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Engineering Design: The Great Integrator

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ABSTRACT

There is much support in the research literature and in the standards for the integration of engineering into science education, particularly the problem solving approach of engineering design. Engineering design is most often represented through design-based learning. However, teachers often do not have a clear definition of engineering design, appropriate models for teaching students, or the knowledge and experience to develop integrative learning activities. The purpose of this article is to examine definitions of engineering design and how it can be utilized to create a transdisciplinary approach to education to advance all students' general STEM literacy skills and 21st century cognitive competencies. Suggestions for educators who incorporate engineering design into their instruction will also be presented.

Keywords: Engineering design; STEM; Integration; Teaching and learning

Background

Perusing the *Framework for K–12 Science Education* (National Research Council [NRC], 2012) and the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013), one quickly recognizes the degree of support and rationale for integrating engineering into science education. According to Hosni (2013),

> The meaningful integration of engineering practices in the NGSS will promote critical thinking, provide new levels of relevancy to motivate students to learn science content, make engineering and engineering careers more accessible to all students, and prepare the next generation to solve global problems facing humanity." (p. 1)

However, engineering alone does not produce such outcomes. Specifically, *engineering design*, a form of problem solving (Visser, 2009), affords students the opportunity to develop 21st century cognitive competencies, engage in authentic engineering practices, and integrate science and mathematics concepts.

Engineering design is most often represented through design-based learning (DBL), a pedagogical approach that Grubbs (2013) states has already been adopted across multiple science, technology, engineering, and mathematics (STEM) disciplines (e.g., Crismond & Adams, 2012;

Doppelt, Mehalik, Schunn, Silk, & Krysinksi, 2008; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Jacobson & Lehrer, 2000; Kolodner et al., 2003). However, as deviations of DBL have emerged with varying utilitarian perspectives, teachers often do not have a clear definition of engineering design, appropriate models for teaching students, or the knowledge and experience to develop integrative learning activities. The purpose of this article is to examine definitions of engineering design and how it can be utilized to create a transdisciplinary approach to education to advance all students' general STEM literacy skills and 21st century cognitive competencies. Suggestions for educators who incorporate engineering design into their instruction will also be presented.

Engineering and Engineering Design

The notion of integrating engineering into science education is not a novel idea. Originating in *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1990) and *Benchmarks for Science Literacy* (AAAS, 1993), assimilating both disciplines was attributed to the belief that they were inseparable beyond formal education (NRC, 2009). Scientific knowledge informs the engineering process, whereas new scientific discoveries are fueled by technology created through engineering design. As the *Framework for K–12 Science Education* (NRC, 2012) indicates, engineering has not received the same level of attention in science curricula as traditional science disciplines. Therefore, the NGSS (NGSS Lead States, 2013) were developed with a commitment to further integrate engineering into science education by treating engineering design as tantamount to scientific inquiry. Blending scientific and engineering practices into the structure of science education and including engineering design as one of the disciplinary core ideas are fundamental themes of the NGSS. However, the infusion of these practices also presents pedagogical implications for nonengineering educators. In his critique of the 2013 NGSS draft, Buchanan (2013) argued that "the draft presents engineering and science as synonymous terms, rather than the interrelated yet distinctly different fields that they are" (p. 1). Although science and engineering are "interrelated," it is important for students to understand that they are "distinctly different fields."

