick, E. J., Colesworthy, P., and Wittmann, M. C. (to be given July, 2017), Understanding Middle School Physics Teachers' Content Knowledge of Acceleration, contributed poster, Physics Education Research Conference, Cincinnati, OH.

C. Teaching and Learning of Physics Topics: Electronics

1. Student Understanding of Analog Electronics (University Students)

To date, there has been relatively little work conducted by the physics education research community on upper-division laboratory courses. Perhaps even more importantly, while there is a large and incredibly rich body of literature on student understanding of introductory electric circuits, there is surprisingly little published work on student understanding of (non-introductory) analog electronics. This is even more surprising given that the topic is covered in both physics and engineering courses. For this reason, student understanding of analog electronics remains a primary focus of my scholarly activities.

In upper-division laboratory courses on analog electronics, students are expected to develop a functional understanding of the behavior of electronic circuits so that they may design and construct practical circuits for applications in both research and the real world. At the same time, many studies have shown that students struggle with basic dc circuits in introductory physics courses, and some of these difficulties have been found to persist both during and after upper-division electronics instruction. For these reasons, the investigation initially focused on student conceptual understanding of analog electronics exclusively, with an emphasis on both canonical electronics topics (*e.g.,* transistor and op-amp circuits) and the application of fundamental circuits concepts (*e.g.,* Kirchhoff's rules). We are also examining the extent to which the nature of student understanding of analog electronics (including, for example, the specific difficulties identified and their relative prevalence) in physics and engineering courses depends upon disciplinary context. In addition, we are currently developing and refining research-based instructional materials for use in both disciplines.

<u>Researchers on project:</u>
Kevin Van De Bogart (Ph.D student) and MacKenzie Stetzer

<u>Publications</u>

K. L. Van De Bogart and M. R. Stetzer, “Investigating physics and engineering students’ understanding of ac biasing networks,” *Proceedings of the 2016 Annual Conference & Exposition of the American Society for Engineering Education* (New Orleans, LA, June 26-29, 2016), American Society for Engineering Education (2016).

C. P. Papanikolaou, G. S. Tombras, K. L. Van De Bogart, and M. R. Stetzer, “Investigating student understanding of operational-amplifier circuits,” *Am. J. Phys.* **83,** 1039-1050 (2015).

K. L. Van De Bogart and M. R. Stetzer, “Student understanding of circuit loading in physics and engineering,” *2014 Physics Education Research Conference Proceedings* (Minneapolis, MN, July 30-31, 2014), edited by P. V. Engelhardt, A. D. Churukian, and D. L. Jones, 251-254 (2015).

2. Student Learning in Upper-Division Laboratory Courses (University Students)

In all upper-division laboratory courses (including those on analog electronics), there are many important learning goals (*e.g.,* the development of experimental design skills and troubleshooting expertise); many of these are neither assessed nor articulated explicitly, and, in general, relatively little is known about the extent to which these goals are being met. To date, there has been little research by the PER community in these areas, despite the fact that many of them are highlighted in the 2014 “AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum.”

For this reason, in the context of analog electronics, we have begun to investigate student skills in the areas of circuit troubleshooting and circuit design and chunking. An ongoing collaboration with colleagues at the University of Colorado Boulder (Heather Lewandowski and Dimitri Dounas-Frazer) has led to an in-depth analysis of interviews in which pairs of students were asked to repair a malfunctioning operational-amplifier circuit. We have employed complementary theoretical frameworks of experimental modeling (Zwick *et al.* 2015) and socially mediated metacognition (Goos *et al.* 2002) in order to gain greater insight into the nature of students’ authentic troubleshooting practices. It is hoped that our findings may inform instruction in troubleshooting and may guide the development of research-based instructional strategies.

<u>Researchers</u>
Kevin Van De Bogart (Ph.D student) and MacKenzie Stetzer

<u>Publications</u>
D. R. Dounas-Frazer, K. L. Van De Bogart, M. R. Stetzer, and H. J. Lewandowski, “Investigating the role of model-based reasoning while troubleshooting an electric circuit,” *Phys. Rev. Phys. Educ. Res.* **12,** 010137 (2016). (*Note:* Editors’ Suggestion.)

K. L. Van De Bogart, D. R. Dounas-Frazer, H. J. Lewandowski, and M. R. Stetzer, “The role of metacognition in troubleshooting: An example from electronics,” *2015 Physics Education Research Conference Proceedings* (College Park, MD, July 29-30, 2015), edited by A. D. Churukian, D. L. Jones, and L. Ding, 339-342 (2016). (*Note:* 2015 PERC Notable Paper.)

D. R. Dounas-Frazer, K. L. Van De Bogart, M. R. Stetzer, and H. J. Lewandowski, "The role of modeling in troubleshooting: An example from electronics," *2015 Physics Education Research Conference Proceedings* (College Park, MD, July 29-30, 2015), edited by A. D. Churukian, D. L. Jones, and L. Ding, 103-106 (2016).

D. Studies of Teaching, Learning, and Professional Development in Chemistry at Middle School, High School, and University Levels

1. Fostering Connections Between Macroscopic, Submicroscopic and Representational Levels Using Analogical Reasoning in the Chemistry Lab (Undergraduate Students)

This project addresses gaps in current knowledge related to understanding what types of instructional strategies are effective in helping students make connections between macroscopic, submicroscopic and representational domains. There are two overarching research questions for this study: 1) How do students use analogical reasoning in constructing scientific arguments related to chemistry lab work? and 2) How does repeated exposure to **CORE** (Chemical Observations, Representations, Experimentation) lab experiments influence students' abilities to coordinate ideas across macroscopic, submicroscopic and representational levels? The frameworks used for assessing analogical reasoning are based on structure mapping theory and the Teaching-with-Analogy Model, while analysis of scientific arguments is adapted from Toulmin's argumentation model, which frames construction of a scientific argument in terms of using evidence and reasoning to make claims. The USEP student will focus on examining student work associated with construction of an analogical reasoning activity, scoring it using a framework associate with structure mapping theory.

Researchers
Anna Turner, Joseph Walter, Alice Bruce and Mitchell Bruce

Project Dates
Data collection for this three-year study began in September 2016 and analysis is ongoing.

Data collected
Student participants in the 1st semester general chemistry lab course responded to three surveys: 1) prior exposure to inquiry type labs; 2) GALT (Group Assessment of Logical Thinking) and 3) MLLI (Meaningful Learning in the Laboratory Instrument). Lab notebook pages, analog to target worksheets, designing experiments worksheets and lab reports were collected for lab experiments completed during the semester. All student work has been redacted and coded. The USEP student will examine an Analog to Target Worksheet which students fill out during **CORE** laboratory experiments.

Findings
Based on preliminary analysis of student work from the first **CORE** lab in the semester, the data suggest that the **CORE** polymer lab has a positive impact on students' understanding of polymer crosslinking through analogical reasoning. The USEP student has analyzed a set

of data associated with the Analog to Target Worksheet for the 27 students performing the first **CORE** experiment.

These findings fit into the broader study which has shown for the first **CORE** experiment, that every student, at least once during the lab was able to make a significant connection between the macroscopic and submicroscopic characteristics of the slime polymer while using the paperclip representation. Further, many students consistently demonstrated a sophisticated use of the analogy. Additionally, the data show that a larger proportion of operationally formal students were able to consistently demonstrate the highest level of analogical reasoning. However, students were less capable of discussing the limitations of the analogy. Although only one student consistently described the limitations of the analogy at the most sophisticated level, many expressed limitations both in their lab notebooks and the analog to target worksheets, and every student was able to clearly describe a limitation of the analogy at least once. This suggests that while students are able to think about and work with the limitations of an analogy when directly prompted, they may not recognize the importance of including the limits of an analogy when using it to connect macroscopic and submicroscopic ideas to form a scientific argument.

<u>Next Steps</u>
Ongoing analysis of data. The USEP student will continue examining the Analog to Target Worksheets for other **CORE** experiments.

<u>Publications</u>
Turner, A. C.; Walter, J. C.; Bruce, M. R. M.; Bruce A. E. (in progress). *Scaffolding Understanding of Analogical Reasoning in Phase 2 of the CORE Laboratory Learning Cycle.*

2. Teacher Professional Development using Iterative Inquiry-Based Chemistry Activities

<u>Researchers</u>
Mitchell Bruce, Clint Eaton, Stephanie Virgilio, Somnath Sinha, Laura Millay.

<u>Research Subjects</u>
Middle school Chemistry Teachers; 7th and 8th grade students

<u>Focus of the project</u>
In order to address the overall goal of the PSP to reform and vertically align science education in rural school districts, this chemistry project focused on improvement of teachers' instructional strategy with regards to scientific inquiry and subsequent learning gains of students. With regard to teachers, there was one week long intensive professional development workshop during summer (2014) besides other year round workshops. This particular project focused on the week long professional development of middle school science teachers during June, 2014. The overall goals of this project are: (i) to promote teachers' understanding of scientific inquiry, (ii) to enhance their skills of scientific

communication, and (iii) to help teachers with instructional strategies in alignment with scientific inquiry.

As an extension of this above study and to gauge the impact of teachers' learning, we also looked on students' understanding of various scientific concepts. In that regard, we focused on two years of survey data from classes which followed the Science Education for Public Understanding Program (SEPUP) Chemistry curriculum. The purpose of this survey was to study the students' understanding of major Chemistry concepts and their misconceptions.

Project Dates
Teacher data: Started June, 2014 and is still ongoing.
Student data: 2013, 2014

Data collected
· Teacher Interviews, Teachers' clicker responses, Teachers' pre/post surveys, Teachers' poster presentation
· 7th and 8th grade student survey data (survey was aligned with SEPUP chemistry curriculum)

Findings
Teachers' understandings of using evidence and reasoning to support claims increased during professional development and teachers increased their skill in scientific communication as evidenced by sophistication of posters they created. One of the characteristic features of the professional development workshop – *iterative cycle* seemed to be contributing towards teachers' educational gains.
Significant student learning gains across multiple chemistry concepts were found. For example, with regards to 'conservation of mass,' 52% of the students answered with the correct response post instruction with an overall learning gain of 28%
Several persistent misconceptions were also identified. For example with regards to the 'conservation of mass,' one third of the student population selected a response that reflected a common misconception.

Next Steps
To investigate how the learning gains of these teachers get transformed into their classroom instruction by specifically observing their classroom instruction.
To investigate how teachers address a persistent misconception among students.

List of publications or presentations directly related to this project
Sinha, S., Eaton, C., Virgilio, S., Bruce, M. R. M., & Millay, L. A. (2015, February) *Teacher growth during chemistry professional development and middle school student learning of chemistry content through innovative science partnership in the Maine PSP.* Poster presented at the 2015 meeting of International Teacher-Scientist Partnership Conference. San Francisco, CA.

