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Driven by Beliefs: Understanding Challenges Physical Science Teachers Face When Integrating Engineering and Physics

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Abstract

It is difficult to ignore the increased use of technological innovations in today's world, which has led to various calls for the integration of engineering into K-12 science standards. The need to understand how engineering is currently being brought to science classrooms is apparent and necessary in order to address these calls for integration. This multiphase, mixed-methods study investigated the classroom practices and beliefs of high school physical science teachers following an intensive professional development on physics and engineering integration.

Classroom observations showed that teachers new to incorporating engineering into their physical science classrooms often struggled to maintain focus on physics concepts, focusing instead on the development of the "soft skills" needed by engineers, such as teamwork or communication. Interviews and surveys further revealed the beliefs of these teachers when considering integrating engineering into physics lessons. Teachers placed student engagement and enjoyment high on their priority list when considering integrating engineering into their classroom. In addition to this somewhat driving force, three main components were identified as important when considering engineering in physical science classrooms: providing hands-on experiences for students, allowing students to apply physics concepts, and developing general problem solving skills that students can take to the "real-world." While teachers identified both physics and engineering goals for their students, they realized that their students learned more about how to be an engineer.

Results from this study provide insight on obstacles current science teachers face as they begin to add engineering to their classrooms. Overall, teachers are motivated to bring engineering to their classrooms as a result of student enjoyment of engineering activities. This may drive the creation of teacher goals for students and determine how emphasis is placed on different goals during these engineering design challenges. Implications for this study include ascertaining knowledge about teacher beliefs prior to professional development, fostering discussions about what integration looks like in the classroom, and modeling the creation of instructional goals that include both physics and engineering content.

Keywords: physics, engineering, integration, professional development, beliefs, practices

Introduction

It has become increasingly difficult to ignore the world's dependence on technology in the 21st century. Along these same lines, calls to include engineering in K-12 education in an effort to maintain the United State's status in the global economy also cannot be ignored. National reform documents (National Research Council (NRC), 2013) are calling for the integration of engineering into K-12 science standards as a mechanism to not only improve the quantity and quality of the workforce in

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Science, Technology, Engineering, and Mathematics (STEM) fields, but to increase STEM literacy for all. Ever since Massachusetts became the first state to include engineering and technology standards in their K-12 state science standards other states have followed this precedent of incorporating engineering into science classrooms through the integration of the state standards (Massachusetts Department of Education, 2001). In particular, Minnesota state science standards currently include nature of engineering standards, thus teachers in this state are currently expected to incorporate engineering into their science classes (Minnesota Department of Education, 2009). More than just adding engineering to science is the *integration* between these two disciplines that has ignited interest in STEM education. The difficulty, though, is in helping teachers understand how to integrate engineering with the science content their classrooms.

In order to assist teachers who will likely need to integrate TEM into their science classrooms, it is important to understand how teachers are already implementing engineering into their classrooms so as to help those new to engineering during the transition from science classrooms to STEM classrooms; however, knowledge of this is limited. In fact, the 2009 NAE and NRC report entitled *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* explains the results of a two-year long study to learn about engineering education practices in the United States. The puzzling result was that there is a general lack of guidelines regarding "how to do" engineering in K-12 education, though three models were identified as being used: ad-hoc engineering in science class, engineering as a stand-alone class, and engineering instruction in fully integrated STEM courses (NAE & NRC, 2009). This information does not provide teachers with strategies to bring engineering to their science classrooms. This is an area that begs for more attention to understand the experiences that teachers have in their science classrooms when it comes to engineering integration.

Literature Review

Previous research has already identified engineering as the key component that brings the concepts of STEM together through the investigation of an engineering design challenge. Researchers also identify engineering as a way to (Brophy et al., 2008; Hirsch, Carpinelli, Kimmel, Rockland, & Bloom, 2007; Koszalka, Wu, & Davidson, 2007):

(1) Provide a real-world context.
(2) Develop problem-solving skills in that context.
(3) Develop communication skills and teamwork.

Many states have adopted engineering standards into their curriculum, and as pointed out above, in many cases engineering has been *integrated* into the state science standards to model the harmonious integration of these fields of study. Though the standards require engineering, teachers are left to figure out *how* to teach and integrate it on their own. Roehrig, Moore, Wang, and Park (2012) point out that there is a lack of professional development opportunities for teachers to learn about STEM, which conflicts with the push to have teachers integrate engineering into their science classrooms.

Roehrig et al. (2012) found that science teachers who implemented STEM units in their classrooms took one of three approaches. In the first approach, engineering was added as a culminating activity in which students were expected to use their physical science concepts to solve an engineering design problem. The second approach began with an engineering design challenge as a *context*, but these lessons typically resulted in a trial and error approach, often termed *tinkering*, to solve the challenge, missing opportunities to explicitly connect science content directly to the design challenge. The third approach, common for life science teachers, focused on engineering as a process of thinking. In the case studies described by Wang, Moore, Roehrig, and Park (2011), this problem solving process was identified as integral to integrating the STEM disciplines.

Both Roehrig et al. (2012) and Wang et al. (2011) used a STEM integration framework as discussed in Moore et al. (2014). Moore et al. (2014) describe a framework that includes six major tenets for successful STEM education: 1) a motivating and engaging context, 2) the inclusion of mathematics and/or science content, 3) student-centered pedagogies, 4) an engineering design or redesign challenge, 5) learning from failure, and 6) an emphasis on teamwork and communication. The purpose of the motivating and engaging context provides students with real problems that require them to draw from multiple disciplines in order to solve a given problem or challenge (Moore et al., 2014). Two distinct models for integrating engineering into science (or mathematics) classrooms have been identified by Moore et al. (2014): *context* and *content* integration. With *context* integration, there is one content focus that can be placed in contexts from another disciplines; the primary objective is to develop understanding in only one content area that can be used in other contexts. *Content* integration is nearly the reverse of this in which there is one overarching motivating and engaging context that relies on using and developing understanding of content from multiple disciplines. This type of integration allows teachers to teach content in relation to solving an engineering design challenge (Roehrig et al., 2012).

Instead of merging all four STEM disciplines as done in Roehrig et al. (2012) and Wang et al. (2011), our work has focused on the integration of just two of the four STEM disciplines: science, specifically physics, and engineering. Physics and physical science classrooms make for a prime target for this exploration, as jumping from knowledge of physics concepts to mechanical engineering projects can be

Table 1
Outline of the five training days for 9th grade physical science.

