

2012

Infusing Engineering Concepts: Teaching Engineering Design

Jenny L. Daugherty

Follow this and additional works at: https://digitalcommons.usu.edu/ncete_publications

 Part of the [Engineering Education Commons](#)

Recommended Citation

Daugherty, Jenny L., "Infusing Engineering Concepts: Teaching Engineering Design" (2012). *Publications*. Paper 170.
https://digitalcommons.usu.edu/ncete_publications/170

This Report is brought to you for free and open access by the Research at DigitalCommons@USU. It has been accepted for inclusion in Publications by an authorized administrator of DigitalCommons@USU. For more information, please contact dylan.burns@usu.edu.





Infusing Engineering Concepts: Teaching Engineering Design

Jenny Daugherty
2012



ncceteTM

National Center for Engineering
and Technology Education
www.nccete.org



The material is based on work supported by the National
Science Foundation under Grant No. ESI-0426421

Infusing Engineering Concepts: Teaching Engineering Design

Jenny L. Daugherty
Purdue University

Engineering has gained considerable traction in many K-12 schools. However, there are several obstacles or challenges to an effective approach that leads to student learning. Questions such as where engineering best fits in the curriculum; how to include it authentically and appropriately; toward what educational end; and how best to prepare teachers need to be answered. Integration or infusion appears to be the most viable approach; instead of stand-alone engineering courses squeezing into the already crammed curriculum. An integrative approach whereby engineering is infused into the existing curriculum, within science, technology, mathematics or other courses, appears to be the best approach to expose students to engineering learning.

Given this perspective, emerging new national assessments and calls for new standards to include engineering strands, suggest a new curriculum structure, as well as more effective teacher preparation to deliver instruction. For example, the National Research Council 2011 report, *A Framework for K-12 Science Standards*, includes engineering as one of four strands and identifies cross-cutting concepts in engineering and in science education. However, little is yet known about how best to infuse engineering concepts into the K-12 curriculum. What does it mean to infuse engineering concepts into high school instruction? This question raises significant issues that need to be addressed in order to integrate appropriate engineering concepts and accomplish important learning outcomes.

In order to explore this larger question, an expert focus group meeting was convened to inform the development of a model or descriptions for infusing engineering concepts into high school instruction and to address some of the pertinent questions involved. This meeting was funded by the National Center for Engineering and Technology Education¹ (NCETE) and builds upon earlier work funded by NCETE to study teacher professional development and identify an engineering concept base for secondary teachers (Custer, Daugherty, & Meyer, 2010; Daugherty, 2009; Daugherty & Custer, 2010). The focus group was assigned the primary task of identifying the instructional design problems encountered when infusing engineering concepts into high school science instruction. The primary questions guiding this focus group were:

- What does it mean to infuse engineering concepts into instruction?
- What are the implications for infusing engineering concepts into instruction?

Background

The focus group meeting is an important input toward a larger project, in which the researcher is a co-Principal Investigator. The Infuse Project was funded by the National Science Foundation to research teacher learning through an innovative approach to professional development that is engineering concept-driven.² The project is focused on the infusion of engineering concepts into life science and physical science education. A partnership among life science educators at Stevens Institute of Technology, a

¹ This material is based upon work supported by the National Science Foundation under Grant No. 0426421. Any opinions, findings, and conclusions of recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

² Project Infuse is supported by the National Science Foundation under Grant No. 1158615. Any opinions, findings, and conclusions of recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

physical science educator at the University of Massachusetts-Boston, and engineering teacher educators at Black Hills State University, Purdue University, and University of Maryland-Baltimore County is developing an engineering concept based professional development approach and examining its viability.