Engineering

Operationally defining engineering and the role it plays in education provides a framework for nonengineering educators to move forward. The National Research Council (2009) defines engineering as the process of designing the human-made world, which is composed of technological developments such as buildings, roadways, airplanes, and televisions. Engineers use the process of designing to modify the natural world to meet human needs and desires by creating solutions to life's problems using the scientific knowledge obtained through scientific inquiry (NRC, 2009). In addition to this definition, two important distinctions also need to be considered: the purpose of including engineering in K–12 education and what design actually entails. From a progressivist standpoint, the purpose of engineering in K–12 education is to immerse students in a setting in which they can all benefit from thinking like engineers. This view is modeled by technology and engineering education, a school subject that identifies engineering as a profession closely related to its instructional practices and strives to prepare all students to solve modern societal problems through engineering design (Asunda & Hill, 2007; ITEEA, 2002; NRC, 2009). "Exposure to technological concepts and hands-on, design-related activities in the elementary and secondary grades are the most likely ways to help children acquire kinds of knowledge, ways of thinking and acting, and capabilities consistent with technological literacy" (National Research Council, 2002, p. 57). This view is explicitly distinguished by the International Technology and Engineering Education Association (ITEEA) who distinguishes teaching "little 'e'" over "Big 'E'" engineering. Whereas "Big 'E'" engineering focuses on the noun, or career oriented purpose, "little 'e'" engineering focuses on the verb, preparing all students to think like engineers and developing students to fully participate in a 21st century society. Although the authors of this paper also differentiate between the two different outcomes, they also give moderate attention to both goals becuase this argument is not a concern of the chemistry, biology, or physics classrooms. The authors believe that engineering should be taught in its true sense and not reduced to terms that are not true of the engineering profession. Teaching in this manner can benefit all students, regardless of their career path, but will still provide them the skills and knowledge to pursue an engineering degree. This is similar to the different science disciplines; for example, students in a biology classroom are not all going to become biologists.

Although design is considered to be the distinguishing activity of engineers (Dym, Agogino, Eris, Frey, & Leifer, 2005) and is the focus of various engineering curricula (Jain & Sobek, 2003), the term is used loosely. Various terms and definitions have been presented, encompassing multiple fields from the fine arts to engineering and from technological design to engineering design. Choices about which term to use, such as *informed design* (Burghardt & Hacker, 2004), or what characterizes engineering design (Merrill, Custer, Daugherty, Westrick, & Zeng, 2008) can drastically affect subsequent instructional approaches, cognitive demands placed upon students, and expected learning outcomes.

Characterizing Engineering Design

The capacity design has to increase student learning and foster 21st century cognitive competencies begins with understanding its purpose. Asunda and Hill (2007) define design very simply: "Design refers to the process of devising something. It is a creative, iterative and often open-ended process of conceiving and developing components, systems, and processes" (p. 26). The *Standards for Technological Literacy* (2007), which was originally published in 2000, identifies design as a basic element in learning about technology, which requires both conceptual and procedural knowledge, and describes it as a core problem-solving process of technological development. The *Standards for Technological Literacy* (2007) makes the claim that learning to design provides students with a set of abilities that will serve them throughout their lives. As Friesen, Taylor, and Britton (2005) explain, design is a creative, iterative, and open-ended process for devising a solution to a problem. Defined in this way, design follows a trial-and-error approach, which is often identified as technological design. Although, this approach is suitable at many levels, engineering design follows a more explicit and intentional path.

Contrasting technological design, *engineering design*, is "'design under constraint'" (Wulf, 1998, para. 4). Constraints such as time, capital, safety, materials, tools, energy, environmental regulations, ergonomics, and manufacturability direct individuals in effectively and efficiently solving problems in a practical manner leading to the production of the most viable solution. Employing engineering design can broadly be described as the ability to take a problem, specify its constraints, establish the corresponding criteria, and adhere to the criteria and constraints to enact a design process for creating a practical solution to the problem. The authors of this article view engineering design as a *directed* form of cognition and more than just mere problem solving, which can be *unintentional*. Engineering design includes the practice of optimizing solutions using a variety of tools for modeling and analysis. Because of the inclusion of the elements of optimization, modeling, and analysis in the design process, engineering design has now replaced the older concept of technological problem solving (NGSS Lead States, 2013). As the NGSS (NGSS Lead States, 2013) assert, providing students a foundation in engineering design allows them to better engage in and aspire to solve the major societal and environmental challenges that they will face in the decades ahead.

Achieving Integration Through Engineering Design

The traditional or "siloed" approach to teaching STEM subjects has been a major contributor to the lack of student interest in STEM activities and careers as well as a reason behind the mediocre performance of U.S. students on international assessments (NRC, 2009). Recently, engineering design has been associated with various efforts to teach STEM subjects in an integrated manner (National Academy of Engineering [NAE] & National Research Council [NRC], 2014). Therefore, it may be viewed as a critical component or link for developing integrative STEM curricula. Integrative STEM education (I-STEM ED) can be defined as the "'application of technological/ engineering design based pedagogical approaches to intentionally teach content and practices of science and mathematics education concurrently with content and practices of technology/ engineering education . . . .' (Wells & Ernst, 2012). (as adapted from Sanders & Wells program documents 2006-10)." (Virginia Polytechnic Institute and State University, 2015, para. 2). Engineering design problems not only provide a clear link between science and engineering but also allow connections to other school subjects.

