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Infusing Engineering Concepts into Science: Findings from a Professional Development Project (Research to Practice)

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Infusing Engineering Concepts into Science: Findings from a Pilot Test Professional Development Project (Research-to-Practice)

Addressing the NGSS: Supporting K-12 Teachers in Engineering Pedagogy and Engineering-Science Connections

With the publication of *A Framework for K-12 Science Education*[1] and the creation of the *Next Generation Science Standards*[2] (NGSS) soon thereafter, engineering practices and disciplinary core ideas are being adopted as important components of K-12 science education. Engineering elements are included in the Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts sections of the NGSS. These additions bring about the need for curriculum changes to incorporate engineering and teacher professional development to prepare science teachers to integrate this new content. Recognizing these challenges, the project team working on a National Science Foundation funded Discovery Research in K-12 project[*], Project Infuse, has been investigating how to infuse engineering concepts into science through an innovative approach to professional development that is engineering concept-driven.

A concept-driven approach to professional development is grounded in cognitive science and teacher professional development research. Cognitive science research indicates that conceptual understanding is necessary for situating information, content, and ideas into a particular context, for example engineering into science. Concepts provide learners with the components needed to create a connected web of knowledge, allowing learners to apply what they have learned to new situations and learn related information[3]. From an instructional standpoint, concepts provide a way to organize knowledge into meaningful instruction[4]. In addition, research indicates that professional development should take into account teachers' conceptions of teaching and of the learning process and allow for active learning and reflective participation[5, 6, 7]. Engaging in activities oriented around the engineering concepts and reflecting on students' learning of these concepts are the underpinning elements of the project's teacher professional development approach.

The current project stems from the principal investigators' research on engineering teacher professional development[8, 9, 10, 11]. Case studies of five prominent teacher professional development projects focused on engineering education were conducted, with one of the primary findings being a distinct lack of grounding in an identified engineering concept base. One of the most alarming aspects of this void was teachers' inability to reflect on what they were learning related to engineering, apart from a vague understanding of the engineering design process. Without a clear understanding of core engineering content and concepts, the connection to student learning is tenuous at best. This void poses serious problems for high quality curriculum and professional development as has been documented in the science and mathematics teacher professional development literature[12, 13]. As the National Academy of Engineering Committee on K-12 Engineering Education observed, a "critical factor is whether teachers—from elementary generalists to middle school and high school specialists—understand basic engineering concepts and are comfortable engaging in, and teaching, engineering design"[14].

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In addition to aligning with the cognitive science and teacher professional development research, an engineering concept driven approach to teacher professional development provides a common basis for teachers to define and understand engineering. The concepts also provide a point of comparison to differentiate engineering from science. And perhaps most importantly, engineering concepts provide entry points for their inclusion into the existing science curriculum. Thus the development of a conceptual foundation has been critical to every aspect of the project, grounding the research and activities, including institute planning, instrumentation development, research design and project evaluation. During the initial stage of the project, a systematic process was developed for identifying a set of core engineering concepts appropriate for secondary level education. This involved engaging with the literature to identify, refine, and define the concepts. Four primary concepts (and sub-concepts) emerged as the primary focus of the teacher professional development. These concepts are:

- Design (constraints, tradeoffs, optimization, prototyping)
- Analysis (life-cycle, cost-benefit, risk)
- Systems (structure, functions, interrelationships)
- Modeling (visualization, prototyping, mathematical models

Project Goals and Research Questions

Broadly stated, the goals of the project are to understand how science teachers learn engineering concepts through a concept-based professional development program and to examine the implementation issues and problems encountered by teachers as they incorporate engineering concepts into standards-based curricula and instructional activities. A set of seven research questions have been developed to address these goals. These are:

1. What experiences and techniques are effective for improving science teachers' understanding of engineering concepts through the professional development process?
2. What gains can be achieved in science teachers' understandings of engineering concepts as a result of using the Project Infuse professional development model?
3. What experiences and techniques are effective in enabling science teachers to infuse engineering concepts into their curricula?
4. Is there a relationship between teachers' understandings of engineering concepts and their willingness and perceived ability to infuse engineering into science lessons?
5. To what extent does engagement with engineering concepts and engineering infused science lessons enhance science teachers' self-perceived understanding of science concepts?
6. How do teachers' stages of concern about including engineering concepts in their instruction evolve during professional development and classroom implementation?
7. What are the differences and similarities in life science and physical science teachers' understandings of engineering concepts, their ability to infuse engineering concepts into their science lessons, and progress through the stages of concern?