Time	Content Focus	Overview
Day 1 October	Force and Motion	Teachers engaged in hands-on activities to explore the 1) relationships between physical motion and the graphs that represent them and 2) Newton's 3 laws. A final activity introduced teachers to engineering design processes before engaging in an integrated physics + engineering design challenge to design cars out of pasta as described in Angle (2011).
Day 2 November	Energy	Teachers revisited an activity from Day 1 to expand an activity to explore how energy plays a role in the motion of objects. Teachers furthered their understanding of other types of energy through waves, heat transfer, and electrical energy before using classroom wind turbine equipment to extend their thinking about physics + engineering integrated lessons. Additional topics covered in this activity were gear ratios, energy transfer, and electricity production through induction.
Day 3 February	Matter	Teachers learned how to integrate the practices of science, crosscutting themes, and three representations of chemistry into their instruction (symbolic, particulate, and macroscopic). Topics included the periodic table, atomic structure, and physical and chemical properties.
Day 4 April	Chemical Reactions	Teachers explored inquiry-based activities that are designed to enhance students' understanding of the nature of ionic and covalent bonds. Specifically, teachers explored activities that address how the differences between ionic and covalent bonds accounts for what happens to ionic and molecular compounds placed in water and how to use symbolic and particulate representations in order to develop students' understanding of chemical reactions and the nature of the chemical bond.
Day 5 May	Celebration Day	Teachers continued to learn more about inquiry chemistry from an invited guest speaker. Teachers participated in a poster session to share their inquiry chemistry and physics + engineering integrated lessons with their peers.

considered a relatively mild transition. When this is done in the context of a professional development program with current science teachers, this can help introduce the concept of integrating STEM disciplines with current instruction in a way that is not overwhelming to teachers. Additionally, engineering lends itself particularly well to integration with physical science and physics topics, as many elements of engineering practice are implicitly incorporated in the work of physical scientists. By working with in-service physical science teachers, we can begin to better understand how they interact with this physics and engineering (hereafter, physics + engineering) integration and develop and understanding of their experiences so as to improve professional development experiences for those new to bringing engineering to their classroom.

This study seeks to understand the ways in which physical science teachers approach engineering in their classrooms after participating in a professional development program that explicitly addressed the importance of making clear connections to physics concepts during engineering design challenges. After classroom observations revealed that teachers were not bringing this to their classroom, understanding these teachers' experiences became vital to understand what is important to teachers when it comes to these instructional methods. This is done through understanding how *they* view the integration of physics and engineering and how this might affect the decisions they make when it comes to setting goals for their students.

Methods

Context

Professional development program

In the 2012–2013 academic year, a group of 48 9th grade physical science teachers of different backgrounds participated in a 5-day professional development program to address the needs of physical science teachers. This program was hosted by a local math & science teacher partnership and served teachers from across a mid-west metro area and surrounding suburbs. The purpose of this training was to facilitate 9th grade physical science teachers in their exploration of integrating scientific and engineering practices. Professional Learning Communities (PLCs) were created to allow teachers within the same district or school to meet and plan effective instruction based on the concepts learned during the 5-day program. General concepts included science content, inquiry-based approaches, and engineering design.

The program structure was rather unique, as the topic of physical science demands both physics and chemistry content and was designed to prepare teachers for the Next Generation Science Standards (Table 1). The 48 teachers who participated were split into two groups and each of these groups spent two days immersed in learning either physics or chemistry content before switching to the other content area for the third and fourth days. After each of the meeting days teachers met in their PLCs to spend time

Table 2
Results of examining ten RTOP items.

Item Description	Average Score
Lesson Design and Implementation	
2) The lesson was designed to engage students as members of a learning community.	3.41
3) In this lesson, students engaged in an engineering design project/challenge.	3.32
4) This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	2.65
Lesson Content	
6) The lesson involved fundamental concepts of the subject.	**1.56**
7) The lesson promoted strongly coherent conceptual understanding.	**2.08**
8) The teacher had a solid grasp of the subject matter content inherent in the lesson.	**1.97**
10) Connections with other content disciplines, a client, engaging/meaningful context, and/or real world phenomena were explored and valued.	**1.97**
12) Students made predictions, prototypes, designs, estimations and/or hypotheses and devised means for testing them.	2.29
14) Students were reflective about their learning.	2.33
Classroom Culture	
22) Students were encouraged to generate conjectures, alternative solution strategies, and/or ways of interpreting evidence/data/results.	3.12

discussing and designing lessons or units to bring to their classrooms based on what they had learned. For the physics days, this meant designing (and consequently implementing) a physics + engineering integrated lesson or unit. The purpose of the PLCs was to allow teachers more time to consider their students' thinking with regards to their physics + engineering lessons. The fifth meeting day of the professional development included all teacher participants and allowed them to showcase any activities that they used in their classroom as a result of the professional development.

We designed and led the physics portion of the professional development. The first half of each of the two physics days heavily focused on the Minnesota state science standards and included multiple hands-on, inquiry-based activities. More than just talking about the activities, teachers *did* the activities and reflected upon their experiences in wrap-up discussions of each. After engaging in these activities and facilitating discussions surrounding teacher experiences with students in their classrooms, the second half of the physics days included an example of a physics + engineering activity, descriptions of which are found in Table 1. The design of these activities used aspects of Moore (2014) STEM integration framework, stressing the *explicit inclusion* of physics content during an engineering design challenge.

Classroom observations

As part of our follow-up to the professional development (Garet, Porter, Desimone, Birman, & Yoon, 2001; Richardson, 2003; Supovitz & Turner, 2000), classroom observations of physics + engineering integrated lessons were conducted in the 2012–2013 school year in order to obtain a glimpse at what teachers were bringing to their classrooms from their professional development experiences. While all teachers were encouraged to participate in these observations, only nine teachers were observed; as several teachers were observed multiple times, this totaled to thirty-one individual observations of physics + engineering lessons. A modified version of the Reformed Teacher Observation Protocol (RTOP) was used to quantitatively assess the lessons (Sawada et al., 2002). This protocol contains 25 items that are categorized into the three sections: lesson design and implementation, content, and classroom culture. Each of these items is rated on a 0–4 scale representing the range of *Never Occurred* to *Very Descriptive*, respectively. This protocol has been used extensively in research to determine the quality of reform- based classroom practices and was modified for use in classrooms where the focus is on one or more STEM disciplines. Extensive field notes were also taken during these observations.

At first glance, observations revealed physics + engineering integrated lessons that lacked any direct instruction of physics. Instead, these lessons appeared to be hands-on engineering-like activities – those in which students do not explicitly consider science concepts when making design decisions, but prescribe to a method of trial and error or tinkering. In order to ground these ideas from field notes, several of the RTOP items were examined closely. Ten items were selected for this examination to best represent the goals of these observations (Table 2). Average scores were created for each item for teachers who were observed multiple times and a total average for each item was calculated among all teachers. The four items that had the lowest average scores corresponded to the following, all of which are related to the content of the observed lesson:

(1) The lesson involved fundamental concepts of the subject.
(2) The lesson promoted strong coherent conceptual understanding.
(3) The teacher had a solid grasp of the subject matter content inherent in the lesson.
(4) Connections with other content disciplines, a client, engaging/meaningful context, and/or real world phenomena were explored and valued.