The integrative capability of engineering design is evident in the engineering design process, which is a problem-solving method that engineers use—along with knowledge from science and mathematics—to solve technological challenges (NRC, 2009). The National Research Council (2009) believes increasing the visibility of engineering and technology in STEM education is vital for the interconnections of teaching and learning. This is supported by research indicating integration can improve student scholarship and engagement (Baker, Krause, Yasar, Roberts, & Kurpius, 2005; Silk, Schunn, & Cary, 2009). The outcome of integrative teaching by using engineering design is transdisciplinary learning through an authentic context that promoting student STEM literacy and readiness for STEM-related employment, which contributes to their own economic success as well as the nation's (NAE & NRC, 2014; NRC, 2009).

Promoters of integrative pedagogical approaches emphasize how professions related to the different academic subjects have transformed into transdisciplinary ventures. This transformation has created a need for integrative STEM practices that focus on real-world contexts and student questions related to local or global issues (NAE & NRC, 2014). *Transdisciplinary learning* has been defined as the organization of curriculum and instruction around student questions that are related to societal problems; concepts and skills are developed through authentic contexts, and students are exposed to STEM-related careers (Drake & Burns, 2004; Maryland Department of Education, 2013). This transdisciplinary learning can be accomplished by using engineering design problem-based tasks that involve authentic situations. For example, Strimel (2014a) used the issue of hydraulic fracturing in the shale gas extraction process as the central context for creating lessons across various subjects. In these lessons, he allows students to question the issue of handling the expended and contaminated hydraulic fracturing water used during the shale gas extraction process and engages them in identifying or defining a problem to solve related to this issue. This type of practice requires knowledge and skills from various disciplines in order to enact the engineering design process, devising solutions to a real issue and developing new knowledge through scientific inquiry while also being exposed to potential STEM-related careers.

Engineering-Design-Based Learning

Both engineering-design-based learning and problem-based learning attempt to engage students in addressing complex issues in authentic contexts. A problem-based learning environment centered on engineering design problems can provide students with the opportunity to learn and apply a variety of STEM concepts while also constructing new knowledge. Engineering-design-based learning should be an experiential strategy in a science educator's toolbox for encouraging active learning through engaging students in solving authentic, ill-structured problems that require the integration of theory and practice. This is not to be confused with *project-based learning*, a teacher-structured approach designed for students to learn specific concepts or to demonstrate current competencies. Conversely, *problem-based learning* is a teacher-facilitated strategy constructed around authentic, ill-structured problems that allows for a student's voice in learning and generating new knowledge in order to demonstrate their capabilities without the explicit need to construct a product or intentionality of integration.

The authors believe that there can be two approaches for engineering design activities. The first is to simply engage students in learning through simple, unrealistic, hands-on activities that provide a context for new learning opportunities. This type of activity engages students in the lesson by completing an "engineering" challenge, yet provides few learning opportunities because it is not authentic in nature. Examples of these activities are often found in K–12 engineering curricula (i.e., build the tallest tower using marshmallows and spaghetti). These types of engineering challenge activities lack authenticity and do not actually provide the skills needed to design and create viable solutions to a problem. However, with teacher instruction, these simple activities can be used as a context for teaching essential topics. A second approach is to provide students with opportunities to use industry quality materials, tools, and resources to solve an authentic problem requiring the application of knowledge, leading to the development of new knowledge. The second approach can be more conducive to I-STEM ED but is sometimes viewed as challenging to teach (Ribeiro, 2011), whereas the first approach is easier to achieve because it can be done with little preparation and only uses inexpensive, unrealistic materials. But, with the first approach, how much learning occurs? Can a student learn the concepts involved in designing a new structure using marshmallows and spaghetti to build the tallest tower? Can teachers really say they are teaching engineering if students are not optimizing designs using realistic materials for modeling and analysis? It is important that educators provide students with an authentic experience and move past activities that solely require materials such as popsicle sticks, index cards, hot glue, and tape (Grubbs, 2014). However, using the proper materials, tools, and resources can be challenging and expensive. These challenges are why the authors recommend working collaboratively with a school district's engineering and technology teacher to establish a true authentic and integrative learning experience for students.