Research Design

The research component of Project Infuse has been guided by a mixed method research design. The purpose of the research is to better understand the effectiveness of an engineering concept-based approach to professional development. Effectiveness is defined in relation to the project's research questions and includes changes in teachers' understanding of engineering concepts, their understanding of science concepts, and their concerns about infusion. An Engineering Concept Assessment has been developed as part of the research study to measure teachers' understanding of the four engineering concepts featured in the project. Understanding of science concepts is measured through existing instruments used by each lead trainer in relation to a discipline-specific curriculum. The Stages of Concern Questionnaire has been used to document teachers' feelings about infusion[15]. A key component of the design consists of a comparative analysis of two disciplinary areas of science: life science and physical science.

A longitudinal design has been utilized to document the effectiveness of the program over time. Pre data were collected for all measures at the beginning of the professional development in summer 2012. Short-term impact data were collected on teachers' understanding of engineering and science concepts at the end of the first summer institute (also in summer 2012). Engineering understanding data were collected again at the end of the second summer institute in 2013 to document longer-term changes.

Results from these instruments were then aligned with key components of the project's implementation to answer the research questions. With the benefit of a pilot test cohort of teachers, the project team has deployed an iterative process including data collection and analysis protocols in alignment with the design and development of the professional development activities. The professional development activities were collectively developed and tested during the two year pilot phase and included the engineering concept identification and refinement process, instrumentation development and identification, designing and delivering two summer professional development institutes, engaging teachers in a process of infusing science lessons with engineering concepts, and a school year implementation component. Taken together, the research data will contribute toward a holistic understanding of the teachers' learning processes of the engineering concepts and the impact of this understanding on teaching.

Participants

The pilot phase of the project was designed for science teachers with some previous engagement with engineering so as to help inform the development of the professional development approach and activities. Limited numbers of technology and engineering teachers were also recruited for participation during the pilot phase of the project in order to examine the possible positive impact of these teachers on the professional development model. The physical science institute had 11 teachers (10 physical science and 1 technology & engineering education) while the life science institute had 10 teachers (7 life science and 3 technology & engineering education). Pilot teachers participated in two summer institutes, as well as professional development during the school year. Each summer institute was two weeks in length.

Professional Development Model

Throughout the pilot phase of the project, a set of carefully selected activities were developed and tested in a preliminary attempt to develop an effective professional development engineering infusion model that can be assessed and replicated. These activities were designed to correspond with the existing STEM professional development literature and deliver on the research questions. Given the research-based focus of the project, we refer to these activities collectively as an “Engineering Infusion Professional Development Treatment”. The key elements of this *treatment* are described in this section. A table of elements implemented during each year of the two-year treatment is presented in Table 1. The length of time recommended for each element is also included.

Table 1.

Engineering infusion professional development elements

Professional Development Elements	**Year 1**	**Year 2**	**Recommended Time**
Overview: engineering concepts and design loop	☑		2 hours
Design challenges	☑		3.5 hours
Venn diagrams: science and engineering concepts	☑		2.5 hours
Case studies	☑		2.5 hours
Completion of model module	☑		24 hours
Reflection discussion: the infusion process	☑		2 hours
School year planning	☑		2 hours
NGSS discussion	☑	☑	1 hour (Y1) 1 hour (Y2)
Data collection for research/evaluation	☑	☑	4 hours total (Y1) 3 hours total (Y2)
Daily reflections	☑	☑	.25 hours/day
Reflection discussion: video lessons		☑	6 hours
Lesson critique		☑	6 hours
Group-based infused lesson development		☑	6 hours
Student assessment discussion		☑	1 hour
Individual lesson development		☑	12 hours
Concept mapping		☑	2 hours
Implementation issues discussion		☑	2 hours
Reflective summative discussion		☑	.5 hours