Bruce, M.R.M., Eaton, C., Bruce, A., Sinha, S., Millay, L.A., Haynes, B, & Kumpa, B. (2016 April) *Teacher Professional Development Using Iterative Inquiry- Based Chemistry Activities.*

Present white paper at the 2016 meeting of National Association for Research in Science Teaching (NARST). Baltimore, MD.

3. Students' Understanding of Middle School SEPUP Chemistry Curriculum

Researchers
Stephanie Virgilio, Clint Eaton, Mitchell R. M. Bruce, Somnath Sinha, Laura Millay

Research Subjects
7th and 8th grade SEPUP Students from Rural Schools in Maine

Focus
A survey was developed and revised after a discussion with in-service teachers who participated in a week-long chemistry workshop. The goal was to align a survey with the Science Education for Public Understanding Program (SEPUP) Chemistry curriculum that studied the students' understanding of major Chemistry concepts and their misconceptions. Within the 13-question survey the major concepts covered were conservation of matter, structure and properties of matter, and chemical reactions.

Project Dates
The first iteration of the survey was distributed in the 2013-2014 academic year, which was then revised for the 2014-2015 academic year. The findings reported in this research are from the most recent survey data collection. This project is currently ongoing.

Data collected
A pre- and post-Chemistry-instruction 13-question survey focused on chemistry concepts included within the SEPUP curriculum with some classroom observations that included video and audio recordings.

Findings
The preliminary findings listed below reflect 250 7th and 8th grade students from 7 different teachers that completed both the pre and post surveys.

- Our students outperformed the reported AAAS and MOSART results for every question that we incorporated into the survey across multiple concepts including conservation of matter, structure and properties of matter, and chemical reactions
- Of the 10 multiple choice questions there were 7 questions with a learning gain above 25%
- When the questions provided more context and answer choices for the students they had more difficulty arriving at the correct answer and more of them retained the misconception

Some misconceptions that remained present in the student population:

- In the event that there is a biological decomposition in a closed system, the total mass decreases (Mitchell et al., 2009). 19% of students retained this misconception after instruction in Question #8

- Length, shape, and mass/weight are characteristic properties. 11% of students chose the misconception before and after instruction in Question #6
- Small objects float, possibly with the belief that the smaller piece will weigh less and therefore float (MOSART, 2007). Only 3% of students stuck with this misconception in Question #12
- When there is a formation of gas after the mixture of substances a chemical reaction has not taken place (MOSART, 2007). 28% of students answered with the misconception before and after instruction in Question #11; this was one of the highest percentages and one of the more difficult problems students encountered

Next Steps

The next steps in this project is to take a more in depth look at the written responses and also the implications that our findings have on the curriculum, students' understanding of chemistry concepts, and teaching methods. We have also revised some questions in the survey in order to gain deeper understanding of student thinking, and analysis of survey data is ongoing.

Figures and Tables

Examples of data analysis of chemistry survey questions are below:

Question 2: Is there evidence that a chemical reaction has occurred?

Answer Choices	SEPUP Survey 2014-2015	
	Pre-Instruction	Post Instruction
A. No, because there was no color change when the polyvinyl alcohol and sodium borate were mixed to form slime.	7%	9%
B. Yes, because the volumes are different.	22%	13%
C. Yes, because the denisty and ease of pouring Slime are different than the polyvinyl alcohol and sodium borate.	54%	63%
D. There is not enough information	15%	15%
No Response	2%	0%

Normalized Learning Gain: 20%

Question 4: Choose the correct response: Which statement describes the molecules of a gas?

Answer Choices	SEPUP Survey 2014-2015		AAAS Results
	Pre-Instruction	Post Instruction	Grades 6-8
A. The molecules are soft.	5%	2%	11%
B. The molecules do not move.	5%	5%	8%
C. The molecules are far apart from one another.	63%	80%	61%
D. The molecules are often in contact with one another.	27%	12%	19%
No Response	0%	1%	

Normalized Learning Gain: 45%

4. The Influence of a Multi-Modal Exercise on Conceptual Problem Solving in Chemistry

Researchers working on this project

Dr. Mitchell Bruce, Samantha Dunton, Clint Eaton, Stephanie Virgilio.

Research Subjects

Undergraduate General Chemistry Course Students

Focus

We were looking at the effect of an interactive learning environment on problem-solving. While exploring this, we began to explore the effects of multiple modes within students' free responses.

<u>Project Dates</u>
Data collection occurred Spring 2014, analysis of the data occurred Summer 2015, and writing of the results is ongoing.

<u>Data collected</u>
Tests (multiple choice, free response, clicker data).

<u>Findings</u>
When comparing the group of students that answered all stages of questioning there were in fact high normalized learning gains. This suggests that an interactive classroom environment is beneficial for student learning. Within students' free responses, there was an interesting trend. We found that out of 63 students that used one mode to respond to Q3, only 28 students were successful (44%). Out of the 41 students who responded with 2 or more modes, 38 students were able to reach a correct answer (93%). This suggests the more modes a student has included within the response, the more likely the response was correct.

<u>Next Steps</u>
We are in the process of writing up the research for publication.

5. Evaluation of undergraduate chemistry students' understanding of greenhouse gases following a guided inquiry lab activity. (Undergraduate Students)

This study investigates how students learn about chemistry concepts through participating in a guided inquiry laboratory activity which is part of the General Chemistry Laboratory (CHY 123) curriculum at the University of Maine. In the lab titled "Building a Spectrometer to Explore Infrared Radiation and Greenhouse Gases (IR/GHG lab)," students investigate the thermal effects of molecular absorption of infrared radiation (IR), the driving factor of Earth's atmospheric greenhouse effect. Students use a simple spectrometer to measure and gather data that compares the absorption of IR by at least two different gas samples. In addition, students explore two online resources: 1) an interactive online resource in which users can simulate the interactions between atmospheric gas molecules and radiation (https://phet.colorado.edu/en/simulation/molecules-and-light), and 2) an authoritative resource on the scientific concepts involved in climate science (The American Chemical Society's "Climate Science Toolkit" at http://www.acs.org/content/acs/en/climatescience.html). One goal of the IR/GHG lab is to "provide information and tools such that students can identify atmospheric greenhouse gases."

The researchers hypothesize that performing all parts of the lab will help students improve their ability to identify greenhouse gases by describing one or more of the following characteristics: 1) structural properties of a greenhouse gas molecule, 2) molecular function of a greenhouse gas, and/or 3) temperature effects of a greenhouse gas sample due to IR absorption. To quantitatively evaluate the level of student improvement, the researchers gathered pre- and post-laboratory open-ended text responses to the question "*Please explain how you could identify a molecule that is a greenhouse gas.*" Researchers conducted post-laboratory interviews in order to deepen qualitative understanding of student conceptions about greenhouse gas functions in the atmosphere.

<u>Researchers</u>
Mitchell Bruce and Tiffany Wilson

<u>Project Dates</u>
Text response data were collected in November 2014 and interview data were collected in June 2016. Analysis is ongoing.

<u>Data collected</u>
Open-ended text responses to pre- and post-laboratory questions were collected from students enrolled in the Fall 2014 offering of General Chemistry Laboratory (CHY 123) at the University of Maine using the InterChemNet course management platform. Audio-recorded interviews of students enrolled in the Summer 2016 offering of CHY 123 were conducted in June 2016.

<u>Findings</u>
By focusing on molecular interactions between atmospheric gases and radiation, the goal of the IR/GHG lab is to build a solid foundation with which students can more fully understand the science behind the greenhouse effect. Analysis of pre- and post-laboratory responses of 191 students to the question "*Please explain how you could identify a molecule that is a greenhouse gas*" shows a strong improvement in students' ability to correctly identify and describe greenhouse gas structures and/or functions. The level of understanding provided by each response was evaluated as "correct," "partially correct," or "incorrect" based on a scoring rubric developed by the researchers. From pre-laboratory to post-laboratory, the number of incorrect responses diminished by 67% (94 to 31) while the number of correct responses increased by 111% (57 to 120). The results indicate that the lab provides a favorable learning gain of the physico-chemical mechanisms surrounding IR absorption by gas molecules in the Earth's atmosphere. The lab activity does not explicitly address all physical mechanisms relating to Earth's greenhouse effect, and preliminary analysis of the data shows that common misconceptions about the greenhouse effect occur and persist pre- and post-lab.

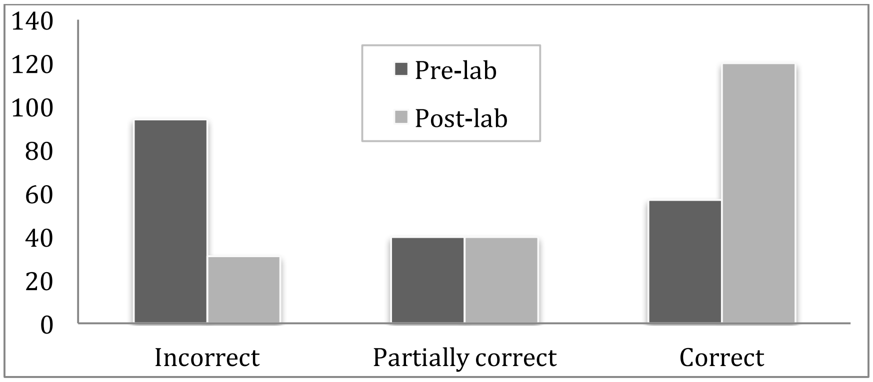


Figure 7. Quantitative assessment of pre- and post-lab conceptual understanding based on 191 student responses to the question "*Please explain how you could identify a molecule that is a greenhouse gas.*"

Next Steps

Ongoing analysis of pre- and post-laboratory data to assess the existence and persistence of common misconceptions associated with the greenhouse effect. Analyze interview responses in order to supplement and deepen our understanding of student conceptions.

Citations related to this research

Bruce, M. R. M., Wilson, T., Bruce, A., Bessey, S. M., and Flood, V. (in review) A simple, student-built spectrometer to explore infrared radiation and greenhouse gases. *Journal of Chemical Education.*

Bruce, M. R., Wilson, T., Bruce, A. E., Bessey, S. M. Infrared Radiation and Greenhouse Gases: An Introductory Chemistry Laboratory Experiment. In *Abstracts of Papers, 249th ACS National Meeting & Exposition*, American Chemical Society: Denver, CO, March 22-26, 2015, CHED-1652.

E. Teaching and Learning of Earth Science Topics

1. Place-Based Education: Evaluation of the Collaborative Design Process and Classroom Implementation of a Place-Relevant Lesson in Ninth Grade Earth Science Classrooms

Researchers

Marina Van der Eb, Susan McKay, Sara Lindsay, Molly Schauffler

Research Subjects

Ninth grade Earth Science students

Focus

Ninth grade Earth Science teachers in the Maine Physical Sciences Partnership (Maine PSP) and researchers at the University of Maine identified a lack of student engagement in the science classroom as a serious problem and have sought to improve engagement by making science classroom experiences more relevant to students' daily lives. To test a possible approach for solving this problem, teachers and researchers worked together to co-design and implement a lesson focused on a Maine topic in rural Maine schools. The design process was documented and data was collected to provide insight with respect to the impacts of the lesson. These data include recorded class discussions, student written work, and follow-up interviews with teachers.