Replicating Engineering Design Problems

The *Framework for K–12 Science Education* (NRC, 2012) states all K–12 students should be provided with opportunities to solve engineering design problems carry out scientific investigations. Signifying the importance of understanding the specifics of an engineering design problem, Jonassen (2011) believes that problems vary in three aspects: *context*, *complexity*, and *structure*. Engineering design problems are considered to naturally be the most complex and least structured problems. The key element here can be the degree of structure within a problem statement, varying from well-structured to ill-structured. An example of a well-structured problem may be found in a physics textbook in the form of a word problem. Such a problem requires students to enact a set of steps or to use a formula to arrive at the correct solution. Conversely, ill-structured problems have no standard process for arriving at a solution and have few implications for a correct final solution. A study conducted in the engineering workplace by Jonassen, Strobel, and Lee (2006) identified engineering problems as “ill-structured and complex because they possess conflicting goals, multiple solution methods, non-engineering success standards, non-engineering constraints, unanticipated problems, distributed knowledge, collaborative activity systems, the importance of experience, and multiple forms of problem representation” (p. 139) and often consist of “aggregates of well-structured problems” (p. 142). Problems of this nature can be found in engineering-design-based classroom activities. A classroom enabling students to attempt to solve ill-structured engineering design problems can provide learners with an authentic learning experience while promoting development of essential 21st century skills.

Engineering design problems themselves can also vary in the extent to which they are structured based on how they are constrained or unconstrained (Hutchison & McKenna, 2008). Fully constrained engineering design problems, such as the problem presented in Figure 1, are well-structured problems; they provide a defined problem statement and a complete list of solution criteria and constraints.

> Your environmental engineering team must design and build an inexpensive, easy to use, easy to assemble, durable, and low maintenance device to improve the quality of water using low cost, readily available materials to quickly remove containments from water.

Figure 1. Well-structured engineering design problem. This problem statement includes a defined problem and portrays what successful solutions will consist of.

Conversely, unconstrained, ill-structured engineering design problems provide a situation involving a global or local issue requiring students to define their own problem and establish their own criteria and constraints based on research, thus, giving them a voice in what they are learning and doing. Strimel (2014b) provides an example of an ill-structured engineering-design-based lesson centered on the global concern of mitigating the devastating effects of a major earthquake on a developing nation. This lesson does not provide students with a defined problem but with a situation involving key concepts related to the course subject in which students can identify their own problem to solve. Dependent upon the experience and capability of students to solve engineering design problems, teachers may initially immerse students in well-structured problems until engineering design strategies can be developed. Teachers may then transition students towards more ill-structured design problems once the students are more capable of solving them.

Developing Integrative Lessons Using Engineering Design

Developing a truly I-STEM ED transdisciplinary lesson requires an intentional and strategic effort when using engineering-design-based learning to meet necessary education outcomes. The lesson should first be based upon desired course content standards and objectives. The required content standards and objectives can then be used to guide the identification of a relevant local issue (such as hydraulic fracturing near Pittsburgh, Pennsylvania or water contamination in Charleston, West Virginia) or a global issue (such as genetically engineered foods, natural disasters, climate change, or sustainable development) to explore. These issues can then provide situations for students to identify, define, and validate an engineering design problem to solve. Investigating these types of issues also require scientific inquiry both to develop knowledge needed for a solution and to evaluate the success of the solution itself. Once again, it is important to remember that these issues should be anchored in content standards.