The Project Infuse research team has been engaged in work that helped to inform this focus group meeting. This has included the development and refinement of an engineering concept base. Building on studies conducted to identify core engineering concepts for the K-12 level (Custer, Daugherty, & Meyer, 2010; Rossouw, Hacker, & de Vries, 2010), the Project Infuse research team employed a systematic process to define the conceptual base for engineering at a level appropriate for secondary level science education. From the lists of concepts identified in the two studies, the project leadership team discussed the merits of each of the studies and discussed the outcomes of each. Based on this information, the team decided that there were too many concepts identified between the two studies to use all as the conceptual base for the project, have each defined in the literature, and assessed on one instrument. It was determined that a more manageable number was required. The team decided to focus on a smaller set of primary concepts that are central to engineering, important at the secondary level, and can provide strong links to science education. From these criteria, four primary concepts emerged and definitions for them were selected and refined from the literature base. The concepts and definitions are presented in Table 1.

Table 1. Definitions of Selected Engineering Concepts

Concept	Definition Selected/Refined
Design	Design is an iterative process conducted within specified constraints to develop products or systems to satisfy human needs and wants. Design typically includes components such as problem definition, data analysis, modeling, and solution refinement and has both technological and social components.
Analysis	Using tools such as physical, graphic and analytical models, empirical equations, and experience to analyze data and predict the performance or behavior of an object or system throughout the life of the design process.
Modeling	Creating a detailed visual, mathematical, or three-dimensional representation of an object or design, often smaller than the original. Modeling is often used to test and communicate ideas, make changes to a design, visualize and analyze systems, and to learn more about what would happen to a similar real object
Systems	A system is a group of interrelated components designed collectively to achieve a desired goal. Systems should be studied in different contexts, including the design, troubleshooting, and operation of simple and complex systems.

Review of Previous Research

The emphasis on concepts is rooted in cognitive science research findings that conceptual understanding is necessary for understanding facts and ideas in a particular context, allows learners to apply what they have learned to new situations, helps them learn related information, and provides for the creation of a connected web of knowledge (Bransford, Brown, & Cocking, 2000). Concepts should organize knowledge, including content or discipline-specific knowledge, into meaningful instruction (Donovan & Bransford, 2005). In order for this emphasis to be included in the curriculum, concepts must be made explicit in the instruction. Given the four engineering concepts described above, the expert focus

group was convened to decide how best to infuse these concepts into the existing curriculum. However, it is important to note that previous work informed the discussion as well.

Engineering Infusion

Infusing engineering into the K-12 classroom has been approached from a variety of perspectives. Much of the focus has been on engineering design within technology and science education. Technology education is at the forefront of engineering education; incorporating into its disciplinary identity a focus on engineering. For example, the professional association for technology education recently changed its name to include engineering (i.e., the International Technology and Engineering Educators Association). Technology education, however, is not a part of the standardized testing program in schools, is often an elective, and does not even exist in all schools; these factors limit the number of students exposed to engineering education. Technology education programs typically have enough curricular flexibility to encompass a considerable variety of approaches to the infusion of engineering. As a result, there is a large range of variability in approaches to incorporating engineering in secondary technology education. There are two distinct philosophies: (1) a pre-engineering perspective that focuses on developing an engineering pathway for capable students; and (2) an engineering literacy perspective that views engineering knowledge as important for all students (Daugherty, 2009).

Science education is also undergoing reorganization to include a focus on engineering. The motivation for infusing engineering into science and possible approaches for doing so were discussed by Leonard and Derry (2011). They advocated a focus on engineering, basing their argument on student motivation, alignment with several learning theories (cognitive constructivism, social constructivism, and pragmatism), and education standards that have either explicitly called for engineering or have emphasized teaching science in authentic contexts. The New Generation of Science Standards also include engineering knowledge and skills (for more information see: <http://www.nextgenscience.org/>).

Much of the focus of infusing engineering into science education has been on teaching scientific concepts and processes, with an emphasis on scientific inquiry through the design of artifacts (i.e., Edelson, 2001; Harwood & Rudnitsky, 2005; and Rockland, Bloom, Carpinelli, Burr-Alexander, Hirsch, & Kimmel, 2010). Kolodner's (2002) *Learning by Design* is one such approach that situated science learning in the context of designing devices. The design challenges provided students with opportunities for scientific inquiry and the application of what they learned to the development of a solution. Fortus, Krajcik, Dershimer, Marx, and Mamlok-Naaman (2005) proposed a Design-Based Science (DBS) approach, which is "an inquiry-based science pedagogy in which new scientific knowledge and problem-solving skills are constructed in the context of designing artifacts" (p. 856). They developed three ninth grade instructional units that engaged students in design without any explicit instruction about design. A pre/post-test study of 92 students documented considerable gains in learning (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004).