The first goal of this research was to describe and assess the collaborative process of designing a new lesson with a Maine focus and how successfully this lesson was implemented in the classroom. The second goal of this research was to understand how a Maine-based lesson impacts student engagement and students' ability to synthesize information. The design and implementation process was very successful as a result of the collaboration. However, it was difficult to measure classroom impacts due to small sample sizes. Findings show that students likely appreciate, and prefer, place-relevant material and find class more interesting when it is focused on issues related to where they live. This research is intended to guide and inform the long-term goal of making science content more relevant to students in Maine schools.

<u>Project Dates</u>
December 2014-August 2016

<u>Data Collected</u>
Video/audio recordings and classroom observations
Student written worksheets
Student pre- and post-attitude survey responses
Teacher interviews

<u>Findings</u>
The design and implementation of the place-relevant lesson was successful from both the researchers' and teachers' perspectives. The collaborative process ensured that the lesson design was targeting the persistent problem of engagement while also aligning with Next Generation Science Standards and the instructional resources teachers are currently using in their classrooms. Findings indicate that teachers appreciate the collaborative process and think it is beneficial to the implementation of new instructional material. Students indicated in surveys that they appreciate and, in many cases, prefer place-relevant material to material that is not relevant to their lives. Surveys also show that students find class more interesting when it is focused on issues related to where they live. During the lesson students had productive, on-task conversations and teachers stated that students were more likely to contribute to discussion than normal.

<u>Next Steps</u>
The next step is to generate a concise set of recommendations for incorporating place-relevant material into science classrooms for teachers and researchers. Ideally this will lead to the creation of a template that educators can follow that will allow them to efficiently connect locally relevant issues to national science standards and increase student engagement in their classrooms.

<u>Publications</u>

Van der Eb, M. 2016. Evaluation of the Collaborative Design Process and Classroom Implementation of a Place-Relevant Lesson in Ninth Grade Earth Science Classrooms. M.S. thesis, University of Maine, Orono, ME

Presentations

Van der Eb, M. 2016. Making Science Relevant for Students. Maine Center for Research in STEM Education. RiSE Center Fall Summit: Collecting Meaningful Evidence to Guide STEM Education Improvement

Van der Eb, M. 2016. Evaluation of the Collaborative Design Process and Classroom Implementation of a Place-Relevant Lesson in Ninth Grade Earth Science Classrooms. M.S. thesis defense, University of Maine, Orono, ME.

Van der Eb, M. 2016. Quality of group discussion during place-relevant lessons. Maine RiSE Center Research Group, University of Maine, Orono, ME.

Van der Eb, M. 2015. Place-relevant education in the ninth grade MainePSP. Maine RiSE Center Research Group, University of Maine, Orono, ME.

Posters

Van der Eb, M. 2015. A case study looking at use of a place relevant lesson in an ocean science module of the Maine Physical Science Partnership (MainePSP) ninth grade global climate change instructional resources. 2015 RiSE Partnership Summit. Sugarloaf Mountain Resort, Carrabassett Valley, Maine.

Van der Eb, M. 2015. Place-based education in the Maine Physical Sciences Partnership (MainePSP) ninth grade global climate change instructional resources. No Question Left Behind: Teaching, Learning, and Assessment in the Context of the Next Generation Science Standards and the Common Core State Standards in Mathematics Conference. University of Maine, Orono, Maine.

2. Evidence Construction in a Field Geology Environment (K-12, SEPUP Teachers)

This study examines how aspects of scientific practices (e.g. modeling, evidence construction, argumentation, etc.) support learning in a field geology environment.

Researchers

Lauren Barth-Cohen, Daniel Capps, Jonathan Shemwell

Project Dates

Data collection started in June 2013 at summer academy and there is ongoing analysis of the 2013 data. Data was collected at the 2014 Summer Academy.

Data collected

Video, audio, drawings, and survey's from teachers at summer academy

Findings

Evidence is key to many scientific practices including argumentation, explanation, and modeling. For learners engaged in scientific practices, often we aim for them to construct scientific evidence from observations in the world, but the details of how learners go from observation to verbal accounts of evidence in support of a claim in a complex environment has been overlooked. Here we argue that much can be learned about scientific practices from examining how evidence is constructed from human sensory data while interacting with an environment. Using theoretical machinery from coordination class theory we model the evidence construction activity, specifically how observations as connected with prior knowledge turn into evidence for a claim. Using this model we illuminate one case of a middle school earth science teacher constructing evidence as part of a professional development workshop. The focal teacher constructed evidence to support a claim about the relative ages of two rocks(granite and basalt) and she attempted to construct hypothetical evidence for an alternative claim. We describe how her observations connected with her prior knowledge to turn into evidence to support both her initial claim and the alternative claim. We also argue that for her this process of evidence construction led to some learning. The contribution of this work is to highlight the evidence construction process as an important aspect of scientific practices and as supportive of learning.

<u>Next Steps</u>
This work has been published in ICLS conference proceedings.

<u>Papers, Presentations, and Abstracts</u>
Barth-Cohen, L., Shemwell, J. & Capps, D. (2014). Learners' Intuitions about Geology*. To be presented at the International Conference of the Learning Sciences: Learning and Becoming in Practice. (ICLS, 2014).* Boulder, Colorado, USA / ISLS

> Many principles in geology are intuitive to geologists who already understand those principles, but little is known about learners' intuitions in geology. We apply existing theoretical machinery about learners' intuitions in physics to learners' intuitions in geology, and we present several examples of geology intuitions from teachers' reasoning about relative age relationships during field instruction. Implications are discussed for how to productively harness learners' intuitions in geoscience education.

Barth-Cohen, L., Capps, D. & Shemwell, J. (2014). Modeling the Construction of Evidence Through
Prior Knowledge and Observations from the Real World*. To be presented at the International*
Conference of the Learning Sciences: Learning and Becoming in Practice. (ICLS, 2014). Boulder,
Colorado, USA / ISLS

> Evidence is key to many scientific practices including argumentation. For learners engaged in scientific practices, we aim for them to recognize scientific evidence from observations in the natural world. Here, we provide an early depiction of evidence construction, namely how evidence is constructed from one's prior knowledge and one's observations. We illuminate instances of teachers constructing evidence while engaged in a professional development workshop where they are tasked to

reconstruct the geological history of a national park. We illustrate four cases, some of which involve the successful construction of evidence and some of which involve embedded challenges with constructing evidence, such as difficulties with background knowledge and individuals "seeing" different information in the same phenomena. This analysis illustrates the role of prior knowledge in scientific practices that rely on evidence construction in field-based complex environments.

There was also an honors thesis by Jean Stevens that was completed in May 2014 within this project. The title of her thesis is: "Situtational Interest in Profesional Development". Lauren Barth-Cohen was the thesis advisor and Dan Capps was the co-advisor.

> In this case study we look at three cases of situational interest during a teacher professional development workshop. The cases were selected because they illustrate events where multiple teachers exhibited spontaneous interest in a geologic feature or phenomena. This research was conducted at a three-day professional development workshop on the seashore in the northeastern part of the United States. The professional development involved 17 middle school teachers who spent the three days at three different locations learning about the geologic history at those locations. In this study, we express the signs of interest shown by the teachers in each case and then compare and contrast the commonalities in the cases themselves. The study ends with a list of implications for future professional development to increase situational interest

Barth-Cohen, L., Capps, D., Shemwell, J. (2014, April). Profiles in Learning by Argumentation. Poster presented at the National Association of Research in Science Teacher (NARST) 2014 Annual Conference, Pittsburg PA.

Capps, D., Shemwell, J. Barth-Cohen, L. Avargil, S. (2014, April). From using models to developing models: Professional development that pushes on teacher thinking. Paper presented at the National Association of Research in Science Teacher (NARST) 2014 Annual Conference, Pittsburg PA.

Stevens, J. Barth-Cohen L., Capps, D. (2014, April). Capturing Teachers Engagement with Scientific Modeling. Paper presented at the National Association of Research in Science Teacher (NARST) 2014 Annual Conference, Pittsburg PA.

Barth-Cohen L., Shemwell, J. T., Capps, D. K. (2013, October). Using the Knowledge in Pieces to Understand Teachers Productive Knowledge in the Field. The Geological Society of America (GSA) 125th Annual Meeting, Denver, Colorado

F. Teaching and Learning of Biology

1. Student Learning About Evolution Across the Undergraduate Major

This study investigates undergraduate student learning about evolution throughout their major. Students in multiple courses (BIO100, BIO200, BIO222, BIO310, BIO350, BIO402, BIO434, BIO465, graduating seniors, and graduate students) answered ACORNS short answer questions about evolution (for example: A species of oak has nuts. How would biologists explain how a species of oak with nuts evolved from an ancestral oak species without nuts?) (Nehm *et al.* 2012). We then used a tool known as EvoGrader to determine how often students expressed purely scientific ideas versus naïve ideas, and what concepts they wrote about in their answers. Our research questions include: 1) Do students respond differently to these evolution questions as they progress throughout the major? 2) Do students write about different concepts as they progress through their major? and 3) Is the UMaine biology major supporting students in learning about evolution or over time are we selecting for students who understand more about evolution?

<u>Researchers</u>
Andy Clement, Michelle Smith, Farahad Dastoor, Hamish Greig, Robert Northington, Seanna Annis, and Brian Olsen

<u>Project Dates</u>
Data collection began in December 2015 and analysis is ongoing.

<u>Data collected</u>
Student open responses to ACORNS questions (Nehm *et al.* 2012) over several semesters. Data are analyzed by the EvoGrader tool. Several statistical tools are used (paired t-test, Chi square).

<u>Findings</u>

1) Do students respond differently to these evolution questions as they progress throughout the major?
   -Yes, students are significantly more likely to write purely scientific answers in the 300+ level courses when the data are compared to the introductory 100/200 level classes
   -Significant within course (pre to post) gains are only observed in upper division classes with an explicit focus on evolution (BIO350 genetics and BIO465 evolution).
   -Students do not show signifcant differences in writing about animal versus plant examples or trait gain versus trait loss examples.
   -Nonmajors are significantly more likely to use naïve logic when answering questions and do not show any significant within course (pre to post) gains.
2) Do students write about different concepts as they progress through their major?
   -Student scientific answers throughout the major largely focus on the concepts of variation and differential survival
   -Despite instructor efforts to help students learn about the role heritability, competition, and non-adaptive processes (ex. genetic drift) in evolution, students rarely include these ideas in their answers.

<u>Next Steps</u>
Continue working on this question: Is the biology major selecting for students who understand more about evolution or are students making progress in their learning? We have some limited longitudinal data that we are beginning to explore but we may need to collect additional data over the next year.