It is unsurprising that the last item above did not occur often in the observed classrooms, since connections to clients, contexts, and real-world settings was not stressed during the professional development. What is most alarming, though, is the fact that the physics content of these lessons was not clear in the teacher-created physics + engineering integrated lessons given that the professional development examples stressed the importance of *explicitly* linking physics concepts with engineering activities. Physics content was only apparent in several lessons in the form of ad-hoc physics problems that appeared at the end of a packet which accompanied the engineering activity.

The third item relates to the first two as follows: since students spent their engineering time purely designing, building, and redesigning, there was no formal instruction of the physics concepts during these teacher-identified integrated lessons. This meant that physics concepts were not apparent in the lessons, thus it was oftentimes not clear whether teachers did or did not have a solid grasp of the subject matter. However, it should be pointed out that these physics concepts were discussed *prior* to the engineering activities, similar to lessons described in Roehrig et al. (2012) in which engineering was used as a culminating activity to a science unit.

Since these observations revealed that teachers' implementation of physics + engineering integrated lessons deviated from what was discussed during the professional development, we sought to better understand the experiences that these teachers had when bringing engineering to their classrooms. From a brief content assessment administered during the first day of the professional development, it was clear that all of these teachers were knowledgeable with regards to the physical science content they taught, so for this content to disappear during what they claimed were physics + engineering integrated lessons was puzzling. The teachers who participated in the professional development were relatively new to integrating engineering into their classrooms and had never participated in a formal setting to learn about integration techniques. Our observations showed that between the professional development and classroom implementation, something failed to transfer, as the physics content was not represented in these lessons. Instead, the content was either presented before an engineering design challenge or not at all in some cases. This is likely related to teacher's goals for their students. In order to understand what happened in translation from professional development to classroom implementation and further understand the needs of teachers who are expected to bring engineering to their classrooms, we developed the following research questions:

(1) What features of physics + engineering integration are important to physical science teachers?
(2) How do teacher values concerning physics + engineering integration affect their goals for student learning?

To examine these questions, we needed to access teachers' beliefs and attitudes about physics + engineering integration experiences in their classroom. This was done through the use of interviews and surveys.

Research Design

Data collection and analysis followed emergent and exploration methods often found in mixed-methods research (Creswell & Plano Clark, 2011). While this study contains both qualitative and quantitative data, answering the research questions depends primarily on the qualitative analysis and interpretation, informed by findings of the quantitative data. A multiphase design was selected due to the nature of this work in aiming to understand the experiences that these teachers had in their classrooms (Creswell & Plano Clark, 2011). To do this it became important to learn about integration experiences directly from the teachers; this meant eliciting responses from teachers and not through outsider observations, but through interviews and surveys.

To fully understand the experiences of these teachers and to identify differences between these experiences and what was presented in the professional development, multiple methods of analysis were used (Figure 1). Due to time limitations, only three interviews took place before the end of the 2012–2013 school year; these interviews make up Phase I of the study. Thematic analysis was used to understand these teachers' experiences. In order to understand if these three experiences were unique or representative of the experiences of a larger sample of our teacher participants, we created a survey that is explored in Phase II of our study. This survey was distributed on Day 5 of the professional development and contained both Likert and free-response items to learn about teachers' experiences with bringing physics + engineering integrated lessons to their classrooms. A binary coding scheme was used to analyze three focal free-response questions in order to understand the alignment between what was presented in the professional development and what teachers took away from it. Phase III of this study re-examines one of those free-response items using thematic analysis in order to further understand themes identified in interview transcripts.

Phase I: Methodology

Method

This first phase of research resulted from classroom observations in which it was obvious to us that physics content was dropped during physics + engineering integrated lessons. As a result, it was important to understand teachers' experiences in this process. Three teachers from one school who developed a physics + engineering integrated unit together were interviewed shortly after their implementations, which was observed and scored using the RTOP as discussed above. This unit was a wind turbine unit that was one of the physics + engineering activities demonstrated

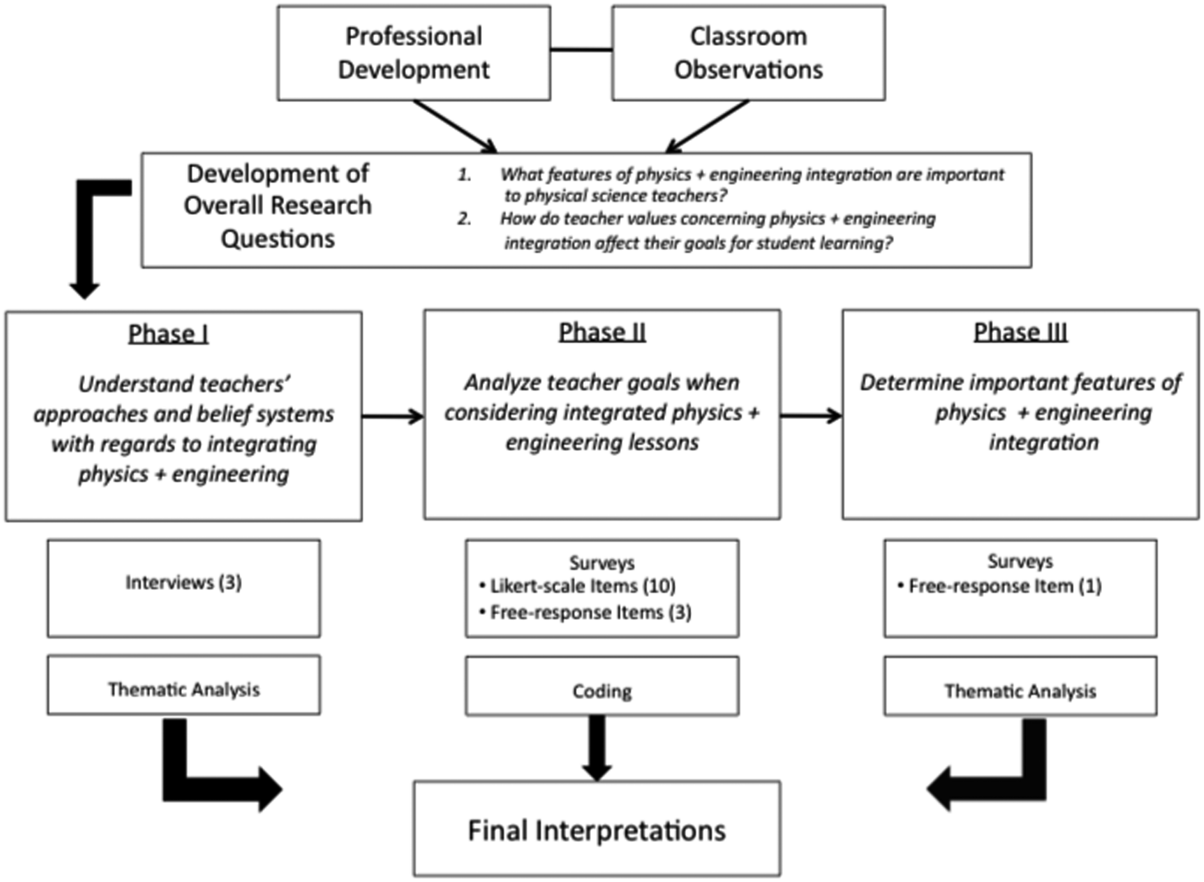

Figure 1. Visual representation of research design.