Teacher engagement with the conceptual base. Developing the teachers’ understanding of the four engineering concepts began with a review and discussion of the four concepts, identified by the project team. Teachers also read additional background information on K-12 STEM education and engaged in group discussions regarding the articles. Additional activities included teachers' creation of individual concept maps for engineering design at the beginning and end of the first institute, watching a video of the design process in action *(Deep Dive)*, and ongoing discussions of the engineering concepts. Teachers also completed several design challenges which familiarized them with the engineering design process. Early in the development phase, the project team identified the need to develop well defined standard-type statements and performance expectations aligned with the four engineering concepts. A document called the *Project Definitions, Standards, and Performance Expectations* document provided the project team and teachers a common basis for understanding engineering throughout these activities, enabling the teachers to infuse the engineering concepts into their curriculum. This document was valued by several of the teachers as a guide to help the development of their own infused lessons.

In addition, the teachers created Venn diagrams for each of the four engineering concepts, comparing the similarities and differences of science and engineering concepts. Below is an example from the cohort of physics teachers. Given that these four terms are used in both engineering and science, the project team realized that distinctions should be made apparent to the teachers and their students to help them better understand both the terms and the context in which they are applied. To do this, the teachers and professional development providers created Venn diagrams to show how each term is used in engineering, in science, and where there is overlap. The Venn diagrams were developed with the teachers and should be considered preliminary in nature. They are presented here in Figure 1 in a linear format for ease of reading.

Figure 1.

Venn diagrams for design, analysis, models and systems

DESIGN

1. **SCIENCE**
   a. Design an experiment.
   b. Knowledge for knowledge sake (not product driven).
   c. Generalization.
   d. Design experiment → Predict results.

2. **ENGINEERING**
   a. Purposeful → End result is a product.
   b. Within defined criteria.
   c. Optimization.

3. **SCIENCE AND ENGINEERING**
   a. Methodical-Iterative.
   b. Build models.
   c. Data driven
   d. Collaborative.

ANALYSIS

1. **SCIENCE**
   a. Staring with the simplest case and trying to generalize.
   b. Laws and theories first and last.
   c. Impartial and objective criteria.
   d. Answering a question just to know the answer.

2. **ENGINEERING**
   a. Clear purpose → specific case or product.
   b. (Material, measurements, constraints)

      \+ ↓

      (Laws and theories)

      ↓

      (Make it work)
   c. Subjective and objective criteria.
   d. Answering a question to make the product work.

3. **SCIENCE AND ENGINEERING**
   a. Iterative to define.
   b. Data driven.
   c. How and why things happen.

MODELS

1. **SCIENCE**
   a. Scientists create unified universal models.
   b. Strive for simple models.

2. **ENGINEERING**
   a. Engineers create specific models for each design.
   b. Models are used for optimization.

3. **SCIENCE AND ENGINEERING**
   a. Models change the way we think.
   b. Used for communication and explanatory understanding.
   c. Models have limitations.

SYSTEMS

1. **SCIENCE**
   a. Scientists choose system boundaries.
   b. Idealization.
   c. Descriptive.

2. **ENGINEERING**
   a. Engineering constraints dictate system boundaries.
   b. Always practical [solution-serving].
   c. Modularity.

3. **SCIENCE AND ENGINEERING**
   a. Account for interrelationships among components.
   b. Systems work together.

Concept mapping. The goals of the concept mapping process were to (a) facilitate the teachers' conceptual understanding of engineering concepts in relation to each other, and (b) to provide evidence to the project team of the teachers' understandings of the concepts. The use of concept mapping is based on the premise that developing visual representations of conceptual understandings facilitates and deepens the level of conceptual development [16, 17, 18]. The process included providing teachers with sample concept maps (with non-engineering content) to facilitate their understanding of how maps can be configured and a list of possible concepts that they could include at their discretion. In addition to developing the graphic representations of the interrelationships between concepts, the process also included a debriefing protocol whereby the teachers explained the rationale for their concept mapping decisions.