Hmelo, Holton, and Kolodner (2000) described an approach to teaching middle school students about complex systems (in this case the respiratory system) through design. They argued that design activities are "well-suited for helping learners understand systems because of their emphasis on functional specification and their requirement that behavior be implemented" (p. 251). Given a set of constraints, designers must create a system or artifact in order to accomplish the desired functions. The functional requirements and iterations that occur in design afford opportunities for students to understand science concepts and apply those understandings to the design. This knowledge is often created through the design, construction, testing, and refinement of models. In order to design models, students "describe, predict, or explain some phenomena, which requires them to discuss and invent objects and their relations to each other as well as to consider functions and casual behaviors of the components in their model" (p. 252).

Approaches

Infusing concepts into the curriculum can be approached in different ways from an instructional design perspective. Ryan, Gane, and Usselman (2011) reviewed two curriculum models for integrating engineering core concepts into science and mathematics curriculum: (a) project-based inquiry science (PBIS); and (b) integrated teaching and learning (ITL). The two models were compared using task analysis and a cognitive walkthrough based on learning outcome variables. The PBIS approach is based on a problem-based inquiry learning model, is designed as an entire curriculum, and focuses on experience prior to explanation. In contrast, the ITL approach provides explanations before the activity and may require less time because it is designed as individual units. The ITL approach explicitly identifies engineering concepts, while the PBIS approach makes no specific provision for a focus on engineering.

Others have outlined approaches or models for infusing engineering. The learning-for-use (LfU) model (Edelson, 2001) provided a set of learning activities intended to achieve learning objectives associated with design. These activities include construction and modification of knowledge structures, understanding goals, and structuring knowledge for future use. Kolodner (2002) described a set of strategies based upon the Learning by Design project. These included: (a) foregrounding the skills and practices; (b) reflective practicing; (c) establishing the need to use the skills and practices; (d) ritualizing the practice of important skills; and (e) establishing and enforcing expectations. Fontenot, Talkmitt, Morse, Marcy, Chandler, and Stennett, (2009) at the Texas Tech T-STEM Center created an engineering design process model to help science students distinguish engineering design from the scientific method. Their Frame model includes the following components: (a) frame the problem; (b) research the possibilities; (c) analyze the data; (d) model the design; (e) execute the design; and (f) evaluate – both formative and summative.

In their approach to engineering infusion, Leonard and Derry (2011) concluded that it was important to make the distinctions between science and engineering clear to students when infusing engineering. They outlined three areas where the distinctions can be made clear: (a) goals, (b) practices, and (c) knowledge. The goal of engineering is to meet human needs and wants and the goal of science is understand natural phenomena. With these differences, “come different beliefs and theories about the nature and limits of knowledge and its acquisition, as well as different norms for accepting assertions” (p. 6). In terms of practices, engineers engage in modeling and experimenting of the same kind used in scientific inquiry but with different qualities and purposes. Models in engineering need to explain the natural phenomena as they are intended to do in science. In terms of knowledge, within engineering, scientific (and mathematical) principles are necessary, as well as technological knowledge, which is described as “an intermediate form of knowledge between abstract scientific knowledge and specific device knowledge” (p. 7).