during the professional development (see Table 1). This unit was implemented to connect physics and engineering in these three teachers' 9th grade physical science classrooms as part of a new district-mandated unit on alternative energy. This first phase sought to understand teachers' approaches and belief systems with regards to integrating physics + engineering.

Interviews followed a semi-structured interview protocol and lasted 14, 17, and 24 minutes. The interview questions were designed to allow teachers to reflect on their experiences and to consider improvements for future classroom implementation. These interviews were fully transcribed for analysis. The three teachers that were interviewed ranged in experience and can be described as: 1) experienced teacher (24 years of experience), 2) new teacher (2 years of experience), and 3) second career teacher (8 years of experience, former chemical engineer for 20 years). All three teachers were relatively new to integrating engineering into their physical science classrooms and had not previously received formal instruction on integration methods prior to this professional development.

Data analysis

Interviews were analyzed using thematic analysis (Miles & Huberman, 1994) to understand the patterns both within each participant, but more importantly, to understand patterns that occurred across all three participants with regards to their experiences in bringing a physics + engineering integrated unit to their classroom. The interviews were transcribed and read by the first and second authors independently with each reader noting patterns in the transcripts in order to build themes for a given interview. After reading each interview, individual participant themes were discussed before moving on to reading the next transcript. Multiple passes through the transcripts were taken to more fully develop the themes across the participants. This constant-comparative method allowed us to examine and re-examine previously identified themes and bridge common themes across the three interviews (Corbin & Strauss, 2008). We identified four major themes at the end of this analysis: nature of engineering, role of content, student engagement, and proposed improvements. The purpose of identifying these themes was to better understand each of them in turn in order to gather a holistic picture of a teacher's experience in integrating physics + engineering in the classroom.

Phase I: Results

Reflective interviews with three teachers revealed extreme enthusiasm in bringing engineering to their physical science classrooms. The three interviewed teachers all felt very strongly about the benefits of including engineering into their physical science courses, but prior observations revealed and interviews confirmed that the physics content took a back burner position to engaging in an engineering design challenge. Before discussing the general themes between these three teachers, we examine the experiences of each teacher individually.

Individual Teachers

Experienced teacher

Kyle identified himself as a constructivist teacher and strongly believed that students need to be taught how to become problem solvers. His goal as a teacher is to make a difference in the world through teaching, challenging students to think outside-the-box and not always giving them the answer right away. His experience as a teacher for 24 years has given him the tools to actively engage his students, allowing them to direct their own learning.

Kyle had some previous experience with bringing engineering activities to his classroom prior to the 2012–2013 academic year, including mousetrap cars and bottle rockets. He described his approach to integrating physics and engineering in the wind turbine unit as an experimental design in which students heavily focus on testing variables to create a wind turbine that used a generator to produce the highest electric potential (measured in volts). When reflecting on his approach, Kyle differentiated this from what he calls "pure" engineering in which students are given money and constraints – his main focus was to give students a chance at experimental design. In a sense this was also *his* way to work on an experimental design, viewing this first implementation as a way to, "…work the bugs out for the next time through." In this, Kyle discussed this as a set of steps one must do to accomplish a goal:

> I guess I'd say I framed it kind of like an experimental design. Like, you know, where you pick a variable, test it, and see the results. Pick a different variable, test it, and see the results, and so on.

What is more is that Kyle saw a difference between "pure" engineering in the real world and engineering in the classroom, choosing to focus on the problem solving abilities that engineers use. This, according to Kyle, is the content of these lessons, along with developing "soft skills." The physics content was discussed as an afterthought:

> And just the content stuff being the experimental design part, so here is the parts of an experiment, here's how you go…scientifically go about answering a question, and that part of it. Um…the…yeah, I don't know if content's the right word, but just working with people, other people in your group. And then calculating, like, power and things like that and those types of calculations because those are part of our deal too.

Additionally, Kyle strongly believed that science isn't just about learning facts, but that, "science is something you *do*." When integrating engineering, this became a prime focus, allowing students to meaningfully put what they believe is useless knowledge to use:

> You're going to use this when you get out there into the real world. And to me it's problem solving, it's applied science, it's all those things we want.

This is related to not having just one answer, but that there are multiple answers to problems. This provides students with a real education (deep, not wide), but this is limited to constraints set forth by the school and the state. Kyle is a firm believer that, "*this* kind of learning," is what needs to take place in schools, but teachers are restricted due to policies and time. He expressed concerns about having time for hands-on experiences, feeling limited by school and state mandates, feeling that they are, "…so much more valuable than all those benchmarks and standards that the state or whoever gives us to do." Kyle felt very strongly that engineering in classrooms would increase student learning and especially the ability to problem solve, even outside of school:

> But, if I can solve problems and take and then know where to look for information and know what *do* to with information, and all those things, then I'm making a graduate that's useful to college, to businesses, to wherever they go after they get out of here…. There isn't always one right answer. You know, there's lots of different ways you can approach a problem and there's lots of different results you can get. In a way that's kind of how the real world goes.

In addition to Kyle feeling that integrated experiences are invaluable to students, he strongly believed that his students enjoyed the design challenge, though he described it as chaos. He believed that since this was the first time in implementing this unit, things could have been organized better and his repeating and improving this organization will be extremely beneficial for future students to learn more, but for this first time he specifically chose to simplify engineering for his students to a design, test, and redesign approach.

New teacher

Lisa is a relatively new teacher, only in her second year of teaching after spending a year working in industry with her chemistry degree. She approaches teaching as a cooperative student-based learning environment, seeing herself as a facilitator through inquiry-based activities with real-world applications. Lisa discussed engineering as an iterative process, and almost exclusively talks about engineering as a need to focus on the "trial and error aspect of engineering." She emphasized that in her physics + engineering wind turbine design challenge, there was a need to test variables in order to maximize the voltage output from the generator. Like Kyle, she discussed this almost as a set of steps to do to accomplish some goal through the use of systematically testing variables. Lisa has a unique outlook on engineering, coming from a family of engineers, and personally feels that her students do not know what it is, but through exposure could end up being interested in a field they knew little to nothing about.