Work with faculty to revise their classroom materials focused on helping students learn about the role heritability, competition, and non-adaptive processes (ex. genetic drift) in evolution

G. Teaching and Learning of Mathematics

1. How Do In-Service Geometry Teachers Reason About Spatial Construction Tasks? A Study of the Instructional Affordances of Immersive, Room-Scale Virtual Reality

The goal of this project is to allow geometry teachers to work with 3-dimensional geometric constructions in a immersive, room-scale virtual reality environment. Classic geometric constructions involved fixed, plane-based tools, such as a collapsible compass and an unmarked straightedge. Higher dimensional analogs of classical geometric constructions, such as those figures that can constructed from the intersections of planes and spheres in space, have been described theoretically, but until the advent of dynamic digital displays it has not been possible to realize such constructions. Our project will investigate how in-service geometry teachers reason about plane-and-sphere construction tasks in immersive, room scale virtual reality. To study how geometry teachers reason about these tasks, the IMRE Lab is designing and developing a plane-and-sphere construction scene in its HandWaver virtual mathematical making environment. The primary tasks that need to completed to implement this scene are the development of a tool for spawning planes, a tool for spawning planes, and a tool for defining the figures that result from their intersections.
The intersection manager is crucial, as it will allow for the creation of new shapes based on the ones that already exist. One of the other major features it will have is the ability to construct line segments from two points that already exist. This allows for the essential feature of being to construct a polyhedron from vertices that have already been found.

The work to develop the plane-and-sphere construction scene is ongoing. A limited version of the scene is expected to be available during early July. Once the virtual plane-and-sphere construction tools are viable, researchers at the IMRE Lab will design spatial construction tasks that in-service geometry teachers will complete in teams. The purpose of the tasks will be to create a context where the affordances of immersive, room-scale virtual reality--such as the ability naturally move among and dynamically alter three-dimensional mathematical figures--could be resources for participants as they work to complete novel tasks.

Researchers
Justin Dimmel,Camden Bock, Nathan Gazey, Davis MacDonald, Cody Emerson, Joseph Haney, Tim Bruce.

Project Dates
Began working on plane / sphere construction in April. The goal for this summer is to have the software ready in time for content immersion workshop in July.

III. Studies of Instruction and Instructional Strategies for Teaching Middle and High School Physical Sciences

Several projects in the MainePSP did not focus directly on content learning, but instead used content learning as a vehicle to understanding other aspects of learning, including argumentation, the use of scientific practices, and classroom discourse and other classroom practices. These projects are organized roughly by topic.

A. Research in Teaching Practices and the Teaching of Science Practices

1. Knowledge for Assessment (K-12, SEPUP Teachers)

This study examines teachers' assessment knowledge (AK), knowledge of student ideas (KSI), and the specialized content knowledge (SCK) that guides instructional and assessment decisions within earth science content areas.

<u>Researchers</u>
Millay, Bruce, Avargil, Wittmann, Shemwell, Gallagher

<u>Project Dates</u>
Ongoing; started Summer 2011

<u>Data Collected</u>
Baseline interviews with four SEPUP teachers, multiple cycles of pre-assessment interviews, pre-assessment classroom observations and video/audio during teaching, post-assessment interviews, and classroom artifacts.

<u>Findings</u>
Analysis to date has focused on one assessment cycle (pre-and post-assessment interviews with the teachers, and classroom audio/video analysis of teaching of the material related to the studied assessments) with each of two teachers. Findings from one cycle showed that the teacher focused on assessing a specific student "misconception" without considering the relationship between the student misconception and the target earth science content that she had intended to teach. In the process, the teacher's assessment goals were not met. Analysis of an assessment cycle with another teacher showed that during classroom discussion, the teacher responded to students in ways that were closely aligned with her goals for instruction and assessment. A tentative finding through the case comparison is that assessment planning that explicitly relates key science content, goals for student learning, and ways to work with student ideas may help teachers to align their implementation of instruction and assessment with their goals for teaching and learning. In addition, the research suggests some possible descriptions of the relationships between teachers' knowledge, their planning process, and the outcomes of their implementation of assessment.

The findings have been presented in two talks to teachers and researchers through RiSE Center conferences, one in Summer 2012 and the other in Summer 2013 and was also presented at the MainePSP Summit in May 2012.

Next Steps

Findings will be written up as Millay's Master's thesis.

Presentations

Millay, L.,"Beyond Misconceptions: Honoring Student Ideas While Teaching Science." Invited talk at RISE Center NQLB, Northport Maine, June 2013.

"Opening a can of worms," Wittmann, M.C., Millay, L.A., Avargil, S., Bruce, M.R.M., and Shemwell, J., Science Teaching Responsiveness Conference, Seattle, WA, 2013 July.

2. New Assumptions about the Pace of Science learning: How Will Teachers React? (K-12 Teachers)

The field of science education has increasingly acknowledged that the most valuable learning in science develops over the long term and cannot be reduced to the steady acquisition of concepts and skills that are taught one day and assessed the next. However, in seeking to make systemic changes to teaching practice, it is easy for the rhetoric of reform to be preoccupied with changes in what gets taught, so that the organizing idea of reform is seen as a shift from shallow treatment of many topics to deeper treatment of a few. This rhetoric can easily obscure changes in assumptions about how learning occurs that call for reduced emphasis on short-term acquisition of knowledge and skills, and increased emphasis on longer-term development of intellectual capacities. The contribution of the present study is to underscore and illustrate the impact on teachers of shifting to more developmental approaches to instruction. The study followed 12 experienced middle-school teachers who enacted a developmentally-oriented curriculum, which we call MDC, for the first time. Quantitative and qualitative evidence from teacher journals and interviews showed that many teachers enacting MDC expressed appreciation for its focus on developmental learning. This appreciation was often paired with disfavor of acquisition-centered instruction of the past. However, many of these same teachers also expressed ideas in favor of acquisition learning, showing that they had not let go of acquisition approaches to instruction. These results illustrate how reforms that steer teachers toward more developmental learning will demand fundamental changes to how teachers think about science learning and act to promote it. These changes will likely require extended time, support, and experience to develop.

Researchers

Shirly Avargil, Jonathan Shemwell, Daniel Capps,

Project Dates

Data collection started in September 2011and ended in June of 2012. An article from this work was published in 2015.

Data collected

Teacher journals, audio files of teachers interviews

<u>Publications</u>
Shemwell, Jonathan T., Avargil, Shirly, Capps, Daniel K. (2015) *Grappling with Long-Term Learning in Science: A Qualitative Study of Teachers' Views of Developmentally Oriented Instruction.* Journal of Research in Science Teaching. 52:8,1163.

B. Argumentation

1. Paying Attention to Theory in Science Classroom Argumentation (K-12 Teachers)

This study examined teachers' knowledge of the role of theory in scientific arguments and growth in knowledge through professional development in argumentation.

<u>Researchers</u>
Gurschick, Shemwell, Capps, Avargil, Meyer

<u>Project Dates</u>
Fall 2012-2015

<u>Data Collected</u>
Data collected included video, audio, and artifacts from teacher professional development activities over a five-month period.

<u>Findings</u>
Impetus for the project came from examination of student work by Capps and Shemwell, and noticing a lack of generalization to theory from observations. Initial video, audio, and artifacts collected during Phase 1 provided baseline data on teachers' knowledge in argumentation, showing that in general the teachers did not make generalized claims, but rather made localized claims based on observations. During Phase 2, a worksheet was introduced into professional development that guided the teachers to generalize claims based on observed evidence. Analysis of data collected during Phase 2 indicated that through use of the worksheet, teachers began to construct more generalized claims. During Phase 3 teachers piloted the worksheet in their classrooms, classroom observations were conducted and student work collected, and teacher PD included analysis of student work. Findings from data analysis of Phase 3 showed that, although teachers were constructing more generalized arguments in their own work, they were less able to identify differences between student work with higher or lower levels of connection to theory. Overall findings of the research showed that with the curriculum modification (a scaffolded argumentation worksheet) teachers' understanding of how to generalize claims increased. They included

more theory in their own arguments, and they began to think generatively about why and how to support students in theory construction in argumentation.

Outcomes
This work culminated in Gwarjanski's 2014 Master's thesis, "Paying Attention to Theory in Science Classroom Argumentation" and was published as the following journal article:
Shemwell, J. T., Gwarjanski, K. R., Capps, D. K., Avargil, S., & Meyer, J. L. (2015). Supporting Teachers to Attend to Generalisation in Science Classroom Argumentation. *International Journal of Science Education*, *37*(4), 599–628. https://doi.org/10.1080/09500693.2014.1000428

C. Classroom Discourse and Practices

1. Productive Talk: Does Productive Talk Improve Students' Abilities to Use Evidence to Support Claims in their Written Work?

Researchers
Rachel Martin, Susan McKay, Molly Schauffler, Mindi Summers

Research Subjects
7th and 9th grade Earth Science students at rural Maine schools

Focus of the project
Researchers and teachers collaborated to research the connection between different classroom discussion protocols and student written argumentation skills. Seventh and ninth grade Earth Science students at central Maine schools answered two questions. For the first question, students wrote their answers with no discussion beforehand. For the second question, classrooms were assigned a discussion protocols—no discussion, discussion without Talk Science, or discussion with Talk Science. Students wrote their answers using the Claim, Evidence, Reasoning (CER) framework. The responses were evaluated using a CER and Content rubric to determine improvements made with each discussion protocol. Finally, students wrote reflections about classroom discussions.

Project Dates
10/2015—8/2016

Data collected
Student written responses, audio of classroom discussions, student discussion reflections

Findings
Following a Talk Science discussion, ninth graders improved their scores on evidence, reasoning, and content and seventh graders improved their scores on claim. Audio recordings suggest that the teachers focused on different moves and, thus, structured their discussions differently. Most students valued the discussions either for obtaining information to include in their answer or for gaining further knowledge of concepts.

Next Steps

Results of this study will be used to influence classroom instruction and professional development within the MainePSP. Because of the positive results, other teachers should be encouraged to use Talk Science and CER in their classrooms. Though teachers often report that classroom discussions are not beneficial, it is apparent here that students do value discussion.

Outcomes

This work culminated in Martin's 2016 Master's thesis, "Discussion in Middle and High School Earth Science Classrooms and Its Impact on Students' Abilities to Construct Evidence-Based Arguments in Their Written Work."

Presentations:

ByersSmall, B., Martin, R., Van der Eb, M. Using Productive Talk in Middle and High School Classes to Get The Most Out of Classroom Discussions, Los Angeles, CA, National Science Teachers' Association National Conference on Science Education, April 1, 2017, contributed.

Martin, R. A. 2016. Influence of productive talk discussions on written arguments in middle and high school science classes. University of Maine Graduate and Undergraduate Student Research Symposium, Bangor, ME.

Martin, R. A. 2015. Does discussion affect students' written arguments? Maine RiSE Center Research Group, University of Maine, Orono, ME.