Challenges

In addition to describing the approaches to infusing engineering, authors describe the several challenges confronting this type of instruction, particularly within science education. For example, Leonard and Derry (2006) articulated what they called the tensions and tradeoffs associated with the inclusion of engineering into the K-12 curriculum. The most often-cited are the time required to include engineering in the already crammed curriculum and the focus on content not assessed on standardized tests. Kimmel, Carpinelli, Burr-Alexander, and Rockland (2006) also pointed out that the lack of instructional materials that integrate engineering and science. Many science textbooks do not include engineering and much of the K-12 engineering material needs to be redesigned to specifically address the science standards. However, as they pointed out, simply organizing a curriculum is not an adequate

intervention to insure the infusion of engineering. They suggested that the inclusion of engineering requires adequate preservice teacher preparation, professional development of current teachers, and recognition of the importance of aligning instruction with content standards so that students are prepared for standardized assessment tests.

Edelson (2001) argued that much of the challenge with infusing engineering into science has to do with the way science is traditionally taught; where content and inquiry skills are taught separately. In traditional science classrooms, “content is taught didactically through lecture, reading, and problem sets, and scientific practices are taught through structured laboratory experiments” (Edelson, 2001, p. 356). This traditional approach of focusing on the memorization of facts does not translate well either to inquiry or to engineering design. Hmelo, Holton, and Kolodner (2000) indicated that three tradeoffs need to be made in order to facilitate an effective approach. The first is finding a balance between having students work on the design and asking them to reflect on the learning. The second is learning how to integrate real world aspects without overwhelming the class with irrelevant details. The third is emphasizing understanding as more important than the task of completing the design activity.

Leonard and Derry (2011) argued that tensions arise in a design-based approach to science because of the epistemological differences between science and engineering. A distinct challenge of infusing engineering into science for the goal of learning science is that rarely “does a science concept appear in an isolated form that allows it to be studied discreetly – it operates in concert with multiple, intersecting science and technological concepts” (p. 45). There is tension between dealing with the abstract nature of science and the need to translate that into the concrete context of engineering. Engineering demands “an intermediate form of knowledge between the abstract and concrete” (Leonard & Derry, 2006, p. 414). A related tension is determining the appropriate level of complexity of an activity. This is particularly relevant when it comes to modeling as students have to determine which elements to include and which elements are optional.

Leonard and Derry (2011) offered suggestions for alleviating some of these challenges. The first is the development of instructional materials that identify common design variables that transfer from challenge to challenge and that provide for the learning of science through explanations of an artifact’s behavior. The science knowledge may need to be recast so it is relevant to the design problem. They also suggested that time be allotted to the learning of both science and engineering. Engineering is not merely included as a vehicle for science learning but as important to understand as well. Finally, modeling, with the appropriate level of complexity, should be incorporated because “explicit attention to modeling can facilitate better links between the products under design and the science behind them” (p. 46).

Based on the literature reviewed, there is evidence of the desire for and benefits of including engineering in the K-12 classroom. A few approaches to infusing engineering into science have been identified with some of the commonalities being a focus on design and attending to the learning of science content. Attention to the gap between traditional approaches and an engineering-based approach; adequate teacher preparation to help navigate this gap; balancing the time investment with accomplishing the important (assessed) learning outcomes; and addressing the pedagogical concerns that are presented with an engineering approach are all important as well. However, a well-researched, specific model for infusing engineering concepts was not located in the literature, spurring the need for the focus group meeting.

Expert Focus Group Meeting

The expert focus group meeting was convened to provide specific approaches for the development of an instructional design process for the infusion of core engineering concepts. Fifteen participants were selected based upon their recognized expertise in pre-college engineering education and their experience

developing and implementing pre-college engineering curriculum. The majority of the participants were science (n=5), technology (n=3), or engineering (n=2) faculty, administrators, and/or educational center directors/associates. A technology and engineering education high school teacher, a technology education graduate student, a science education post-doctoral student, and a program evaluator with expertise in K-12 STEM education also participated. The assumption was that the participants' experience with K-12 engineering education provided a strong base to offer guidance in the development of an approach for infusing engineering concepts. It was also assumed that those selected understood the engineering concepts sufficiently to be able to teach them and infuse them into instruction.