> I think it is important that they know [about engineering] because they could go to college and love it, but they don't know what it is – they think it's something else.

However, Lisa felt that her students (even those who typically do well) struggled with this new type of learning, finding that when things stopped working, students shut down. She is hopeful that the continued use of engineering in classrooms will be beneficial to students, stating, "The more we do it in the classroom the more it will rub off and they'll get more used to it." Though they struggled, Lisa was convinced that her students enjoyed engineering because it was not lecture, but filled with hands-on activities. She sees engineering as giving science life, turning a subject that is often, "very dry and hated by the students," into something that they can connect with once they see a real-world connection. Lisa believed that her students enjoyed the activity because it was very hands-on, saying of her students, "They hate sitting and listening to me all day long and I hate doing it."

With regards to content, Lisa was not sure of what students learned, but was hopeful that they understood the engineering. Like her peers, Lisa felt that this experience was rather unorganized and hopes to be better prepared for the next implementation. When asked about what physics content students learned from this experience and whether or not they understood the critical role of a generator in a wind turbine, Lisa responded:

> I would hope so. I talked about it and we watched a movie about it. I really never did a formative assessment on that. And, I mean, I know part of the packet they were just regurgitating information from the website or something, so…I don't know at this point.

This hopefulness seems related to her desire for more organization and structure for her students with these activities, especially when it comes to variable testing; she also revealed that she did not have a formal type of assessment, which could be an indication of a lack of clear goals. Lisa noticed that her normally high achieving students tended to struggle with this experience, noting that they, "were the ones who seemed to shut down when they don't get the answer right away."

Engineer-turned teacher

James sees his role as a teacher to allow students to find *their* way to learn, believing that students are unique and require individualized attention in order to succeed. He believes that inquiry-based teaching allows students to create a welcoming and comfortable learning environment. After working for 20 years as a Chemical Engineer, James turned to teaching as his other life passion. Having had experience as an engineer in the field, James was hesitant to bring engineering to his physical science classroom, stating, "I would say I just dove into it. I wasn't sure what to expect or what to do or how to do it. Um, I would say I talked to other people because I was, like, not sure." James used his own experiences with engineering and could not figure out how it was appropriate for his 9th graders, but when he started to look at engineering in science classrooms as problem solving, it made more sense to him. James struggled to wrap his mind around bringing engineering to high school students, but eventually found a way to think about engineering for students in a simplified manner:

> I guess the way I think of engineering is engineering is how to solve a problem, so that's where here you had to make electricity.
>
> That's where I just broke it down to a more simple approach instead of looking at a classical engineer-type thing.

For James, there is a clear distinction between real-world engineering and school engineering; by viewing engineering in schools as problem solving, engineering becomes beneficial to students in James' mind. His emphasis for engineering in the classroom relies heavily on this problem solving and how students react to problem solving situations. He related this to being instructional to prepare students for the real world, similar to Kyle and Lisa. Perhaps the biggest thing that he wants his students to take away from engineering is learning that failure *is* an option, that the real world does not necessarily have one right solution and that sometimes your ideas don't work as planned, stating, "…part of engineering is things don't always work right the first time you try it. And things you *think* will work may not work and just to see how they [students] handle different problems is really what I wanted them to see."

When talking about challenges in the classroom, James indicated that his students lacked general lab skills and felt that students needed to work on this. Students needed to know how to look at different variables individually to make decisions, and James saw engineering as a way to help do this. This is very similar to the experimental design approach Kyle discussed, but in James' class, "They just had one class period to get a maximum output and to see what they could get. And that turned into a competition."

While the biggest takeaway for James was problem solving skills, the physics content in the lessons stood by the wayside and was seen as an after-thought:

> Um, that's where, in hindsight, yes. I would want to do *more* of looking at how we can transfer energy and bring more into the law of conservation of energy. Some of those things weren't really done in this first time, so there's a lot of things that would have to be changed. And that's where I'd say as a classical engineer, I am *never* happy with what I did. I always gotta go back and try to fix it and tweak it. And I would say in five years I'll still be tweaking it.

James heavily referenced the fact that this first time implementation was weak on the science content, but hoped that future implementation would be better at this representation. In terms of content, James wanted his students to understand that using wind turbines was just one was of generating and storing electricity. He acknowledged that understanding the energy transfer through the use of the generator was "in hindsight" the science content that students were to learn through all of this. What is more is that James saw this unit as a place for himself to use experimental design (similar to Kyle), and one of the biggest improvements he wanted to implement was to have smaller groups working together.

When asked to talk about student enjoyment, James did not hesitate to claim that his students enjoyed this wind turbine unit, plainly saying, "They enjoyed it," following up by stating, "It was different than sitting in the class doing paperwork and watching things on theory. They actually got to see it work." James' opinion of his students' enjoyment informed his decision to continue with these types of activities in the future. He noticed that his normally high achieving students became frustrated, but that by keeping hands busy, his normally distracting students were not distracting, which pleased James. However, James saw the realistic problem of finding appropriate content and contexts and having the time to develop these types of lessons or units.

Common Themes

The final themes that were identified in these three interviews were: nature of engineering, role of content, student engagement, and proposed improvements. These four themes were present in each of the interviews in a variety of ways.

Nature of engineering

Each of the three interviewees talked at length about how they approached integrating engineering to their classroom and what benefits engineering in the classroom might have for students. These two aspects were collapsed together to discuss the nature of engineering for these three teachers. Lisa's hopefulness in what her students learned presents an interesting take on integration and Kyle's approach may explain why she hesitated; perhaps it is easier to consider engineering as a type of experimental design and to just focus on variable testing in order to solve an engineering problem or challenge. Since these two teachers have science backgrounds, this might explain some level of comfort in sticking to this type of learning. This variable testing almost alludes to the fact that engineering is a series of completing tasks to accomplish some goal.

Kyle and James both discussed engineering as problem solving, which is tied to the use of variable testing in these three classrooms, which inevitably became the focus of the challenge (i.e., which combination of variables will produce the highest voltage output from the generator). Oddly, variable testing is not necessarily a problem solving skill, but all three of these teachers felt that knowing how to approach problems was necessary for the "real world." Kyle and Lisa talk about engineering as applied science, but this was not evident in the way that they discussed their physics + engineering unit and was not seen in the observations; it was only seen in the way they think about engineering integration. None of these interviews revealed that students were making informed decisions based on science content, but all stressed that, "*this* kind of learning," in which students are using their hands, was necessary and beneficial to students.