Posters:

Martin, R. A. 2015. Using Productive Talk to improve students' written work in middle and high school science classes. 2015 RiSE Partnership Summit. Sugarloaf Mountain Resort, Carrabassett Valley, Maine.

Martin, R. A. 2015. Does Productive Talk improve students' abilities to use evidence to support claims in their written work?: A pilot study. No Question Left Behind: Teaching, Learning, and Assessment in the Context of the Next Generation Science Standards and the Common Core State Standards in Mathematics Conference. University of Maine, Orono, Maine.

2. Elements of Productive Clicker Conversations (K-12 Students)

There is growing interest in using classroom response systems or "clickers" in science classrooms as it is widely viewed as a promising technology by both university and K-12 instructors. The existing literature on this technology has largely focused on the efficacy of clicker implementation, however few studies have investigated discourse in the context of students' clicker conversations. This study is motivated by an expectation that using clickers can lead to productive student conversations about relevant science content. Some have been skeptical about clickers due to concerns that students will be off-task during clicker discussions or that one student will tell peers the correct answer without further discussion. We asked middle school students to answer a physical science clicker questions individually, talk to their peers, answer the same questions again, and then subsequently answer matched-pair questions. We analyzed students' learning gains on each question and audio taped the peer conversations. From the analysis we found that neither of these concerns were manifested in our data and a subsequent grounded analysis is used to characterize the nature of students clicker conversations with a focus on four elements: revision of ideas, asking questions, science content and multiple individuals contributing. The later analysis was connected to the analysis of learning gains on each question and we find that the more elements in a conversation, the better the conversation.

Researchers
Lauren Barth-Cohen, Michelle Smith, Daniel Capps, Justin Lewin, Jonathan T. Shemwell, MacKenzie Stetzer

Project Dates
Data was collected in 2011-12. A peer-reviewed journal article from this work was published in 2016.

Data collected
Audio of middle school students' clicker conversations and quantitative data of learning gains from clicker questions.

Next Steps
This project is complete.

Publications
Barth-Cohen, L., Smith, Michelle K., Capps, Daniel K., Lewin, Justin., Shemwell, Jonathan T., Stetzer, MacKenzie R. (2015) *What are Middle School Students Talking About During Clicker Questions? Characterizing Small-Group Conversations Mediated by Classroom Response Systems.* Journal of Science Education and Technology. 25:1, 50.

3. Studies of Instruction and Instructional Strategies for Teaching Middle and High School Physical Sciences

University Classroom Observation Program (UCOP)

Researchers
Michelle, Erin, Justin, and MacKenzie

Research Subjects
K-12 Teachers observing UMaine classes

Focus
Because of the national call-to-action to reform undergraduate STEM instruction, there is increasing interest in collecting information on the range and frequency of teaching practices at department-wide and institution-wide scales. To help facilitate this process, we helped to develop a classroom observation protocol known as the Classroom Observation Protocol for Undergraduate STEM, or "COPUS" (Smith et al., 2013). This protocol allows

observers, after a short 1.5-hour training period, to reliably characterize how faculty and students are spending their time in the classroom.

At the University of Maine, local middle and high school teachers have been using the COPUS observation protocol to collect snapshots of the types of instructional techniques used in STEM classes. During the past year, teachers completed 194 classroom observations in 101 courses, taught by 96 different instructors and attended by more than 8000 students. These courses spanned 23 different STEM departments. In 2013, Drs. Michelle Smith, MacKenzie Stetzer, Susan McKay, and Jeff St. John--who were awarded an NSF WIDER grant (DUE 1347577) to explore how to use the observation data to develop meaningful campus-wide professional development opportunities at the University of Maine--have been implementing additional new professional development programs under the WIDER program.

<u>Project Dates</u>
The project began in 2011, but has been modified over the four-year period. The project is currently ongoing. Observations take place during both the fall and spring semesters. Observation results were shared and discussed with the observed UMaine instructors in one-on-one meetings with the program coordinator.

<u>Data collected</u>
1. COPUS observation data of faculty - 221 observations of 91 STEM instructors.
2. UMaine faculty filled out a survey about the types of teaching strategies used as well as a request for any specific feedback they would like from teachers (such as “were the students engaged?” and “what suggestions do you have for better engaging the students?”).
3. UMaine faculty filled out a survey about their teaching practices. This survey is called the Teaching Practices Inventory (Wieman and Gilbert, *2014* CBE-Life Sciences Education).
4. UCOP teachers completed post-observation surveys for each class observed. One survey was completed as an observation pair and another was completed by each teacher individually. Both surveys were developed by MST student, Justin Lewin.
5. Middle and high school teachers filled out feedback surveys about their observation experience.

<u>Findings</u>
As described in a recent publication: Lewin JD, Vinson EL, Stetzer MR, Smith MK. A campus-wide investigation of clicker implementation: The status of peer discussion in STEM classes. CBE-Life Sciences Education. 2016, 15:1-12.
http://www.lifescied.org/content/15/1/ar6.full

We have found:

1) Investigation of various modes of clicker use in the classroom revealed differences in the range of behaviors, the amount of time instructors lecture, and how challenging the clicker questions were to answer.
2) Because instructors can vary their instructional style from one clicker question to the next, we also explored differences in how individual instructors incorporated peer discussion during clicker questions.
3) These findings provide new insights into the range of clicker implementation at a campus-wide level and how such findings can be used to inform targeted professional development for faculty.

For data collected during Spring 2017, we are interested in continuing to explore the following question: How do teaching practices vary from middle school, high school, and undergraduate courses (both introductory and advanced)? Are there differences in how active-learning tools are used?
We are also interested in looking at longitudinal data from UCOP 2014-2017 to see if instructors who have been observed each year show any changes in the teaching strategies used in the class.

Next Steps

We will be continuing to analyze the data to answer the research questions above, and MST student, Kenneth Akiha, is defending his Master's thesis based on these research questions in July 2017. Ken also plans to submit a manuscript in the fall based on his research.
This fall we will be looking at four years of observation data from UCOP 2014-2017 to explore a longitudinal study examining whether instructors who were observed each year of the program show any changes in their in-class teaching strategies.
We would also like to continue providing space for an open dialogue between teachers and faculty about teaching and learning.

List of publications or presentations directly related to this project

Lewin JD, Vinson EL, Stetzer MR, Smith MK. A campus-wide investigation of clicker implementation: The status of peer discussion in STEM classes. CBE-Life Sciences Education. 2016, 15:1-12. http://www.lifescied.org/content/15/1/ar6.full

Smith MK, Vinson EL, Smith JA, Lewin JD, Stetzer M. A Campus-Wide Study of STEM Courses: New Perspectives on Teaching Practices and Perceptions. CBE-Life Sci Educ. 2014*, 13:624-635.*

Michelle Smith Interviewed as part of a video on the Festival of Learning in Teaching in Adelaide, Australia: http://www.adelaide.edu.au/festival-lt/

Michelle Smith Guest on RRR FM Australian science radio show Einstein A Go Go: http://rrrfm.libsyn.com/einstein-a-go-go-16-november-2014

UCOP teacher blog post:
http://www.hurricaneisland.net/science-for-everyone/2015/4/24/improving-stem-teaching-through-course-evaluation

Invited talk by MacKenzie Stetzer:
"Two projects focused on undergraduate STEM education: The University Course Observation Program and an investigation of the role of metacognition in student reasoning in physics," Center for Teaching and Learning Seminar, Technischen Universität Hamburg–Harburg, Hamburg, Germany, July 2, 2014.

Invited talks by Michelle Smith:
NSF, March 2015, "Strategies that Promote Institutional Transformations in STEM Education"

Dartmouth, March 2015, "Using Student Learning and Observation Data to Guide Changes in STEM Classrooms" Festival of Learning and Teaching, Adelaide, Australia, November 2014

D. An Investigation into the Interrelationship of High School Student STEM Attitudes and Content Performance

In this study, we explored the possibility of an interrelationship between student content performance and attitudes toward STEM using data collected from three ninth grade Earth science classrooms within the MainePSP. Identifying such a relationship could give us ideas for how to motivate students to gain as much content understanding as possible. Likewise, we could also understand better how content understanding motivates student attitudes and STEM interest. However, this study only used a relatively small data set of 96 students and should be seen as a preliminary step as we wait for more data to be collected in the 2015-16 school year.

<u>Researchers</u>
Adam Rogers and Laura Millay

<u>Project Dates</u>
March 2016

<u>Data Collected</u>
This study utilized content and attitude survey data of 9th grade Earth science students within the MainePSP. The MainePSP designed and revised the content survey through multiple years, trying to adhere to NGSS standards and the curriculum while incorporating a variety of question styles which include misconception-based items. The MainePSP also created the attitude survey several years ago to elicit a variety of student attitudes toward STEM, such as self-efficacy and STEM career interest. The data set for this study was collected in the 2014-15 school year from students who were administered the surveys pre- and post-instruction by their teachers. Students were matched across the post-instruction content and attitude surveys resulting in 96 matched students, 40 of whom could also be matched to the pre-instruction content and attitude surveys.

<u>Findings</u>

When the students of all three teachers were aggregated, there was a significant correlation between their favorable attitude score and their content score, with a linear R^2 of 17%. However, once the students were split based on teacher (which I'll refer to as class), the relationships between attitude and content scores were highly variable. For two of the classes, there was no significant relationship, while the third class had a significant relationship with a linear R^2 of 45%. This hinted that class could be having a significant effect on content and attitude scores. Indeed, we found that class had a significant effect on both content and attitude scores. However, class explained 44% of the variation in content scores compared to only 10% for favorable attitude scores. These results suggest that student attitudes may have an effect on their content scores (or vise versa), but this relationship is very variable by classroom. Furthermore, which classroom students are from could have a relatively predictable effect on content scores but not attitudes, highlighting the difficulty of addressing student attitudes through classroom experiences alone.

We then investigated the effect of specific attitude questions on content score. We found that three attitude questions comprised the best ANOVA model:

- (Q12) Science is a hard subject
- (Q17) I look forward to taking science classes in college
- (Q29) Which of the following best describes yourself as a student in science?

The model showed that whether students were favorable or unfavorable on these questions was significantly related to their content scores with a linear R^2 of 37%. Seen in the table below, all three questions resulted in a mean content score gap >10% between those who were favorable or unfavorable.

	Mean Content Score of Favorables (MCS_F)	Mean Content Score of Unfavorables (MCS_U)	Content Gap Between Unfav and Fav (MSC_U - MCS_F)
Q12	66%	52%	-14%
Q17	68%	48%	-20%
Q29	66%	49%	-17%

Furthermore, all three of these questions experienced net unfavorable shifts for the 40 students that could be matched pre/post. These results suggest that students' perceptions of their self-efficacy and their abilities and futures in STEM could be related to their understanding of the content.