In advance of the meeting, participants were asked to read a narrative describing the process by which the four engineering concepts (design, analysis, systems, and modeling) were identified and defined. They were also asked to consider how the concepts could be integrated into instruction by considering the following questions:

- How should the infusion process be enacted in order to ensure appropriate content coverage and assessment?
- What concepts should be infused and how should these be selected?
- Can engineering concepts be infused into all lessons or do they need to be of a certain type (e.g., a design scenario)?
- What is the inter-relationship between infused engineering concepts and the content and experiences included in the lesson?

During the eight hour meeting, spread over two half-days, the participants were guided through a series of discussions to elicit elements for the creation of a model and descriptions of effective procedures for infusing the four engineering concepts (design, analysis, systems, and modeling) into instruction. The discussion was rooted in specific exemplar instructional units. Three exemplar curriculum projects that include a focus on engineering were presented: (a) the *INSPIRES* curriculum, (b) an algae farm module (developed at the Center for Innovation in Engineering and Science Education at Stevens Institute of Technology), and (c) the *Active Physics* curriculum. The curriculum developers presented the overarching goals of their curriculum and their approach to engineering.

The *INSPIRES* module requires students to design a heart-lung system after developing the associated knowledge and skills. The algae farm module asks students to design a device and/or process that will feed the combustion gases from a burning candle into an aquatic environment to model the use of stack gases from fossil fuel burning power plants to provide carbon sources for full size algae farms. The *Active Physics* module entitled "Electricity for Everyone" begins with a scenario where team members are part of an organization "Homes for Everyone." The purpose of the organization is to address housing and electricity needs in areas throughout the world.

The discussions at the focus group meeting were documented through observation notes and artifacts from the meeting. In addition to the researcher, three participants agreed to keep notes during the meeting to ensure adequate coverage of the discussion. Three other participants were designated to serve as rapporteurs, who presented their summaries and impressions of the discussions at the end of the session. These summaries were also captured to complete the record of the conversations.

Results

The results of the expert focus group meeting are grouped according to the research questions that guided the study. Notes captured by the researcher and the three participant note takers were read and relevant issues related to the research questions were noted. These are summarized below.

RQ. 1 – Engineering Concept Infusion

The first research question asked what it meant to infuse a lesson with the engineering concepts. The intention was to investigate the approaches taken by the expert participants in infusing engineering at the K-12 level in order to identify best practices or strategies. Several of the issues discussed related to the meaning of infusing engineering into instruction. These issues were grouped into two primary themes concerning the meaning of engineering concept infusion: (a) engineering as a distinct way of thinking; and (b) engineering concepts as the “tools” for infusion.

Several of the participants discussed the meaning of engineering in the K-12 environment as a “way of thinking” or engineering practices as “habits of mind.” One participant described engineering as the mental models that engineers have for organizing information and approaching problems. The disciplinary distinctiveness of engineering as compared to science was described by participants over the course of the meeting. Many of the participants believed it was important for teachers and students to understand what it means to “do” science and “do” engineering; as well as how the two fields are similar and how they differ. Their connections and overlapping areas should be reflected upon throughout the learning process. One participant suggested that a Venn diagram might be created to characterize the primary features of both fields.

On several occasions throughout the meeting, participants identified tools for infusion. For example, one participant suggested that inquiry and design are tools and that students should learn how to decide which tool is needed in problem solving. This decision is dependent both upon the problem and upon the purposes for solving the problem. For example, students can engage in inquiry as a method to collect data in solving a design problem; using both tools in the same context. The consensus among the participants was that design is crucial to engineering and should be the focus of infusion. Using an engineering approach implies approaching problems in a specific way, one that is informed by a general design process. One participant described it as a way to approach ill-defined and ill-structured problems and another offered the definition of engineering as design within constraints. Problem based learning was mentioned during the discussion, with the expectation that engineering could offer design contexts for a problem based approach to instruction.