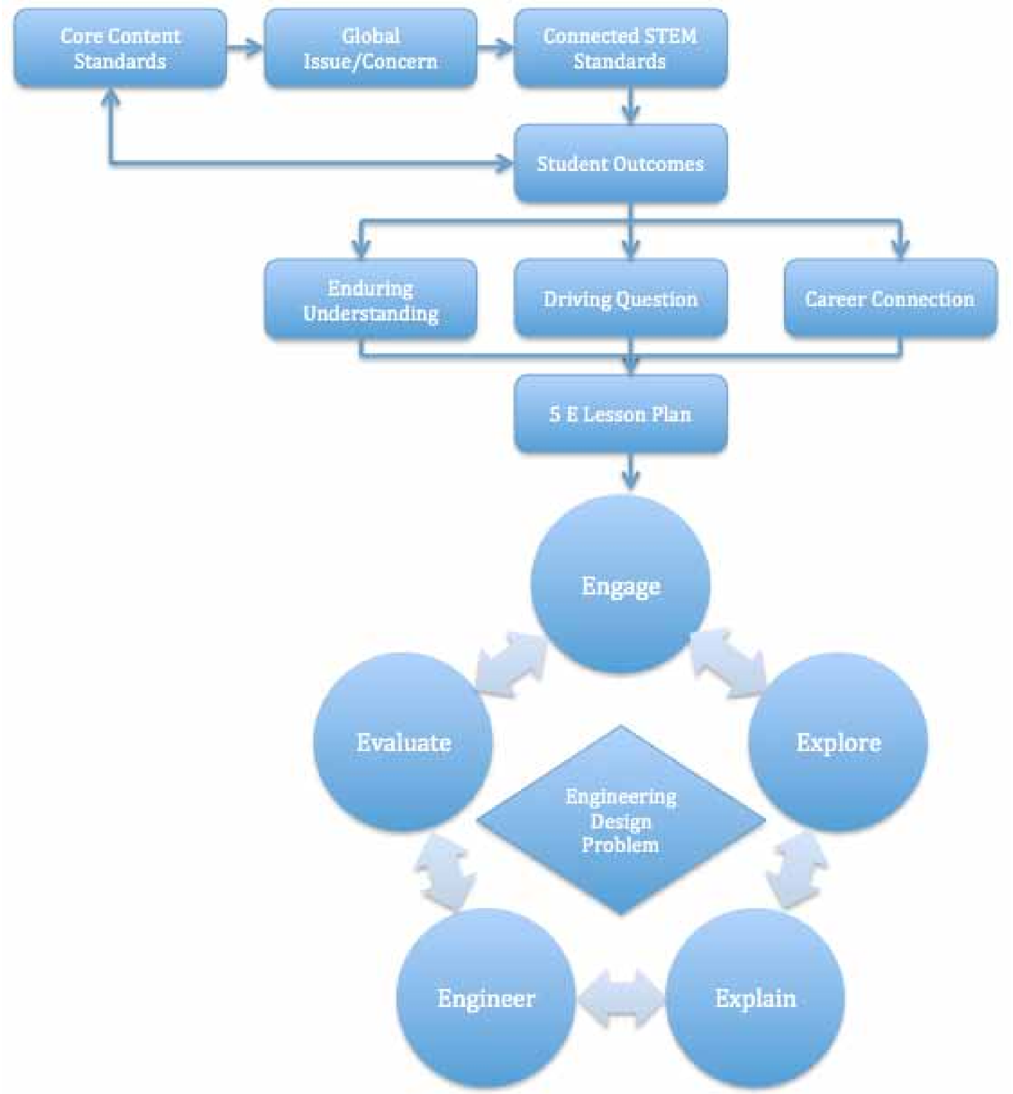


Figure 2. I-STEM ED transdisciplinary lesson planning process.