Innovation Configuration (IC) Mapping. Based on the Concerns Based Adoption Model [19, 20], an innovation configuration map (IC Map) was developed by the project team to describe what engineering infused science should look like in the classroom. Innovation Configurations describe an innovation in action along a continuum from high-quality implementation to least desirable practices[21]. An IC Map is developed to provide "word pictures" of how the innovation is being put into action by describing the different forms that an innovation might take when being implemented. For the purpose of the current project, the innovation was defined as "using engineering concepts to teach science." The project's IC Map includes three dimensions: (a) curriculum materials, (b) teacher practices associated with design, and (c) teacher practices associated with engagement of engineering concepts. Each dimension contains a number of components with a range of descriptions that can be used to document the component's implementation from ideal to nonexistent. Each level of implementation is described in terms of observable teacher behavior. The pilot test teachers helped refine the project's IC map during the second summer institute.

Case Studies. Five engineering case studies were developed to engage the teachers with the core concepts in authentic contexts. These included the rise and fall of a medical device design company, analysis of a Frank Lloyd Wright design, a solar design device for a third world country, plasma gasification of waste, and engagement with the Maker movement. Each case study included probing discussion questions designed to engage the teachers with selected engineering concepts. The case studies were included at various points across the two weeks of the first summer institute.

Directed mentoring and assessment of design based activities. During the second summer institute, an experienced secondary level technology education teacher was commissioned to conduct a session on assessing applied engineering activities. This individual has had extensive experience with curriculum development and assessment and is also an experienced mechanical engineer. This component of the institute was timed to coincide with the infused engineering curriculum development process.

During the second summer institute, the same teacher who had been commissioned to assist the teachers with assessment development was also commissioned to attend and assist the physics teachers with their infused lesson development. One of the project's PIs, an engineer with experience with life sciences curriculum development, served a similar role with the life sciences cohort. As engineers and experienced teachers and professional developers, these individuals were uniquely positioned to provide guidance and ideas for how to craft science lessons to include core engineering concepts in engaging and innovative ways.

Curriculum Infusion Activities. A central element of the professional development process has consisted of engaging the teachers, in a variety of ways, with engineering infused lessons. The premise of involvement with curriculum has been that it provides learners with a platform for an active and engaged arena for applying the conceptual base. In short, given the inherent applied nature of engineering, it makes sense to engage the teachers in engaging and authentic applications of the concepts. Broadly stated, the process involved moving from engagement with an existing engineering infused module (during the first summer institute) to the infusion of an existing science lesson with engineering concepts (during the second summer institute).

During the first summer institute, the teachers were engaged as learners with an intact engineering infused curriculum module. Working in groups, the life science cohort used an algae farm development activity while the physics cohort used an infused energy audit unit of instruction. Throughout the lesson implementation, they were encouraged to reflect on ways in which the core engineering concepts were woven throughout the module. Subsequent to the implementation of the model activity, the teachers moved on to the development of a draft of an infused lesson based on what they had learned through their engagement with the infused module. One significant challenge of this process was to first identify appropriate science topics/lesson ideas that could be infused with engineering concepts. As might be expected, this selection process proved to be more challenging for the life science teachers since many bio-related engineering activities are exceptionally complex, expensive and require knowledge beyond the secondary school level. Once the topics/lesson ideas were identified, the teachers worked in groups to develop and present draft lesson plans. During the school year following the first summer institute, the teachers engaged their science students in one of the engineering infused lessons that they had used or developed during the institute. The lessons were video-taped for use as reflective analytical tools during the second summer institute.

During the second summer institute, the teachers began with a critique of an existing engineering infused curriculum module. A set of guided questions was used to focus their analysis including such things as identifying the infused engineering concepts, the perceived effectiveness of their use, and ways in which the engineering facilitated the learning of the science.

They then moved on to develop an infused lesson in small groups to share with the whole group. The goal was to develop an infused lesson that could be delivered to students during the school year and was designed to build on a base of knowledge about engineering infusion developed during the first year. Examples for the life sciences included creating a soap-based biological detergent that is effective at removing oil, gelatin, and grass stains; and developing a self-watering device to maintain a moderate moisture level for a medium-size house plant for 5 days. The physics group designed and tested a fuse for an electrical circuit and designed an experiment to determine and compare the power consumption and efficiency of three systems that could be used to heat water. The final step of the curriculum engagement process involved infusing a lesson that they had been delivering on a regular basis with engineering concepts. The culminating activity during the second summer institute consisted of presenting the lessons to their colleagues in preparation for delivering the lessons to their students during the school year.