The participants also discussed the importance of the four engineering concepts (design, analysis, systems, and modeling) as providing students with the language and tools for an engineering approach. These were discussed as key building blocks for students to navigate design-based problems. Teaching the engineering concepts in abstraction misrepresents the integrative and robust nature of engineering; thus they should be embedded in the design challenges. For example, modeling and systems were discussed as being particularly important to engineering infusion because they provide strong connections to science content learning and engineering applications. Although some of the participants questioned whether engineering should be reduced to only four concepts, the majority of the participants believed these (and perhaps other) engineering concepts should be elicited from the design context so students are able to transfer learning outcomes from one context to another.

RQ. 2 – Implications

The second research question focused on the implications of infusing engineering concepts into instruction. This question attempted to target the key elements of an approach toward infusing engineering and was the primary focus of the discussion. Several implications were identified by the participants throughout the meeting. These were summarized into two main themes: (a) the purpose and value-added component of engineering infusion; and (b) general approaches for engineering infusion.

An important implication for engineering infusion is determining the educational purpose of engineering. Purposes may range from offering authentic problems as a way of engaging students to the utilization of engineering practices as a means of providing a context for the science content that students are expected to learn. While these goals may co-exist, most of the participants believed that the intended purpose for including engineering has a direct impact upon how it is infused into the instruction. Indeed, they thought that the specific connections should be explicitly pointed out to students.

Related to the purpose of infusing engineering, the issue of the value-added component was discussed in terms of the learning gains offered by an engineering approach. In order to include engineering into existing instruction a tradeoff or balance between the time it takes to infuse engineering vs. the learning and engagement gained by such a lesson must be articulated. The payoff from engineering infusion must accompany any discussion of including engineering into existing instruction, according to a majority of the participants.

In terms of specific approaches for engineering infusion, engineering design was identified as key to infusion. It is important that design challenges be realistic and of appropriate size and scope. Two broad approaches to this were described during the meeting. These approaches differed in the sequencing of the content and design component. One approach was to teach the content associated with the design activity to scaffold the learning, equipping students to tackle the design problem. The science content is in place before students engage in the design challenge and the design problem is closely connected to the science content. The opposite approach is to begin with the design context or problem and elicit the key concepts and content knowledge components as the students progress through the design problem. Several participants described this approach as “just in time” learning or a “utilitarian” approach to teaching where concepts are taught when they are needed and at the depth necessary to progress with the engineering design problem.

There was no consensus as to which of these approaches is better; instead, participants expressed a general belief that the choice is dependent on the identified purpose for including the engineering. In terms of the model units that were presented, the science-based engineering units generally followed the first approach (science content followed by a design challenge), while the engineering-focused unit was situated in the engineering context and allowed students to build their content knowledge as they progressed through the problem solution. However, there was a general belief that it is important for students to reflect and be able to graphically represent (i.e., a concept map) their progress. This approach could provide an entry point for students to describe the engineering and science components of their process describing the tools they used to solve the problem and the learning outcomes that resulted.

The idea of an “entry point” is one of the key elements of infusing engineering. Particularly when working with existing instruction, infusing engineering begins with the identification of entry points so it can be introduced in a meaningful and natural way that leverages the necessary learning outcomes. Once these entry points are identified, either the engineering concepts or design challenge can be included into the instruction. The balance of the engineering component and the content knowledge pieces must be negotiated given the educational goals of the lesson. However, it is important that the engineering concepts are explicitly taught as a part of the lesson so students build those engineering habits of mind.

Finally, an important implication that was highlighted during the meeting was the development of “intermediate” knowledge and skills so students can navigate the design challenge. For example, when the design context requires mathematics and calls for the creation of artifacts, it is important that the instruction scaffold the learning and development of these knowledge and skills. Participants described this as the development of “craft skills” and the “technological know-how” so that students are able to implement the design challenge sufficiently. If students are to be expected to develop and create a solution to a design problem, they need to be provided the skills necessary to do so.