<table>
<tr><td colspan="2">Lesson Title</td></tr>
<tr><td colspan="2">Time:</td></tr>
<tr><td colspan="2">Lesson Overview/ Purpose: <i>Provides a paragraph stating the overall big idea of the lesson and its intended outcome.</i></td></tr>
<tr><td colspan="2">Core Content Standards: <i>Lists the specific core standards required for the course.</i></td></tr>
<tr><td colspan="2">Global or Local Issue: <i>Describes an overarching issue or challenge related to the core content standards.</i></td></tr>
<tr><td colspan="2">STEM Standards: <i>Lists and describes the connections between the overarching issue or challenge with other standards and objective from various school subjects.</i></td></tr>
<tr><td colspan="2">Student Outcomes: <i>Provides the measurable student outcomes for the lesson's standards and objectives.</i></td></tr>
<tr><td colspan="2">Enduring Understandings: <i>Lists the key takeaway items from the lessons that transcend the lesson itself and are applicable to various situations.</i></td></tr>
<tr><td colspan="2">Driving Question: <i>Provides a question for driving student investigations about the overarching issue or challenge that will guide inquiry and problem identification and definition.</i></td></tr>
<tr><td colspan="2">Career Connections: <i>Lists and describes specific career relationships that are to be incorporated throughout the lesson.</i></td></tr>
<tr><td colspan="2">Engineering Design & Scientific Inquiry Based Lesson</td></tr>
<tr><td>Engage: Sets the context for what the students will be learning in the lesson, as well as gaining their interest in the topic.</td><td><i>Should involve some type of hands-on problem-solving activity that engages students in the lesson and provides a context for the lessons overarching challenge or issue.</i></td></tr>
<tr><td>Explore: Enables students to build their own knowledge on the topic while making connection to their prior conceptual and procedural knowledge.</td><td><i>Should involve some type of investigation activity that will enable students to identify and define a specific problem to solve from the overarching challenge or issue.</i></td></tr>
<tr><td>Explain: Summarizes new and prior knowledge while addressing any misconceptions the students may hold.</td><td><i>Should involve a student-centered discussion of the overarching issue or challenge, as well as the student-defined problems with a purpose of identifying the key concepts needed to be learned to begin developing solutions.</i></td></tr>
<tr><td>Engineer: Requires students to apply their knowledge and skills using the engineering design process to identify a problem and to develop a solution.</td><td><i>Should require students to enact the engineering design process to create a model or prototype to solve an authentic problem using realistic tools and materials.</i></td></tr>
<tr><td>Evaluate: Allows a student to evaluate hers or his own learning and skill development in a manner that enables them to take the necessary steps to master the lesson content and concepts.</td><td><i>Should require students to reflect on the effectiveness of their developed solution and their level of achieving the intended lesson outcomes.</i></td></tr>
</table>

Figure 3. Engineering design problem-based lesson format

Next, a teacher can select standards and skills from other school subjects considered necessary for investigating the identified issue and developing potential solutions to a student defined engineering design problem. When students are solving these problems they should be required to use and apply the proper and industry-quality materials, resources, and technological tools. Strimel (2014b) explains that this is where a team of teachers is beneficial because if one teacher is uncomfortable with the integration of a certain standards, concepts, or technological tools, the other teachers, especially an engineering or technology teacher, can assist. Then, the teacher can develop the specific student outcomes of the lesson that describe the transferable knowledge and skills that they should acquire throughout the lesson. The outcomes may be written as a short statement, beginning with a verb, that provides actionable student items. These outcomes should be used to identify what can be assessed at the conclusion of the lesson and then be used to guide the planning of the lesson events. From the standards and student outcomes a teacher can create the enduring understanding of the lesson, which focuses on the larger concept of the experience that can be applicable to situations beyond the lesson. The driving question is created to provide students with an open-ended question that promotes inquiry about the concepts involved in the local or global issue. Subsequently, the teacher can highlight specific STEM-related careers that are relevant to the situation and ensure that students achieve an understanding of what professionals in these careers do. Lastly, the teachers can utilize an updated version of the 5E model for planning learning activities developed by Bybee (1997) and modified by Burke (2014). This model breaks the lesson into five different nonlinear phases that promote student-centered learning necessary to design, make, and evaluate a possible solution to the complex issue at the center of the lesson. Figure 2 illustrates this integrative lesson planning process.

As Burke (2014) explains, a modified version of the 5E model that includes engineering can be used to develop a student-centered learning environment that blends the benefit of both design- and inquiry-based learning. In Figure 3,this model is explained in a lesson plan format (Strimel, 2014b).