<u>Next Steps</u>

We plan to conduct analysis of additional data and validation tests on the surveys through student interviews to ensure our interpretations of student responses are realistic. We'd also like to extend the study to include content and attitude data from other curricula within the MainePSP. We'd like to extend it this way to test whether other grades have similar predictive attitude questions, especially since our other research into the attitude data show significant attitude differences depending on grade level.

IV. Studies of Instruction and Instructional Strategies for Teaching University Sciences

A. Observation-based description of secondary to post-secondary transition in STEM education

This study examines instructional practices of STEM instructors at different levels of secondary (middle and high school) and post-secondary (introductory and advanced courses). The researchers conducted observations of these courses utilizing the Classroom Observation Protocol for Undergraduate STEM (COPUS) which captures the actions of the students and instructor for every two-minute time interval for a given class period. For the analysis, both overall class time use and individual activities are being compared between educational levels. In addition, other variables such as class size are being used to sort and compare classes.

Researchers
Ken Akiha, Erin Vinson, Justin Lewin, MacKenzie Stetzer, & Michelle Smith

Participants
5-Post-Secondary, UCOP Teachers and UMaine Faculty

Project Dates
University Campus Observation Program (UCOP) Data Collection began in Feb 2014 and is scheduled to conclude in April 2017

Data collected
COPUS data was collected in person by either the researchers or secondary teachers participating in UCOP beginning in February 2014.

Findings
Our initial analysis shows many important differences between secondary and post-secondary STEM classes, highlighting important issues to focus on when considering the transition our education system asks students to make when entering college. For one, the amount of time students are asked to listen in a given high school class period is significantly less than the amount of time students are asked to listen in an undergraduate class, introductory or advanced. Similarly, the amount of time an instructor spends lecturing in a high school class is significantly less than an instructor in an undergraduate class, introductory or advanced. Within secondary and post-secondary levels, some differences can be observed. Middle school students spent a significantly longer time listening compared with high school students. In addition, introductory classes have a significantly higher percentage of student working codes compared with advanced undergraduate classes.

Next Steps

Ongoing analysis of data and publication in progress. This work will culminate in Akiha's Master's thesis.

B. Findings from Work to Identify and Support Struggling Students in Introductory Biology (Undergraduate Students)

During the 2012-2013 academic year, 3 sections of introductory biology students were identified as potentially "struggling students" at risk for low grades or for dropping the course by a low first exam grade. These 3 subsets of potentially struggling students (n=310) were offered one of three help options - either the normal university resources (no additional help); weekly sessions facilitated by Maine Learning Assistants (MLAs) to go through problems and help with homework; or a one-time help session with the course instructor. Students' help-seeking behaviors were analyzed, along with work habits and course grades, as part of a statistical analysis. The researchers found a significant difference among students who participated in the interventions offered and those who were invited to participate, yet declined and never sought out extracurricular help of any kind (ANOVA, $p<0.0001$, $CI=0.031\pm0.07$). Students who declined participation showed a negative improvement score, indicating that they never recovered from the first initial low score and continued to decline. However, there were no significant differences in grade improvements among the remaining groups of students (those who sought some type of help on their own such as university tutoring, those who participated in MLA help, those who participated in instructor help) who participated in the interventions. Researchers attribute this finding in part to inconsistent training for MLAs and to overall low participation in the help sessions, and plan to increase support and professional development for the MLAs who run the help sessions and find ways to increase student participation in the offered help.

Another aspect of the analysis looked at the reliability of first exam grade as a predictor of struggling students, and found that improvements could be made in identifying students who truly are struggling. Refinements are being worked out and will be tested in the coming year. Finally, the researchers found that students who chose to attend the offered help sessions did better than their peers who did not seek help, and as well as the high-achieving students in the class on effort-based elements of their course work, such as lab reports, in-class clicker questions, and homework. However, the help sessions did not seem to help them improve their exam grades, suggesting a need for more help with rigorous content. This finding will be incorporated into the new help sessions in the coming year.

This work was presented with a poster at the 2013 National Meeting of the Society for the Advancement of Biology Education Research, and is written up as a completed Master's thesis by Zachary Batz. The work is also now a published journal article.

C. Examining the Roles of Metacognition and Reasoning in the Demonstration of a Functional Understanding (Undergraduate Students)

We often argue that students possess a functional understanding of a given concept if they recognize, on their own, the need to apply that concept in a new situation and then are able to do so successfully. (In essence, this is equivalent to the notion of transfer.) At the same time, a collaborative investigation with Mila Kryjevskaia (North Dakota State University) revealed that, on pairs of questions targeting identical concepts/knowledge, a significant percentage of students who demonstrated the requisite conceptual understanding by answering the first question correctly failed to apply that knowledge on the second question; these students typically abandoned correct lines of reasoning in favor of more intuitive reasoning strategies. Our paired-question methodology allowed for the disentanglement of student conceptual understanding and reasoning approaches; we then used Evans' extended heuristic-analytic theory of thinking and reasoning (a dual-process theory of reasoning drawn from psychological research) to account for, in a mechanistic fashion, the observed inconsistencies in student responses. As there is reason to believe that metacognition plays an important role in regulating the interaction between heuristic-based (or intuitive) reasoning and analytical reasoning, we (along with colleagues at two other institutions) have begun to develop methods to assess and promote student metacognition in physics.

Ultimately, however, students' ability to demonstrate a functional understanding is also linked to their qualitative, inferential reasoning skills, and relatively little is known about how students construct the kinds of inferential reasoning chains that are required to solve qualitative physics problems and that are emphasized in research-based materials *(e.g., Tutorials in Introductory Physics)*. This has led to a new collaborative grant (involving a total of five PIs at five different institutions) to examine the development of student reasoning skills during scaffolded, research-based physics instruction.

Given that the successful demonstration of a functional understanding necessarily requires a productive interaction among conceptual understanding, metacognition, and reasoning, research in the areas of metacognition and reasoning in the context of physics (in addition to existing research on conceptual understanding) is critical to efforts aimed at improving physics instruction and further enhancing and refining research-based instructional materials. The research outlined in this section has primarily been conducted in the context of introductory physics courses, but in principle can be conducted in physics courses at all levels and in special courses for the preparation and professional development of K-12 teachers of physics and physical science.

<u>Researchers on Project</u>
Thanh Lê (Ph.D. student)
Caleb Speirs (Ph.D. student)
William Ferm (M.S.T. student)
William Johnson (undergraduate student)
Joshua Medina (undergraduate student)

<u>Publications</u>

J. C. Speirs, W. N. Ferm Jr., M. R. Stetzer, and B. A. Lindsey, "Probing student ability to construct reasoning chains: A new methodology," *2016 Physics Education Research Conference Proceedings* (Sacramento, CA, July 20-21, 2016), edited by D. L. Jones, L. Ding, and A. Traxler, 328-331 (2016). doi:10.1119/perc.2016.pr.077

W. N. Ferm Jr., J. C. Speirs, M. R. Stetzer, and B. A. Lindsey, "Investigating student ability to follow and interact with reasoning chains," *2016 Physics Education Research Conference Proceedings* (Sacramento, CA, July 20-21, 2016), edited by D. L. Jones, L. Ding, and A. Traxler, 120-123 (2016). doi:10.1119/perc.2016.pr.025

M. Kryjevskaia, M. R. Stetzer, and T. K. Lê, "Failure to engage: Examining the impact of metacognitive interventions on persistent intuitive reasoning approaches," *2014 Physics Education Research Conference Proceedings* (Minneapolis, MN, July 30-31, 2014), edited by P. V. Engelhardt, A. D. Churukian, and D. L. Jones, 143-146 (2015).

M. Kryjevskaia, M. R. Stetzer, and N. Grosz, "Answer first: Applying the heuristic-analytic theory of reasoning to examine student intuitive thinking in the context of physics," *Phys. Rev. ST Phys. Educ. Res.* **10,** 020109 (2014). (*Note:* Editors' Suggestion.)

M. Kryjevskaia and M. R. Stetzer, "Examining inconsistencies in student reasoning approaches," *Proceedings of the 2012 Physics Education Research Conference*, edited by P. V. Engelhardt, A. D. Churukian, and N. S. Rebello, AIP Conference Proceedings **1513,** 226-229 (2013). (*Note:* 2012 PERC Proceedings Paper Award Finalist.)

V. Pre-Service Teacher Preparation

Two new research projects started in 2016 investigated aspects of pre-service teacher preparation. One investigated students' experiences in the RiSE Center's new Undergraduate STEM Education Professional (USEP) Program, and the other focused on students' experiences in the Master of Science in Teaching (MST) Program, which continues to evolve and grow through ongoing integration with the Maine Physical Sciences Partnership.

A. Undergraduate STEM Education Professional (USEP) Program Research

The USEP program included support for students – USEP students – to develop their skills in teaching and education research, with the goal of recruiting some of these students to become teachers. There were three major components to the program. USEP students were:

- STEM majors, learning the content of their discipline.
- Maine Learning Assistants, acting as facilitators in STEM classrooms, and possibly also K-12 Teaching Partners, visiting K-12 classrooms to be teachers' assistants.
- education researchers, as they did the capstone project of their degree program.

Much of the USEP student work happened in the context of two groups: Teaching Pods, where the USEP student worked in larger groups containing Master of Science in Teaching (MST) students and a K-12 teachers to develop professional knowledge and skills around K-12 teaching, and Research Pods, where a pair of USEP and MST students worked with a UMaine faculty researcher, typically on topics related to the MST student's master thesis and the USEP student's capstone project (with the expectation that these be complimentary and related). Based on the lessons from the summer 2016 USEP program and 2016-17 academic year, the program was modified for the summer 2017 USEP program, as described below.

The goal of studying students in the USEP program was to understand:

1. how USEP students developed as teachers, researchers and STEM majors.
2. how the aspects of the USEP program influenced this development.

<u>Researchers</u>
Erin Vinson, Michael Wittmann, Laura Millay, Adam Rogers, and Carolina Alvarado.

<u>Project Dates</u>
2016: Recruitment selection, finished in May 2016; USEP summer program, June-July 2016
2017: Recruitment selection, finished May 2016; USEP summer program, June-July 2017

<u>Data collected</u>
We collected information from the accepted USEP students. The information included their expectations of the USEP program, career interests, teaching experiences & attitudes. In 2016, we reached out to students to invite them to participate in case studies, described below.

<u>Findings</u>
From the responses obtained so far from the survey (9 of the 10 original USEP students responded to our initial survey and 4 of the 10 responded to a follow-up survey) we know that the 8 of the 9 original USEP students planned to apply to graduate school, three of them in an education related program, four in a STEM discipline, one unsure of program. Five of the original 10 USEP students have now graduated from their undergraduate programs. Of these, 2 entered the Master of Science in Teaching Program, 1 plans to take a teaching position, 1 has been accepted to graduate school for education research, and 1 is taking time away from school before applying to graduate school. Survey responses are still being gathered and analyzed.