Conclusions

Based upon the presentations and discussions during the expert panel meeting, several conclusions were generated. Although a specific model was not developed, characteristics for infusing engineering concepts were identified. These characteristics were that:

- Infusion must begin with specific learning goals in mind and the identification of entry points or “portals” for infusing an engineering approach. These entry points are places in the instruction where engineering can be incorporated in ways that further the targeted learning outcomes at the appropriate scope and depth.
- Once entry points are identified, the next step is to recast or develop the lesson as a design challenge. The design challenge should deliver and reinforce the important content outcomes and provide opportunities for students to develop the necessary “intermediate” knowledge and skills.
- Throughout the learning experience the infused engineering concepts need to be explicitly taught so students develop engineering “habits of mind” and reflect on what it means to “do” engineering (as compared to “doing” science). These elements should transfer from one design challenge to other design challenges.

Engineering design challenges as the focus of infusion is another important conclusion from the expert panel meeting and within the related literature. This calls to question what is an appropriate engineering design challenge for the secondary level and how is it best implemented in the classroom. The NCETE recently published a report generated from two caucuses that were convened to discuss guidelines for the selection and development of engineering design challenges suitable for 9-12 grade students (Householder & Hailey, 2012). In addition to articulating the goals for and the challenges associated with engineering design challenges, the report included nine steps for selecting and implementing engineering design challenges. These steps include: (a) identifying the need or problem; (b) researching the need or problem; (c) developing possible solutions; (d) selecting the best solution; (e) constructing a prototype; (f) testing and evaluating the solution; (g) communicating the solution; and (h) redesigning; and (i) finalizing the design. Important to note is in the selection of the need or problem so that it is connected to student interests so that learners “own the problem” (p. 22); it is authentic and real; and it is relevant to the goals and objectives of the course. Another important component of engineering design challenges offered in the report is the need to construct a prototype because it becomes a “tangible artifact of the design” (p. 26) and can be then tested and evaluated enabling another important component: redesign. Throughout the engineering design process, it is important that students reflect on their product and process and make communicate these outcomes.

Finally, another conclusion from the meeting was the importance of appropriate teacher professional development. Several of the participants returned to this issue throughout the meeting and offered suggestions for preparing teachers to implement engineering into their classrooms. These suggestions were:

- Address the rationale and reasons for learning this type of approach from the teachers’ perspectives. Teachers must invest time and effort to include engineering in their curriculum. Without strong drivers, such as state standards and administrative pressure, teachers need to be motivated via other means. These might include student motivation and evidence of improved student learning on standardized tests.
- Focus as narrowly as possible on how to infuse engineering.
- Provide examples and models of what this approach “looks like” and plenty of opportunities and time for teachers to try this approach before they implement it with students.

- Include master teachers, who have successful experiences infusing engineering, on the professional development team. These experienced practitioners can provide an “on the ground” perspective on this innovative approach.

The importance of teacher preparation was echoed in the research base, as well. For example, Hmelo, Holton, and Kolodner (2000) identified teacher comfort as the biggest challenge to a design approach to science (in this case the LBD approach). Kolodner (2002) described important implications for teacher professional development: (a) teachers need to experience the curriculum as their students will, including the construction-based activities; (b) teachers need to understand the cycles and rituals involved in the approach (iteration, reflection, and redesign); (c) teachers need help learning the engineering content; and (d) teachers need guided experiences trying out design challenges with students. Leonard and Derry (2011) outlined key implications for preparing teachers to teach engineering. They commented that teachers “must become aware of the interactional relationship between science and engineering (as distinct but interrelated domains) and how their relationship, similarities, and differences may play out in the design-based science classroom” (p. 46). Teachers must have a depth of subject matter knowledge in science and technology, because this approach challenges teachers’ science content knowledge and their technological skills. Teachers also need assistance in developing the ability to engage in and teach modeling skills.

The Infuse Project (NSF Award I158615) was funded to help address this problem by developing and researching science teacher learning through an innovative approach to professional development that is engineering concept-driven. That project is focused on the infusion of engineering concepts into life science and physical science through teacher professional development. The present study, which is the subject of this report, addressed issues that needed clarification in order to inform the development of the protocol to be used in the major investigations of Project Infuse. The results and conclusions described above will be of assistance to the Project Infuse staff as they design and implement their study.