School year professional development sessions. The professional development extended throughout the school year with activities including the implementation of the engineering concept-infused unit, observations and responses to reflection questions base on this implementation, and face-to-face professional development meetings. The teachers developed implementation plans during the summer institute to specify when they would implement the engineering concept-infused units. Each teacher was asked to video record an approximately one-hour lesson that was more teacher-centered and exemplified a focus on the engineering concepts. These videos were used as a learning tool during the second summer institute. In addition to the implementation of the engineering-infused units, the teachers were engaged in approximately 8 hours of face-to-face professional development with the institute leaders during the school year. The primary goal of these workshops was to debrief the implementation of the engineering-infused module and learn from the other teachers' experiences, sharing insights and discussing challenges. Two of the project's PIs and a master engineering and technology teacher led two hours of the professional development for each group of teachers.

Discussion of NextGen Standards (NGSS). At various points throughout the institute, the teachers were engaged in discussions of the NGSS including their structure, content and organization. The goals of this component were to examine how engineering is included in a selected standard, to explore the extent to which the emphasis in the NGSS aligns with the four engineering concepts and reflect on the extent to which the NGSS can deliver on its reasons for including engineering in the Standards.

Implementation issues activity. This session, conducted during the second summer institute, was designed to facilitate a discussion of obstacles to implementing engineering concepts into science classes. Teachers were asked to rate and comment on each of the following implementation barriers:

- Keeping the focus on concepts (engineering and science) rather than on activities.
- Interdisciplinary issues associated with getting teachers to work together across the STEM disciplines.
- Challenges associated with implementing the engineering component of the NGSS including the assessment of those components.
- Availability of curriculum materials designed to include engineering kinds of challenges into science lessons.
- School politics including helping key decision makers to understand the value of including engineering and other authentic experiences into the science curriculum.

- Awareness of resources, professional development opportunities, workshops, etc. designed to help science teachers prepare to include engineering concepts and activities into their lessons.

Preliminary Findings and Observations

Participant Level Outcomes. A variety of data were collected in conjunction with the summer institutes. Quantitative data included the Engineering Concept Assessment (ECA) and the science knowledge inventory. We also collected a substantial amount of qualitative data including concept maps, observational data (in conjunction with the External Evaluator), the Stages of Concern (SoQ) data, an in-depth, end-of- institute questionnaire, and daily feedback reflections. Based on an analysis of these data, the project team has identified several significant impressions based on the work conducted to this point. It is important to acknowledge that these are preliminary observations and impressions based on pilot phase implementation with a small sample of teachers.

Based on the interactions and observations that we have had with the teachers, they have been quite receptive to including engineering into their science instruction. This has generally been true of both groups of teachers although engineering terminology and approaches appear to be more natural for the physical science teachers whose content has traditionally been more closely connected and applicable to engineering. While the life science teachers have been receptive and engaged, appropriate engineering design activities at the secondary level have been much more difficult to identify. We suspect that this issue will persist as curriculum specialists work to incorporate the engineering dimension into the life science components of the NGSS. This said, it should be noted that the engineering infusion process into lessons was much easier for the teachers due to their experiences during the first year. They were better equipped to identify appropriate science lessons and were more adept at crafting the lessons as design challenges infused with engineering concepts.

It is important to acknowledge that the study targeted outstanding teachers for the pilot phase of the project, many of whom have had some previous exposure to engineering. We anticipate that it may be more challenging to engage teachers who have no previous engineering exposure in the full cohort implementation. We also need to note that in spite of the receptivity, the teachers' overall level of conceptual sophistication with the engineering concepts was in its early stages. While they have become relatively adept at using engineering terminology, our impression is that several teachers continued to struggle with infusing engineering concepts and approaches into their science lesson planning. The inclusion of engineering and technology education teachers in the pilot cohort was particularly helpful for the biology teachers as they navigated the engineering content. We anticipate that the IC map will be a valuable tool for the teachers as they continue to reflect on what makes a high quality, engineering-infused science. Although there was a significant gap between what we observed during the school year implementations and the "ideal" implementation described in the IC Map, this is not surprising as our understandings of engineering infusion evolved with the teachers' initial attempts at implementation.