Role of content

Classroom observations showed that explicitly connecting physics content was dropped from these integrated lessons and units, but it was important to hear from teachers what they thought about the physics content in their so-called integrated lessons. When teachers were asked to discuss the use of physics concepts in their units, it was clear that the inclusion of content was more of an afterthought. Instead, the content became how to run an experiment, how to do the engineering design process, or developing "soft content" skills. All three teachers, however, recognized that this was the case and reflected on this when thinking about improvements for their next implementation. They were concerned about variable testing in this design challenge, only focusing on design, test, and redesign aspects of engineering, ignoring discussions with students about *why* they made decisions during the challenge.

Student engagement

Not only did each teacher have an experience that led them to want to bring more engineering to their classrooms, they felt that their students enjoyed the activities. The primary reason for this appeared to be that students were not learning in a traditional manner. Lisa pointed out that, "They hate sitting and listening to me all day long and I hate doing it," alluding to the fact that students were being active. James and Kyle had similar views and their reasons for this is due to the hands-on aspect of engagement that allowed students to enjoy the activities. Another aspect of student engagement to consider was that both James and Lisa saw shifts in their classrooms where typically high achieving students reached a point of frustration where normally distracting students might have; Kyle did not see this because his students are used to him not always giving the "right" answer. This is related to confronting failures and improvements, a key point that James made. James was careful in talking about his students' hesitation to begin work with the wind turbines, almost being afraid to touch the equipment because they were afraid that they would do something wrong. He was confident that exposure to the equipment was how students go over this shyness; this is related to Lisa's statement about students not being used to engineering and that the more exposure they have to it, the better they will become.

Proposed improvements

All three interviewed teachers brought up the fact that the wind turbine unit was a first-time implementation, which was important to them in thinking of how to improve it for next time. Interestingly, James was the only one who had never brought engineering to his classroom before and initially struggled with how this would be done. The fact that this was a first-time unit caused all three teachers to discuss and elaborate on future improvements before it was directly asked as an interview question. All three teachers expressed concerns about the organization and structure of the unit, planning to make improvements for the next time. Kyle and Lisa focused on the development of worksheets and how to present the wind turbine unit, while James placed an emphasis on having smaller groups. This lack of organization may be why Lisa sounded unsure of what her students learned through this engineering design challenge; this may also be related to a lack of formative assessment.

Phase I: Discussion

While each of the three interviewed teachers thought very highly of integrating engineering into their classrooms, it was clear from observations and interviews that integration was not being done in the way discussed during the professional development. All three of the interviewed teachers were positive about integrating engineering into their physical science classrooms, seeing it as an opportunity for their students to learn physics in a different way, focusing on the hands-on, application, and problem solving aspects of engineering and engineering thinking. Kyle believed experiences that include engineering will enhance students' ability to problem solve, but the question remains whether or not his students were using content like a real engineer would or if they were just tinkering using a trial and error approach. While Lisa believed that engineering is important for students to not only learn about a career option, but also to learn some life skills so that they may someday be able to do work on a house (or something similar), the physics concepts were left behind. As with his colleagues, James' focus on bringing engineering to the classroom was around developing problem solving skills, but these were not necessarily related to the physics content. These three teachers talked about physics + engineering integration in ways that did not entirely reflect that which was presented during the professional development. This is concerning, especially because all three of these teachers believed that what they were doing is true integration and want to continue doing it. Fortunately, they all viewed bringing this new method of teaching as a learning process for themselves as well and want to continue learning about integration methods.

What seemed to be the most pressing and conflicting issue for these teachers was in their students' engagement and the nature of the activities to help students reach certain goals. While more interviews would have allowed us to see if these themes were common among more of our teacher participants, time was a limiting factor. Instead, a survey was created and distributed on Day 5 of the professional development, discussed in Phases II and III below. The analysis from these interviews led us to consider these themes to further our understanding of the free response questions from the last day of the professional development.

Phase II: Methodology

Method

In order to better understand the experiences discussed in teacher interviews and understand if they were unique to those three teachers or similar to a larger audience, a post-implementation survey was created to reach a larger sample of our participating teachers. While observations had given us some idea of what these lessons looked like, we were not able to see a large number of classrooms. Therefore, we asked teachers to report on their experiences and their views of engineering integration. This survey was distributed on Day 5 of the professional development in an online format; paper versions were supplied to those who did not bring electronic devices and later translated to a digital version. This survey was designed to elicit responses regarding teachers' experiences with physics + engineering integration and contained both Likert-scale and free-response items.

Likert-scale items. Ten 5-point Likert-scale items asked teachers to report on various aspects of their experiences, rating statements related to confidence, student enjoyment, struggles with implementation, and students meeting teacher goals in said lessons.

Free-response items. Free-response items asked teachers to report on a variety of occurrences in their classrooms. Teachers were asked to report upon any previous engineering in their instruction, and more importantly to report upon any physics + engineering integrated lessons that took place during the 2012–2013 school year as a result of this professional development. This included asking teachers to report on their learning goals for students (Item1) and what they felt students learned the most in these lessons (Item 2). The final question on this survey asked teachers to describe what integrating engineering and physics means to them (Item 3). These three questions became the focus for our analysis. By looking into the goals and what students learned, we could attempt to understand what occurred in the classroom and how much emphasis teachers placed on the integration discussed in the professional development. We wanted to understand what teachers were bringing to their classrooms.

Differences in the number of responses in the Likert items and the free-responses resulted from incomplete survey responses. In cases where comparisons were made between items, only complete responses were used. Thirty-six responses were recorded for the Likert items, 24 to the questions regarding goals and students learning, and 33 for the survey question asking about teachers' views on integration. This phase sought to analyze teacher goals and views when considering integrating physics + engineering lessons.

Data analysis

Three of the free-response questions on the surveys were analyzed to understand the participant's experiences in physics + engineering integrated teaching. Pilot coding was conducted for the first two questions and contained four codes: 1) physics, 2) engineering, 3) physics + engineering, and 4) other (i.e. goals that were too general). Disagreement regarding these codes led the first and second author to use a binary coding system, which assessed whether or not teacher responses to the questions were representative of both physics + engineering. Thorough discussion allowed for a clear coding framework to be determined. For instance, if a response included *calculations* without some context, it was not coded as P+E (physics + engineering), but if the response included *calculations* with specific physics content and with a clear engineering challenge, it was coded as P+E. For the first and second questions, Cohen's-κ was found to be $\kappa=0.941$ ($p<.001$) and $\kappa=1$ ($p<.001$), respectively. Final codes where disagreements occurred were resolved through discussion.