References

- Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.
- Cantrell, P., Pekcan, G., Itani, A., & Velasquez-Bryant, N. (2006). The effects of engineering modules on student learning in middle school science classrooms. *Journal of Engineering Education*, 95(4), 301-309.
- 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.
- Daugherty, J. L. (2009). Engineering professional development design for secondary school teachers: A multiple case study. *Journal of Technology Education*, 21(1), 5-19.
- Daugherty, J. L., & Custer, R. L. (2012). Secondary level engineering professional development: Content, pedagogy, and challenges. *International Journal of Design and Technology Education*, 22(1), 51-64. doi: 10.1007/s10798-010-9136-2
- Donovan, M. S., & Bransford, J. D. (2005). Introduction. In M. S. Donovan, & J. D. Bransford (Eds.). *How students learn: History, mathematics, and science in the classroom* (pp. 1-28). Washington, DC: National Academies Press.
- Edelson, D. C. (2001). Learning-for-use: A framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching*, 38(3), 355-385.
- Fontenot, D., Talkmitt, S., Morse, A., Marcy, B., Chandler, J., & Stennett, B. (2009). Providing an engineering design model for secondary teachers. Paper presented at the Frontiers in Education Conference, San Antonio, TX.

- Fortus, D., Krajcik, J., Dershimer, R. C., Marx, R. W., & Mamlok-Naaman, R. (2005). Design-based science and real-world problem-solving. *International Journal of Science Education*, 27(7), 855-879.
- Fortus, D., Dershimer, C., Krajcik, J., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching*, 41(10), 1081-1110.
- Harwood, J., & Rudnitsky, A. (2005). *Learning about scientific inquiry through engineering*. Paper presented at the meeting of the American Society for Engineering Education, Portland, OR.
- Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *Journal of Learning Sciences*, 9(3), 247-298.
- Householder, D. L., & Hailey, C. E. (Eds.). *Incorporating engineering design challenges into STEM courses*. Retrieved from <http://ncete.org/flash/pdfs/NCETECaucusReport.pdf>.
- Kimmel, H., Carpinelli, J., Burr-Alexander, L., & Rockland, R. (2006). *Bringing engineering into K-12 schools: A problem looking for solutions?* Paper presented at the meeting of the American Society for Engineering Education, Chicago, IL.
- Kolodner, J. L. (2002). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education*, 39(3). Retrieved from <http://scholar.lib.vt.edu/ejournals/JITE/v39n3/kolodner.html>
- Leonard, M. & Derry, S. J. (2011). What's the science behind it? The interaction of engineering and science goals, knowledge, and practices in a design-based science activity. WCER Working Paper No. 2011-5. Wisconsin Center for Education Research, University of Wisconsin-Madison. Retrieved from <http://www.wcer.wisc.edu/publications/workingPapers/papers.php#W11>
- Leonard, M. & Derry, S. J. (2006). *Tensions and tradeoffs in a 'design for science' classroom: The 'forces in balloon' lecture*. Paper presented at the International Conference of the Learning Sciences, Bloomington, IN.
- Rockland, R., Bloom, D. S., Carpinelli, J., Burr-Alexander, L., Hirsch, L. S., & Kimmel, H. (2010). Advancing the "E" in K-12 STEM education. *Journal of Technology Studies*. 36(1), 53-64.
- Rossouw, A., Hacker, M., & de Vries, M. J. (2010). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education*, 21(4), 409-424. doi: 10.1007/210798-010-9129-1
- Ryan, M., Gane, B. D., & Usselman, M. (2011). *Comparison of two curriculum models for mapping engineering core concepts to existing science and mathematics standards*. Paper presented at the meeting of the 2011 American Society for Engineering Education, Vancouver, BC.
- Sadler, P. M., Coyle, H. P., & Schwartz, M. (2000). Engineering competitions in the middle school classroom: Key elements in developing effective design challenges. *Journal of the Learning Sciences*, 9(3), 299-327.