Modest gains in science content knowledge were detected from pre- to post-testing for both cohorts (3.7 percentage point gain for the physics group and a 3.3 percentage point gain for the life sciences group). This outcome was somewhat unexpected since science content instruction was secondary to our primary focus on engineering conceptual understanding. The engagement with the engineering-infused modules did, however, contain some new science content and/or content situated within a new design-based context. It may be that they obtained a more in-depth understanding of some science concepts as a result of the connection to engineering. We will continue to probe this dynamic throughout the remainder of the project.

Modest gains were also detected in engineering concept knowledge from pre to post for both cohorts (4.7 percentage point gain for the physics group and a 4.8 percentage point gain for the life sciences group). The largest gains were with newer teachers (with 2-4 years of teaching experience) and teachers with minimal engineering background. Teachers with engineering backgrounds (e.g., engineering degrees and engineering/technology education degrees), as anticipated, had smaller gains. However, given the strong emphasis on engineering concepts throughout the institutes, this modest outcome was somewhat disappointing. Our post-institute item analysis of the ECA detected problems with a number of the items. Given the potential for the instrument's importance for the project and potential wide-spread use by science education following the project, we have invested substantial work into major revisions to the instrument during the pilot phase of the project.

Project Level Outcomes and Challenges

Challenges associated with maintaining a focus on conceptual learning while engaged in active learning. Maintaining student focus on conceptual learning while engaged in active learning exercises is a pedagogical challenge for teachers. As students new to engineering become immersed in an open-ended design challenge, they tend to focus on "building and doing" rather than "planning and thinking". As a result, the active learning exercise becomes a "fun activity" rather than a rigorous exercise that deepens conceptual learning. Even in science classrooms, it is common for students to lose sight of the scientific concepts that are central to the design challenge and rely on trial and error methodologies rather than a systematic engineering design cycle with design decisions grounded in science and engineering concepts. This challenge was one motivating factor behind the creation of the IC Maps. Pedagogical practices that promote student focus on science and engineering conceptual learning comprise a large section of the IC Map developed by the project team. In this instance, the IC Map may serve as a reference resource for implementation of engineering design infused science lessons.

Value of IC mapping tool and process as PD tool. Because many science teachers are inexperienced with engineering, they do not have a strong sense of what engineering infusion "looks like" in a classroom and are therefore unclear about what they are being asked to do. Furthermore, they have little basis for distinguishing strong versus poor classroom enactment and struggle to know how to adjust their pedagogical practices. This is particularly true for the enactment of open-ended engineering design challenges that require the teacher to take on the role of "coach". To bridge this gap in understanding and as indicated earlier, the project team developed an Innovation Configuration Map (IC Map).

The IC Map is being used as a tool for professional development in several ways. It serves as a basis for discussion of pedagogical practices by helping teachers better understand the link between teacher actions and desired student learning behaviors. The IC Map is also as a guide for teachers during lesson enactment and serves as a tool for self-assessment and reflection. Once teachers have used the IC Map in the classroom, they are provided the opportunity to provide feedback on the structure and content of the map. The IC Map is therefore a living document that is revised and refined as teachers gain experience and expertise in the implementation of engineering concepts. This component is critical to the creation of a strong map and helps to ensure teacher buy-in for use of the tool.

Value of lesson development as a mechanism for developing conceptual understandings. Lesson development can be a powerful tool for deepening conceptual understanding. Through the pilot summer institutes, the project team observed teachers becoming more comfortable with engineering concepts and the idea of implementing engineering infused lessons. While most teachers will not go on to become curriculum developers, many will adjust or modify existing lessons in an effort to increase efficacy and student learning. Exercises during the summer institutes wherein teachers infused engineering into existing science lessons allowed teachers to practice lesson modification and provided an opportunity to deepen learning of engineering concepts. In order to infuse a science lesson with engineering concepts, the teacher must ask and answer a number of inherent questions. The questions that emerge naturally from the lesson development activity can be used to provide “just-in-time” learning to teachers about more fundamental questions pertaining to the infusion of engineering concepts into science (see Table 2). This inquiry-based approach allows teachers to have a concrete example while “discovering” answers to fundamental questions of lesson design.