Teaching the Engineering Design Process

The engineering design process is more than just applied science; it involves an iterative process of transforming problems to solutions (NGSS Lead States, 2013). The engineering design process is a problem solving method used by engineers that applies knowledge from multiple domains including mathematics and science to solve technological problems (NAE & NRC, 2014) through a nonlinear process described as defining a problem; identifying constraints; establishing criteria; generating possible solutions through research; and developing, modeling or prototyping, evaluating, and optimizing a design. The authors have included the problem solving activity in Figure 4 to introduce students to the engineering design process. This activity is only designed to engage students and provide a context for learning about the engineering design process. This activity is not meant to engage students in an authentic problem solving experience. In the activity, students are first given the problem to solve and then, through instructor questioning, are guided in the development of their own version of a simplified engineering design process based on the steps they used to solve the given problem. The student-generated steps must then be elaborated on to include optimization, modeling, and analysis. Once again, this activity is only to be used to introduce students to the engineering design process; it does not intentionally teach specific engineering concepts or skills because it does not involve an authentic problem pr the use of industry-quality tools and materials.

<table>
<tr>
<td>Design Brief: Your team must create a self-propelled vehicle to transport a passenger safely from point A to point B using only the materials provided.

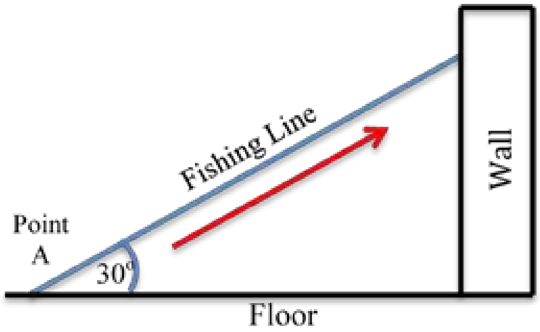
The vehicle must travel up the fishing line to touch the wall and then slide safely back down under its own power. You have fifteen minutes to complete your task.</td>
<td>
</td>
</tr>
<tr>
<td>Constraints:
• Use only the materials provided
○ 12” Tape
○ Popsicle Stick
○ Balloon
○ 2 Paper clips
○ 2 Rubber Bands
○ Passenger (Clothespin)</td>
<td>Criteria:
• You cannot assist the vehicle up the fishing line
• The passenger should remain safe and not hit the wall or fall off of the vehicle
• The vehicle must remain intact
• The vehicle must remain on the fishing line.</td>
</tr>
<tr>
<td>Student Questions:</td>
<td>Simplified Engineering Design Process</td>
</tr>
<tr>
<td>What was the first thing we did during the problem solving activity?</td>
<td>Step 1 (Define the Problem)</td>
</tr>
<tr>
<td>What did you do next? Did you study the materials or the challenge?</td>
<td>Step 2 (Research)</td>
</tr>
<tr>
<td>Did you talk with your partner about possible solutions?</td>
<td>Step 3 (Generate Ideas)</td>
</tr>
<tr>
<td>Did you use your paper to draw your idea?</td>
<td>Step 4 (Develop a Design)</td>
</tr>
<tr>
<td>Once it was built, what did you do?</td>
<td>Step 5 (Test & Evaluate)</td>
</tr>
<tr>
<td>What if it did not work?</td>
<td>Step 6 (Refine Solution)</td>
</tr>
<tr>
<td>How are these steps arranged?</td>
<td>
</td>
</tr>
</table>

Figure 4. Engagement activity to introduce engineering design.

Conclusion

The absence of engineering education in many K–12 classrooms represents both opportunity and uncertainty. Foremost, it provides a context for educators, specifically science educators, to strengthen their relationship with technology and engineering teachers to lead their schools in providing students with valuable learning experiences and fuel student interests in STEM. "Every young student deserves the opportunity to experience such awe-inspiring moments as watching a rocket race toward the sky and feel empowered to develop solutions to our world's most daunting problems" (Milano, 2013, p. 16). Engineering design, which encompasses aspects of problem- and project-based learning (Gómez Puente, van Eijck, & Jochems, 2011), is an essential component for integrating science with engineering, technology, and mathematics as well as other school subjects. As a distinctive form of problem-based learning, engineering design provides a basis for creating connections to concepts and practices from mathematics or science and enabling an I-STEM ED learning environment (Sanders, 2009). Moreover, authentic engineering design experiences and ill-structured challenges are a necessary tool for science education programs to provide students with the STEM knowledge and abilities that are considered necessary for fostering innovation and economic success. However, one cannot assume that a problem-based approach automatically means STEM disciplinary integration. Therefore, in Figure 5, the authors provide the recommendations for using engineering design to provide students with an integrative and authentic learning experience. Because little is known about student cognition during such experiences, future research can provide additional implications and instructional resources to guide implementation.