<u>Case Studies</u>
To answer our two research questions, we followed a small number of students (5, though this number changed over time) to develop longitudinal case studies of their experiences. We gathered a variety of information about each student to help understand if, how, and in what manner USEP students develop as STEM majors, researchers, and teachers.

The case studies were designed to include four interviews over the course of a year after the start of the USEP Summer program. Each interview would include a conversation trying to define: what are the USEP students doing as part of the USEP program? what influence does the program have on them? how are they thinking about their major? about teaching? about research? The hour-long interviews involved talking to one of the researchers about the questions and working through a series of "card sorting tasks" in which we gave them a bunch of note cards and ask them organize the cards according to whatever question we asked.

Our research in this area was at times constrained by circumstances. Due to conflicts of interest between the lead researcher (Michael Wittmann) and many of the USEP students (for example, that he was at the time chair of the Department of Physics and Astronomy and they were students in the department, or that he was teaching a class they were taking), several students were not interviewed. Further, several students chose to drop out of the study, and no longer be interviewed.

Our findings point to the difficulty of engaging students with a STEM background in two unfamiliar activities at once. In the area of research, many of these students had a strong background in doing undergraduate research in their majors. This might have been part of the major and emphasized in course work, or part of previous summer research projects. The social science nature of discipline-based education research was a challenge to those with a science background, who were used to different kinds of data, evidence, and argumentation, and those with a math background, who were not used to working with data and evidence to build arguments, being more used to formal logic. A further result was that there was great variety among those doing the USEP program. Those rising seniors who did their senior capstone projects in the USEP program did quite strong research, while others, typically not as far along in their academic careers, were less able to engage in some of the work. In the area of teaching, we found that the program did not adequately describe the reasons that teachers have for engaging in their at times difficult jobs. Having USEP students interact with teachers primarily in summer months took them away from observing classrooms, which prevented USEP students from seeing the ways in which classroom interactions drive an interest in teaching. This issue was addressed in 2017. Without classroom interactions, the USEP students focused on developing lessons and instructional units with teachers. This work showcased the creativity of turning content knowledge into learnable chunks and building activities (and coherence among activities) to help students learn. The USEP students saw the value of this work, but also saw it as abstract and distant from the true motivations of teachers to be in the classroom.

For the 2017 USEP program, several changes were made, based on these results. The research projects are more closely to match the interests of the students. A large number of students applied to the program, and researchers interviewed several in a way that allowed for a strong match to be made between student and researcher. The teaching program was also changed. USEP students were chosen before the end of the school year and were able to visit several K-12 classrooms to observe teaching, as a result.

B. Study of Transition from MST Program Pre-Service Preparation to In-Service Professional Pratice (MST faculty, MST students, and MST alumni)

<u>Background and Research Goals</u>
The University of Maine's Master of Science in Teaching (MST) program provides students who have undergraduate degrees in mathematics, science, or engineering with preparation to become science, math, and engineering teachers. The two-year program introduces future teachers to education research both as a resource that they can draw upon and also as a practice that they engage in as they prepare and defend a thesis that is required for

graduation. The program seeks to prepare teachers to be reflective as well as effective practitioners.

This study seeks to understand how the reflective, research-oriented approach of the MST program intersects with the instrumental view—where teaching is assumed to just being a matter of having clear goals, knowing "what works," and application of proven methods to achieve intended goals—that some new teachers will encounter as they move into professional practice. The study explores two conjectures:

1. Even though teachers trained in the MST program may experience dissonance arising from the need to adapt to a working environment that takes an instrumental view of teaching, they will, within a few years, begin to use and value the habits and tools to support reflection that they acquired through the MST program.
2. As science teachers or math teachers, teachers trained in the MST program will encounter and struggle with a relatively small, common set of issues related the intersection of subject matter and teaching.

To the extent that the second conjecture is borne out, identification of common issues will provide useful feedback into the design of the MST program.

<u>Researchers</u>
Bill Zoellick, Education Research Director, Schoodic Institute at Acadia National Park

<u>Project Dates</u>
November, 2015 – June, 2017

<u>Data collected</u>

- 17 intensive interviews with MST Faculty and alumni conducted between 02/16 and 06/16
- 2 stage repertory grid interviews with 5 MST students who are either teaching (2) or student teaching (3) between 03/17 and 06/17

<u>Findings - 2016</u>
Findings suggest that the faculty do, as a group, focus on familiarizing prospective teachers with the goals and structure of educational research, recognizing that many of the students with backgrounds in engineering, mathematics, or sciences other than social sciences will be unfamiliar with the theory-rich nature of educational research or with its sensitivity to context. In methods courses, many of the faculty also emphasize familiarity with important research articles.

Findings from interviews with MST alumni suggest that most students completing the program find that writing a thesis is useful for a wide variety of reasons such as increased familiarity with the research literature and the opportunity to think deeply about an instructional issue or problem. Students who have not had previous experience doing research valued having first-hand experience with the process of formulating researchable questions, collecting and analyzing data, and presenting results.

In general, alumni value the reflective orientation of the MST program. As conjectured, many of them do find that the view of teaching that they encounter among some school administrators can be in tension with this reflective orientation, but they also report being able to accommodate the differences productively.

2017 Work

In 2016 the research was built around intensive interviews as described by Charmaz (2014). Intensive interviews have the advantage of providing the interviewer with the flexibility to explore issues and concerns as they emerge and to delve deeply into the research subject's perspective. This research approach was consistent with the stage of research: In 2016 the research was focused on developing a picture of the various problems that MST students confronted as they began teaching.

Research in 2017 continued to attend to developing a broad picture of issues that teachers faced, but also sought to focus more tightly on the second research conjecture, which is that teachers trained in the MST program will encounter and struggle with a relatively small, common set of issues related the intersection of subject matter and teaching. Consistent with other research (e.g., Grossman et al., 2000), we conjectured that teachers would not address such issues all at once, but would make progress in addressing them over several years. Further, we conjectured that the MST alumni might progress through a series of stages or refinements of practice as they made progress in addressing the issues. Finally, if teachers do develop such solutions over time, we are deeply interested in identifying the resources—such as colleagues, professional development, readings, and so on—that they draw upon in order to make progress in refining their teaching.

Narrowing the focus in this way required a shift from intensive interviews to another research approach that, while providing additional focus, was still flexible and open-ended enough to pick up on what teachers are actually doing. To accomplish this Mr. Zoellick adapted and updated an approach to teacher interviews described by Munby (1984) that uses repertory grid interviews (Fransella et al., 2004; Jankowicz, 2004) to develop a picture of the way that a teacher organizes the principal concerns that shape the moment-by-moment decisions that he or she makes while teaching. Interviews consist of two sessions. In the first session the teacher works with the interviewer to create a grid that relates instructional activities to key trade-offs of which the teacher is conscious in the moment-by-moment flow of teaching. Between the first and second interview, we use partitioning around medoids (Kaufman & Rousseeuw, 2008) coupled with multi-dimensional scaling (Pison et al., 1999) to create a two-dimensional graph that clusters the teacher's activities according to his or her principal concerns. In the second interview the teacher reflects on this picture of his or her teaching, says whether the clusters make sense and, if they do, names them, and thinks aloud about possible labels for the axes of the graph and about the arrangement of the clusters in the space. Both interviews are videotaped for subsequent analysis. Our experience has been that these interviews provide a deep picture of the teacher's thinking about teaching—a picture that the teacher has constructed and recognizes as his or her own. Engaging teachers in these interviews over a number of years will provide insights into changes in how teachers construct their practice to address what they see as key goals and challenges. The interviews will also provide opportunities to identify the resources that teachers draw upon to envision and enact such changes.

Findings - 2017

The repertory grid interviews produced approximately 20 hours of video and audio data. Full analysis of these data will take time. Further, since some of the conjectures are focused on change over time, it will be at least a couple of years before we can confirm, modify, or extend these conjectures. Even so, the rich commentary by teachers as they labeled the clusters and the spatial dimensions produced by the cluster analysis supports a number of tentative observations.

- MST alumni generally place a high value on conceptual understanding of subject matter, as distinguished from procedural proficiency in mathematics or knowledge of scientific facts.
- However, alumni confront challenges in figuring out how to focus on conceptual understanding in school settings and with learning standards that emphasize coverage of a substantial amount of material.
- The two MST alumni who are now teaching full time both undertook substantial revision of their approach to teaching in the first months of professional practice. In both cases the motivation for the change was a sense that they were ineffective, at the outset, in engaging the students in the subject matter. Each of these teachers was sharply aware of having changed his or her practice, and each turned to different resources in order to develop a new approach to teaching. Key questions as the research moves forward in studying more alumni in their first full year of teaching will be: (1) whether this is a common phenomenon (existing literature suggests this is likely); (2) whether some teachers have substantial difficulty in effecting this transition; and (3) whether there are commonalities that suggest the possibility of providing new teachers with specific supports to help them with this transition.
- Each of the teachers spoke of struggling with trade-offs related to serving students who were at different stages of developing understanding and proficiency. In each case the teachers had not yet found a satisfactory way of managing these tradeoffs.
- Each of the teachers—and, in particular, each full-time teacher—became aware of issues in student learning and growth that appeared more related to social and emotional development than to development of subject matter understanding. Each was less familiar with research and practice related to social and emotional learning than with research related to helping students develop subject matter understanding. Consequently, each was improvising ways to address these issues without the support of a conceptual framework to guide design work and decision-making.
- At the end of their first year of teaching, both full-time teachers spoke of matters that suggest that they are beginning to think about the operation of their schools in addition to the operation of their classrooms. It will be important to augment the interview process so that it can elicit this thinking as it develops.

<u>Next Steps</u>

The research undertaken this year provides a foundation for longitudinal study of teachers participating in the RiSE Center's Noyce Teacher Fellowship program. Funding for a portion of this work is already in place through the project titled "A Model NSF Teaching Fellowship Program to Improve STEM Teacher Recruitment, Preparation, Professional Development, and Retention in Rural High-Need Schools" (NSF DUE 1557320). This funding will support research focused on a purposefully selected sample of teachers participating in the RiSE Center's Noyce Teacher Fellowship program next year and for a number of subsequent years. We will seek additional support to expand the study to a larger number of teachers.

Mr. Zoellick will propose a paper describing the repertory grid research and findings from this research for presentation at the AERA Annual Meeting that will take place in New York in 2018.

The research described here is important for at least two reasons. First, there are very few longitudinal studies that document and analyze changes in teachers' practice and their conceptions of that practice—together with insight into the resources that they draw upon to construct those conceptions—over the first years of teaching. We know of no studies of this kind that follow more than one or two STEM teachers over a number of years.

Second, the research develops and refines an approach to eliciting teachers' thinking about the structure of their practice that is potentially useful to other researchers. An early iteration of this approach was tried in the 1980s (Munby, 1984), but did not see further use. We conjecture that at least part of the reason for this lack of use was due to the computational complexity associated with cluster analysis and difficulty in performing such calculations on computing hardware that was available 35 years ago.