Table 2.

Example questions that emerged from lesson infusion activities.

Practical Teacher Question	**Fundamental Question**
Which lesson or set of lessons should I choose for infusion?	What are the attributes of lessons that “lend themselves” to engineering concept infusion?
What engineering concepts should be infused in the chosen lesson?	How do specific engineering concepts align with or overlap science concepts? Where are the natural synergies between the two?
How long will the lesson take now that engineering concepts are infused?	How does engineering concept infusion impact how time is managed in the classroom? How do classroom time constraints impact the ways in which engineering concepts can be infused?
How do I write a design challenge?	What are the attributes of a well-written design challenge? How can a design challenge be assessed for quality?
How do I change an inquiry activity into a design activity?	What are the similarities and differences between scientific inquiry and engineering design?

Difficulty associated with understanding engineering infusion process. A particular challenge of the project has been the development of an engineering infusion process. The integration of engineering concepts into science teaching is largely a new undertaking, one that has not been well-researched or documented to guide current efforts. While working with the pilot test teachers it was clear that teachers would benefit from a standard definition of infusion, as well as a series of steps to use when trying to infuse engineering content into science lessons. The project team has attempted to formalize this process, working with the pilot test teachers to identify key components. However given the variety of content taught within biology and physics, it has been challenging to identify a formal process for infusing the engineering concepts. The project team has identified common elements from each group of pilot test teachers (biology and physics) but these have not yet coalesced into a checklist or process. One group of teachers created a document to outline the infusion process during the final summer institute that will serve as a starting place for drafting a checklist in the future stages of the project. With some specific considerations to follow, the IC Map could then be used to provide nuanced detail related to creating high quality infused materials and using ideal teaching practices during implementation.

Evaluation Outcomes

In addition to the research study associated with the project, the external evaluation has also resulted in additional outcomes that are pertinent to the pilot test portion of the project. Methods have included observation of both the professional development and classroom implementations, feedback surveys with teachers and project advisors, and teacher interviews. Two evaluation goals are of particular interest for the current paper. The evaluation was expected to: (1) ensure that the outputs and outcomes of the project are considered valuable, and (2) ensure that the project is making satisfactory progress toward its goals.

The value of the project to teachers has been documented via surveys and interviews conducted throughout the project. Teachers have provided consistent and positive feedback about the training received through Project Infuse. For example, 83% of teachers reported that the 2013 training met or exceeded their expectations. Evaluation results also indicate that teachers have a deep appreciation of engineering and the value of infusing engineering into science classrooms. They believe infused lessons offer stronger real world connections for students and that students are more engaged during infused lessons. Even so, teachers are concerned about the amount of time it takes to both create and implement infused lessons. Time was the top-cited challenge by teachers at the end of each summer institute.

Teachers also believe that the professional development has improved their own teaching practice, and summative evaluation results confirm the value of the experience in relation to teacher knowledge and practices. A series of retrospective-pre items documented statistically significant increases in teachers' self-reported knowledge of engineering content and their ability to integrate engineering into their teaching practice.

To document the extent to which the project team is making satisfactory progress toward its goals, the evaluation has tracked both the successful completion of project deliverables and teachers' implementation of infused lessons in the classroom. Earlier sections of this paper document the research team's success in creating key deliverables, and so we focus here on teacher implementation results. All pilot teachers implemented at least one infused lesson/unit during the 2012-2013 year and some went beyond expectations to implement additional infused lessons as well. As a result, the amount of time the teachers spent integrating content from outside their primary discipline into the classroom increased. The objectives of teachers' lessons, for example, shifted to reflect the goals of the project, with a sub-set of teachers adding learning goals from outside their primary discipline as an explicit focus of their teaching. The majority of the science lessons observed in 2012-2013 featured the use of engineering concepts, terminology, and/or design activities. Many (if not all) of these topics and activities reflected a new approach to teaching.