The third question was coded in a similar fashion, using the framework for physics + engineering integration as discussed in the professional development as a way to determine if teachers were leaving the professional development with a similar framework. The definition of physics + engineering integration that was used was an adaptation of the framework presented in Moore et al. (2014):

> Incorporating physics concepts/theories into an engineering design challenge by using them to make informed design decisions. This requires thoughtful reflection upon the student's part to apply these concepts in a meaningful way (i.e. not trial and error).

For this analysis, Cohen's-κ was $\kappa=0.764$ ($p<.001$). Final codes where disagreements occurred were resolved through discussion.

To understand if there were differences in Likert-item responses based on the assigned codes to these three questions, we looked for correlations in the two groups based on the results of the binary coding of the survey questions. Results from the Likert-items were compared to the final codes only for the free-response item associated with learning goals (Item 1) due to the results of the coding.

Phase II: Results

A summary of the responses to the Likert-scale items is shown in Table 3. These results show that, overall, teachers were confident in their ability to integrate physics and engineering and wanted to learn more about integration. Additionally, there was an overwhelmingly positive response to the item asking teachers about their students' enjoyment in engineering activities.

To address our second research question, we sought to examine three of the free-response survey questions, as discussed above. The results of coding Items 1 and 2 with the binary coding system are found in Tables 4 and 5. Just under 50% of the learning goals of these teachers were identified as containing both physics + engineering aspects, and of these, only 2 reported that students learned both physics + engineering. These two results inform us that when considering physics + engineering integration, only half of our participating teachers took a similar philosophy to ours, at least when it comes to the learning goals for their students. The fact that teachers had both physics + engineering learning goals for their students, but felt that their students only learned engineering reiterates what classroom observations revealed in which the science content (physics) was essentially dropped when engineering was added.

Item 3 was coded based on how the teacher's response aligned with the description of physics + engineering integration that we presented in the professional development. The distribution for this item is shown in Table 5. Results of this coding indicate that most teachers' views on

Table 3
Likert-scale results from day 5 survey.

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
I am confident in integrating engineering and physics content	0 0%	0 0%	2 5.56%	25 69.4%	9 25%
I would like to implement an integrated lesson or unit in my classroom again.	0 0%	1 2.78%	1 2.78%	18 50%	16 44.4%
I created integrated lessons that are well-balanced between engineering and physics content.	0 0%	2 5.56%	8 22.2%	20 55.56%	6 16.67%
My students enjoyed engaging in engineering activities.	0 0%	0 0%	1 2.78%	17 47.22%	18 50%
I would like to learn more about physics and engineering integration.	0 0%	1 2.78%	5 13.89%	21 58.33%	9 25%
It was easy for me to add engineering without major changes to my curriculum.	1 2.78%	5 13.89%	3 8.33%	18 50%	9 25%
I struggled to find relevant content for incorporating engineering in my teaching.	8 22.2%	11 30.56%	8 22.2%	8 22.2%	1 2.78%
I struggled to find relevant contexts for incorporating engineering in my teaching.	8 22.2%	14 38.89	8 22.2%	6 16.67%	0 0%
I think my students would benefit from more engineering in their science courses.	0 0%	0 0%	4 11.11%	17 47.22%	15 41.67%
My students met my goals in our physics and engineering integrated lessons/units.	1 2.78%	2 5.56%	7 19.44%	21 58.33%	5 13.89%

physics + engineering integration differed from the view advanced during the professional development.

As noted in the interviews, we also see evidence in the surveys suggesting that teacher goals related to and understanding of physics + engineering integration differed from those presented in the professional development. While the interviews afforded us the opportunity to explore possible causes and connections between the teachers' ideas related to these differences in the form of a real-time conversation, we chose to adopt a parallel approach with the survey data in the form of exploring correlations between Likert-scale items and our free-response items. Due to the distribution of coded responses, only the Item 1 (related to learning goals) met the conditions for appropriate statistical analysis. Therefore, we conducted a Mann-Whitney U test on each Likert-scale item with our two groups of coded responses forming the independent variable and the Likert-scale responses forming the dependent variable.

Our results showed only one Likert-scale response, student enjoyment, to be statistically significantly correlated to our free-response question about student learning goals ($U=195$, $p=.04$). The prompt read: "My students enjoyed engaging in engineering activities," and teachers were asked to assess their level of agreement. The results of our statistical analysis show a significant correlation between teachers who strongly agree with this Likert-scale item and teachers whose free-response item related to teacher goals coded as "Physics + Engineering."

Phase II: Discussion

This examination of correlations indicates that the level of students' enjoyment and engagement is of great importance to teachers who are actively addressing both physics and engineering goals within their physics + engineering integrated lessons. This was seen in the interviews as well, in which student engagement almost seemed to drive our interviewees' determination to continue to bring more integrated learning to their classrooms. With this in mind, it was important to learn if the views about physics + engineering integration represented in these interviews was representative of those of a larger audience, which led us to Phase III.

Phase III: Methodology

Method

Binary coding of Item 3 in Phase II (Table 5), used to determine whether teachers brought what they learned from

Table 4
Analysis of learning goals and student learning in survey free-response (items 1 and 2).

	Physics + Engineering	Not Physics + Engineering
1. What were the learning goals for your students in this lesson? (n=34)	16 (47%)	18 (53%)
2. What do you think your students learned the most? (n=34)	2 (6%)	32 (94%)

Table 5
Analysis of survey free-response question (item 3) related to personal definition of physics + engineering integration.

	Aligned	Not Aligned
3. What does integrating physics and engineering mean to you? (n=33)	4 (12%)	29 (88%)

the professional development to their own belief system, revealed that there is some discrepancy between what was presented during the professional development and teachers' beliefs since only 4 out of 33 responses aligned to our framework for physics + engineering integration. This was clear through classroom observations and alluded to through the three interviews presented in Phase I. Due to these findings, we chose to use a second method of analysis to better understand how these teachers, new to engineering in their classrooms, view the nature of engineering when it comes to integrating physics and engineering. The purpose of this analysis was to determine what teachers deemed to be important features of physics + engineering integration.

Data analysis

Thematic analysis was employed to re-examine this free-response survey item (Miles & Huberman, 1994). Similar to the analysis of interviews in Phase I, the first and second authors independently read through individual teacher responses and categorized the data via open coding (Corbin & Strauss, 2008). Once these codes were generated individually, the researchers collaboratively used comparative analysis across all coded responses to collapse codes into themes (Corbin & Strauss, 2008). This took several passes and discussions to finalize the themes in these responses. These themes represent teachers' ideas on integrated physics and engineering as a group and correspond to aspects of engineering integration that teachers feel are necessary for their students to benefit. These themes reflected and expanded upon the theme of *Nature of Engineering* found in the interviews.

Phase III: Results

The following themes were identified in the second analysis of the final free-response survey question to define what physics + engineering integration is to teacher participants: *hands-on*, *application*, and *problem-solving*.