Consequently, Mr. Zoellick will develop research publications that address both the methodological issues and the findings about teacher development and thinking that are enabled by the methodology.

<u>Publications</u>
None at this time; AERA proposal will be submitted before the end of July.

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VI. Research in Community and Leadership

A. Study of teacher community structure through social network analysis (Grade 6-9 science teachers)

This study is a multi-year, longitudinal, social network analysis of changes in the structure of the cross-system, multi-district teacher community that the MainePSP developed over the course of the project. The research focuses on the development of social capital--what Michael Fullan (Fullan, 2005) refers to as "lateral capacity"—that might serve to sustain the community beyond the end of funding. It investigates how program design and governance impact creation of social capital.

Researchers
Bill Zoellick, Education Research Director, Schoodic Institute at Acadia National Park

Project Dates
July, 2016– June, 2017 (this year); July, 2010 – June, 2017 (overall).

Data collected
Primarily, responses to an annual survey of teacher advice-seeking that serve as the basis for social network analysis. The social network analysis is supported by an analysis of notes and minutes from meetings, a survey of teacher concerns, and interviews with teachers that assist in analysis of the drivers behind changes in network structure.

Findings and Outcomes
As reported last year, the social network analysis of the MainePSP community indicated that, over the first three years of the project, there was a steady decrease in lateral capacity, which is the social capital that ties the cross-system community together. Then, in the fourth year, lateral capacity rebounded. Analysis of social network and other data suggested that this rebound was not inevitable, but was likely due to actions taken by the program's leadership. These findings were presented in a conference paper in 2015 (Zoellick, 2015).

During the previous reporting year (July, 2015 – June, 2016) Mr. Zoellick prepared these findings and analyses for peer-reviewed publication. A paper titled, "Sustaining Educational Improvement: A Framework for Study of Cross-System Networks and Lateral Capacity" was submitted to the *Journal of Educational Change* (JEdChg) during the fall of 2015. In the course of peer review during that year, it went through two revisions that sharpened the theoretical focus and general applicability of the work. Editorial feedback received in early June, 2016 stated, "I would like to reiterate that you've done solid empirical work, with fine methodology and review of the network literature to back it up. We'd now like to ask you to stretch your thinking a bit further, perhaps exploring some of the broader sociological theories of networks that have been advanced in recent years, to build in a more critical conclusion."

In response to this request to "stretch thinking," Mr. Zoellick revised the paper again, as requested, to put it more firmly in the context of other thinking about networks and submitted this third revision in August, 2016.

In March 2016, the editors of the journal asked for a few more edits, as follows.

> Thank you so much for taking the time to continue to revise this piece, which the Editorial team thinks is a very strong contribution about lateral capacity. Given the extensive revision of this version of the manuscript from previous versions, the Editorial team decided to send this for a new round of reviews from new blind reviewers. Based on their recommendations and our internal analysis of this version of the manuscript, we think that this piece is almost where it needs to be in order to be prepared for publication. As you can see from the attached reviewer commentaries, what is mostly missing in this version of the manuscript is clarification about constructs of interest and the ways in which certain items interrelate.

Mr. Zoellick complied and sent a fourth revision in March, 2017. Unfortunately, while these revisions were underway, JEdChg undertook a review of its editorial focus and decided to change it. As the editor wrote in response to the fourth revision:

> With regret, I must inform you that the Editorial team has decided that your manuscript cannot be accepted for publication in the *Journal of Educational Change*. Though this piece has made considerable progress from its initial submission, and is now a very strong piece about professional capital and the intricate ways in which capacity improvement can develop on-the-ground, the Journal is currently going through a redefinition and shift of emphasis/focus. Therefore, this piece is no longer within the anticipated aims and scope of the Journal as it begins its new conceptual/analytical focus.
>
> I would like to thank you very much for forwarding your manuscript to us for consideration and apologize for making this decision this late in the process. I wish you every success in finding an alternative place of publication. We would recommend a journal such as the *Journal of Professional Capital and Community*, as we think the themes covered in that Journal are very much a close fit for the kind of manuscript this article has become.

Having worked through these four revisions of the article, we believe that makes an important contribution to understanding of how externally funded, ambitious, university affiliated programs can develop effective science education improvement that stretches across many small school districts. This issue is central to most rural science improvement initiatives and has received little attention in the research literature.

The experience of working through the different revisions of this article, responding to questions and suggestions by multiple reviewers, also sharpened our understanding of why the piece might be having difficulty finding its way into publication: it breaks new methodological ground—and so is a somewhat technical article—and also breaks new conceptual ground in its analysis of the tensions and requirements involved in sustaining a multi-district improvement effort. In short, it might make sense to consider rewriting it as two articles, one that describes the innovative approach to using small world networks as a way to develop a quantitative measure of the strength of the "glue" that holds these kinds of cross-district initiatives together (JEdChg found much of the original description of this work to be too technical for its readership, and so much of the methodological discussion has been removed from the most recent revision of the paper), and a second article that then uses this measure, together with analysis of network structures in the MainePSP, to offer insights into how governance structures and network structures interact to support or undercut network growth and sustainability.

<u>Next Steps</u>
Mr. Zoellick will begin by acting on the suggestion from the editor of JEdChg to revise the article as necessary for submission to the *Journal of Professional Capital and Community.* Andy Hargreaves was the founding editor of JEdChg, recently started the *Journal of Professional Capital and Community*, and still works closely with the current editor of JEdChg. All of this suggests that the JEdChg editor's advice is worth exploring.

If that approach fails, Mr. Zoellick will split the article into two articles. We do believe that the insights emerging from this work need to see the light of day.

<u>Publications</u>
None at this time.

<u>References</u>
Fullan, M. (2005). Leadership and Sustainability: System Thinkers in Action. Thousand Oaks, CA: Corwin Press.

Zoellick, B. (2015). Teacher Community Structure and Rural Science Education Reform. Presented at the NARST Annual International Conference, Chicago, IL, April 11-14, 2015.

B. Study of Teacher Leadership (Grade 6-9 science teachers)

This study examines the development of teacher leadership as teachers participated in a leadership academy developed and offered by the MainePSP and as they participated in the overall MainePSP program. Because the MainePSP provided an organizational structure that parallels and complements the organizational structures within the participating teacher's schools, it offered an opportunity to examine the emergence of teacher leadership that reflects the teachers' own views and concerns rather than leadership in service of a school's administrative priorities.

Questions about how this form of teacher leadership emerges and how it functions are important because: (1) in the rural schools that are the focus of the MainePSP there is a high level of administrative turnover, with the consequence that teachers sometimes emerge as a source of continuity in support of improvement; (2) in many schools, improvement of science teaching and learning is not a key administrative priority, with the consequence that improvement depends on teacher's collaborative pursuit of their own improvement goals; and (3) as the professionals who are in closest contact with students and the day-to-day constraints and opportunities in classrooms, teachers' understandings of priorities are sometimes in tension with the perspectives driven by school administrators.

The question of how teacher leadership develops and acts independently of administrative directives is under-studied and under-theorized. The present study contributes to addressing the need for better understanding of teacher leadership as an expression of teacher concerns and beliefs.

<u>Researchers</u>
Bill Zoellick, Education Research Director, Schoodic Institute at Acadia National Park
Somnath Sinha (Post Doctoral Fellow during previous reporting period)

<u>Project Dates</u>
Ongoing after start of Leadership Academy in April, 2013. For this period, July, 2015 – June, 2017.

<u>Data collected</u>
Data were collected through interviews with teachers and observations of teacher interactions. The research uses data collected the 2014-15 school year, consisting of 40 interviews, totaling 22 hours, with the eleven teachers in the second cohort of the MainePSP leadership Academy. These data were supplemented by additional interviews during the 2016 reporting period with four teachers who emerged as case studies that are particularly relevant to the research questions.

<u>Findings</u>
The data provide evidence that the science teachers in this study do act as leaders to engage other teachers in pursuit of concerns and objectives of their own, apart from priorities set by school administrators. The evidence also suggests that the teachers use administrative support strategically, when it is consistent with the teachers' objectives. Mr. Zoellick has found that analyzing these phenomena through a theoretical frame that attends to power relationships (Clegg, Courpasson, & Phillips, 2006; Foucault, 1978; 1982; Hardy & Clegg, 2006; Heller, 1996) rather than just as leadership, which is typically interpreted as action in service of administrative objectives (Donaldson et al., 2008; Johnson & Donaldson, 2007), opens new perspectives on the interactions. In particular, such analysis suggests that the dynamics of change should be analyzed from the teachers' viewpoints as well as from the administrator's viewpoint, which is the more traditional perspective. Such a shift in viewpoint appears to be useful not just from a research perspective, but also from an implementation perspective, suggesting that administrators might usefully attend to teachers' perspectives as a legitimate, important source of power or, alternatively, of resistance.

Mr. Zoellick presented an early version of these findings, focused more on the empirical results and less on the theoretical implications, at the 2016 AERA conference (Zoellick & Sinha, 2016). During April of this year he presented a paper that connected the empirical work in this project to other research and to implications for programs, such as NSF funded collaborations between university-based STEM researchers and schools, that seek to improve science teaching and learning through teacher professional development. The following excerpt from the paper summarizes its focus; the full paper is included as an attachment.

> This paper inquires into how teacher leadership mediates between schools and external agencies seeking to change schools' structures and practices. The external agency might be a university-based improvement initiative or a non-governmental organization seeking equal educational opportunity, encouraging use of place-based education, or something else. The paper examines the role that teacher leaders play in supporting change in situations where these changes are not priorities for administrators in the school or local education agency (LEA—often a school district).
>
> Such external initiatives can deal with educationally important matters. For example, in the U.S., science instruction has become a less important administrative priority in many schools due to increased focus on reading and math in federal programs (Anderson, 2012; Marx & Harris, 2006). There are few formally designated teacher leadership roles related to science at the K-8 level (Spillane & Hopkins, 2013). To the extent that there are teacher leaders working with colleagues to improve science teaching, they are more likely to find motivation and support outside of rather than within formal school and LEA structures.
>
> Most studies of teacher leadership focus on its support of programs initiated by school or LEA administrators. … These are important studies, but leave unexplored the role that teacher leaders play as brokers connecting the external entity to the school.
>
> This paper uses three cases to develop conjectures about the entire triad of external agency, teacher leaders, and school agency that comes into play when external entities seek to create and sustain change in schools.

Next Steps

Mr. Zoellick is working on an expanded version of the paper presented at AERA this year for peer-reviewed publication.

Presentations

Zoellick, B., & Sinha, S. (2016). Teachers, Leadership, Collaboration, and Power. Presented at the Annual Meeting of the American Education Research Association, Washington, D.C.

Zoellick, B. (2017). Change from the Outside: Teacher Leaders and External Change Initiatives. Presented at the Annual Meeting of the American Educational Research Association, San Antonio, TX.

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