A common trend in both the professional development and classroom implementations has been the prioritization of the concept design above the other engineering concepts. For example, the summer institutes have focused on this concept in greater depth compared to the remaining concepts. Teachers also reported they had the easiest time identifying with design and thinking about design in relation to their curriculum, with 73% of Physics teachers and 100% of Biology teachers naming design as the concept that would work best with their curriculum. Finally, the IC Map also prioritizes design by including a component that requires a design challenge in order for an implementation to be scored.

Conclusion

This paper described the results from a pilot test of a two year professional development program focused on infusing engineering into biology and physics at the secondary level. The project research team has been investigating how to infuse engineering concepts into science given the time, resource, and curricular constraints of school environments. Specific implementation issues have been identified as important as teachers incorporate engineering concepts into their instruction. The outcomes and issues that have been identified have provided the necessary feedback to inform the full implementation with the next cohort of teachers. During the next two years physics and biology teachers will be recruited to participate in the project's professional development. Based on this second iteration, further refinement to the project's professional development design and assessments will be conducted. The targeted outcomes of the project that will be disseminated include an engineering concept infusion professional development model, the Engineering Concept Assessment, and engineering infusion innovation configuration maps. The hope is that these outcomes will help inform the implementation of engineering into science as articulated by the NGSS and other such documents.

References

1. National Research Council (NRC). 2011. *A framework for K-12 science education: Practices, crosscutting concept, and core ideas.* Washington, D.C. National Academies Press.
2. NGSS Lead States. 2013. *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press
3. Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.
4. Donovan, M.S., & Bransford, J.D. (2005). How students learn: Science in the classroom. Committee on How People Learn: A Targeted Report for Teachers. National Research Council. Washington, DC.
5. Burbank, M., & Kauchak, D. (2003). An alternative model for professional development: Investigations into effective collaboration. *Teaching and Teacher Education, 19*(5), 499-514.
6. Clarke, D.J. & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education, 18*(8), 947-967.

7. Loucks-Horsley, S., Love, N., Stiles, K. E., Mundry, S., & Hewson, P. W. (2003). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin.
8. Custer, R. L., Daugherty, J. L., Meyer, J. P. (2010). Formulating a concept base for secondary level engineering: A review and synthesis. *Journal of Technology Education*, *22*(1), 4-21.
9. Daugherty, J. L. (2009). Engineering professional development design for secondary school teachers: A multiple case study. *Journal of Technology Education*, 21(1), 5-19.Removed for blind review.
10. Daugherty, J. L., & Custer, R. L. (2010). Secondary level engineering professional development: Content, pedagogy, and challenges. *International Journal of Design and Technology Education*. Retrieved from http://www.springer.com/education+%26+language/learning+%26+instruction/journal/10798
11. Ross, J. M. & T. M. Bayles. (2007). Implementing the INSPIRES Curriculum: The Role of Professional Development. *Professional Development of Engineering and Technology: A National Symposium Proceedings*. Illinois State University.
12. Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915-945.
13. Guskey, T. R. (2003). What makes professional development effective? *Phi Delta Kappan*, *84*, 750-784.
14. Katehi, L., Pearson, G., & Feder, M. (Eds.). National Academy of Engineering and National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press, p. 71-72.
15. Hord, S. M., Stiegelbauer, A. M., Hall, G. E., & George, A. A. (2006). *Measuring implementation in schools: Innovation configurations.* Austin, TX: SEDL.
16. Turns, J., Atman, C. J., & Adams, R. (2000). Concept maps for engineering education: A cognitively motivated tool supporting varied assessment functions. *IEEE Transaction on Education*, *43*(2), 164-173.
17. Wheeldon, J., & Faubert, J. (2009). Framing experience: Concept maps, mind maps, and data collection in qualitative research. *International Journal of Qualitative Methods*, *8*(3), 68-83.
18. Willerman, M., & MacHarg, R. (1991). The concept map as an advance organizer. *Journal of Research in Science Teaching, 28*, 705-711.
19. Hall, G.E., & Hord, S.M. (2011). *Implementing change: Patterns, principles, and potholes*, 3rd ed. Boston: Pearson.
20. Hord, Steigelbauer, Hall, & George, 2006
21. Hord, Steigelbauer, Hall, & George, 2006