Hands-on

The hands-on theme represented Item 3 rests on the idea that engineering is an inherent hands-on activity. There is a strong kinesthetic component to engineering that teachers seem to find important for their students. Examples related to this theme are:

- "Connecting physics topics with hands on activities where they must create, refine, and test."
- "Having students actually do science."
- "More hands-on."

Application

The hands-on theme is related, but not exclusively, to the idea that physics is an application of physics concepts. This application is related to those responses that included some "real world" component to them as well, making it clear that physics is perhaps something that *isn't* done in the real world. Examples include:

- "Bringing what they might do in the real world some day to the classroom."
- "There is a stigma about school that it is geared way more toward theory than practical application. By integrating engineering (a very practical application of science) into physics lessons, the students can get a first-hand understanding of where these theories are applied."
- "Using a design challenge to engage & apply the knowledge & skills we learned in other units."

Problem-solving

Problem solving, again, is related to the above two themes, but is distinctly not the same. Engineering as problem solving to these teachers is a way of thinking, but it is still considered doing science.

- "Making physics useful to solve problems."
- "Teaching students how to solve problems."

Phase III: Discussion

By using this second method of analysis with Item 3, we were able to better understand the low scoring items on the RTOP as well as the themes in the interviews. Several of the themes from the interviews inform the themes found in the free responses, touching on *Role of Content* and *Student Engagement*, but better elaborating on the *Nature of Engineering* theme. Survey responses show an emphasis on hands-on, applications, and problem solving aspects of engineering, all of which were described in the interviews. These components appear to be what teachers hold as the features that are necessary for physics + engineering integration and are likely key features for integrating engineering into any science.

An interesting view of the survey responses in combination with interviews is that it seems as though engineering has the ability to bring science to life. This appears to be in conflict with ways that are not done organically in physics instruction. This begs us to ask what was going on in these classrooms before these teachers were thinking about engineering integration.

Overall Discussion

The three phases in our study have allowed us to create a big picture representation of what experiences teachers have when bringing engineering to their physical science classrooms. It has become clear through our analysis that the most important features that teachers pay attention to are the hands-on, application, and problem solving aspects of engineering. This comes at a price, though, and may hinder the direct instruction of physics content, as indicated in preliminary classroom observations.

As discussed in the interviews, the nature of engineering was defined by aspects such as completing tasks (a means to an end), solving problems, and applying science. We see this again clearly in the survey responses. When considering the role of content, surveys reveal that the physics content is what is applied in engineering design challenges and gives students a chance to transfer their knowledge to real-world contexts or applications. While this is certainly part of the goal when integrating engineering with any science, there is still a lack of evidence suggesting that teachers and students are *explicitly* making engineering decisions based on their physics knowledge.

The analysis of the Likert items reveals another key component for integrating engineering into physical science classrooms: student enjoyment and engagement. While free-response survey items do not discuss this aspect, interviews suggest that it is an extremely relevant piece of motivation to bringing engineering to the classroom. It appears that the line of thinking is something akin to: If students are enjoying the activities, teachers are motivated to bring engineering to their classrooms. This may align with how teachers create goals for theirs students and how emphasis is placed on different goals during these engineering design challenges.

Conclusions

Our findings indicate that there is more work to be done to understand how to best support teachers as they transition from science classrooms to STEM classrooms. This study began with our observations that adding engineering to physics and physical science classroom instruction may lead to the degradation or complete elimination of explicit science content connections. Analysis of both interview and survey data indicates that teachers' conceptions of what physics + engineering integration is may exist independently of what we advanced in the professional development. Teachers place a strong emphasis on the merits of physics + engineering integration that are not necessarily content-related; interview data shows that they prize elements of instruction that include hands-on activities, applications to real-world contexts, and development of problem solving skills. Further, survey data suggest that teachers may be more confident in creating truly integrated physics + engineering lessons when they feel that students are enjoying the addition of engineering to the curriculum.

Limitations of Present Study

While this study is broad in terms of data sources, we have identified a few limitations that are worth mentioning and perhaps addressing in future work. First, further investigation of the RTOPs from classroom instruction could prove valuable. While we used the RTOPs primarily as an introduction to the phenomena we wished to explore further, a future study with more observations, and thus more RTOP data, could begin to uncover information about *why* teachers might teach in the way that they do when brining engineering into their physical science instruction. One area that we are particularly interested in exploring is comparing classroom instruction between teachers who hold physics degrees and teachers who do not. How might these two groups of teachers approach engineering integration differently? Is physics content presented differently as well?

Our second limitation is regarding the number of interviews. While we felt that our interview data was both rich and informative, a greater number of interviewed teachers would increase the amount of qualitative data from which to draw conclusions about our identified themes. Similarly, the interview protocol could be fine-tuned in order to elicit more in-depth and targeted responses from the interviewed teachers. Future work with regards to these two areas would provide us with more information about how to work with teachers new to integrating engineering in their classroom, having been able to understand their experiences.

Future Prospects

Though this study only focuses on the transition from physics to physics + engineering, we can assume that similar issues occur in other science content courses. Our findings suggest that adding engineering to science curricula is challenging for teachers, even after extensive and immersive exposure to it through a professional development program that not only discussed what this integration looked like, but had participant teachers engaging in activities that they could bring to their classrooms. If future professional development related to physics + engineering integration is to be successful, we recommend the following guidelines for instruction:

(1) **Ascertain knowledge about teacher beliefs related to engineering integration prior to conducting the professional development.** Most teachers held beliefs regarding engineering integration that were very different from the views expressed by the

professional development facilitators. More importantly, these beliefs were retained after the conclusion of the professional development and during their subsequent classroom instruction. In order for professional development facilitators to both understand the expressed beliefs of their participants and create meaningful professional development activities, it is important for facilitators to begin their work with knowledge of teacher beliefs regarding engineering integration.

(2) **Foster discussions about what engineering integration in the classroom would look like.** While we spent a great deal of time in our professional development modeling classroom activities, teachers in interviews discussed the unique challenges and limi

(3) **Spend time modeling the creation of instructional goals that include both physics and engineering content.** Many teachers did not craft instructional goals that included both physics and engineering content, and even fewer felt that students learned both physics and engineering concepts. We feel it would be valuable to devote time to actually designing a curriculum unit complete with goals that address the needs of both physics and engineering content. This is something that, for many teachers, is a new challenge. Further, assisting teachers with ways to assess these integrated activities may help to structure and organize experiences for first-time implementation.

As far as teacher education goes, it must be kept in mind the bringing engineering to classrooms is not done overnight, but takes time. It is perhaps a much longer process for teachers to find balance between the science content and engineering than once thought, and it is recommended that more research be done to understand the concerns and beliefs of teachers when introducing engineering.

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