1. Utilize engineering design problems as a way to make ongoing, intentional, and natural connections to other subjects.
2. Employ engineering design problems that vary in structure to ensure that students are required to apply prior knowledge and to generate new knowledge.
3. Collaborate with technology and engineering teachers to go beyond having students solve problems using unrealistic technological tools and materials.
4. Require students to truly engage in engineering design by optimizing solutions through modeling and analysis.
5. Utilize authentic engineering design problems as the context for relevant transdisciplinary learning.
6. Design lessons using the student-centered format provided in this article.

Figure 5. Six recommendations for successful engineering design.

References

American Association for the Advancement of Science. (1990). *Science for all Americans*. New York, NY: Oxford University Press.

American Association for the Advancement of Science. (1993). B*enchmarks for science literacy*. New York, NY: Oxford University Press.

Asunda, P. A., & Hill, R. B. (2007). Critical features of engineering design in technology education. *Journal of Industrial Teacher Education, 44*(1), 25–48. Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v44n1/pdf/asunda.pdf

Baker, D., Krause, S., Yasar, S., Roberts, C., & Kurpius, S. (2004, April). *An intervention on tinkering and technical self-confidence, and the understandings of social relevance of science and technology*. Proceedings of the National Association of Research in Science Teaching, Vancouver, Canada.

Buchanan, W. W. (2013, February 4). [Letter to Dr. Stephen Pruitt]. Retrieved from https://asee.org/Walter_Buchanan_to_Achieve_re_NGSS_2-4-2013.pdf

Burghardt, M. D., & Hacker, M. (2004). Informed design: A contemporary approach to design pedagogy as the core process in technology. *Technology Teacher, 64*(1), 6–8.

Burke, B. N. (2014). The ITEEA 6E Learning byDeSIGN^{TM} Model: Maximizing informed design and inquiry in the integrative STEM classroom. *Technology and Engineering Teacher, 73*(6), 14–19.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education, 101*(4), 738–797. doi:10.1002/j.2168-9830.2012.tb01127.x

Doppelt, Y., Mehalik, M. M., Schunn, C. D., Silk, E., & Krysinski, D. (2008). Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education, 19*(2), 22–39. Retrieved from http://scholar.lib.vt.edu/ejournals/JTE/v19n2/pdf/doppelt.pdf

Drake, S. M., & Burns, R. C. (2004). *Meeting standards through integrated curriculum*. Alexandria, VA: Association for Supervision and Curriculum Development.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103–120. doi:10.1002/j.2168-9830.2005.tb00832.x

Fortus, D., Dershimer, R. 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. doi:10.1002/tea.20040

Friesen, M., Taylor, K. L., & Britton, M. G. (2005). A qualitative study of a course trilogy in biosystems engineering design. *Journal of Engineering Education*, *94*(3), 287–296. doi:10.1002/j.2168-9830.2005.tb00853.x

Gómez Puente, S. M., van Eijck, M., & Jochems, W. (2011). Towards characterising design-based learning in engineering education: a review of the literature. *European Journal of Engineering Education, 36*(2), 137–149. doi:10.1080/03043797.2011.565116

Grubbs, M. E. (2013). Bridging design cognition research and theory with teaching and learning. In P. J. Williams, & D. Gedera (Eds.), *Technology Education for the Future: A Play on Sustainability* (pp. 189–195). Hamilton, New Zealand: University of Waikato. Retrieved from http://www.iteaconnect.org/Conference/PATT/PATT27/PATT27proceedingsNZDec2013.pdf

Grubbs, M. E. (2014). Genetically Modified Organisms: A design-based biotechnology approach. *Technology and Engineering Teacher, 73*(7), 24–29.

Hosni, M. H. (2013, January 29). [Letter to Next Generation Science Standards Writing Committee]. Retrieved from https://www.asme.org/getmedia/25be935b-0b66-466e-acf1-e212b534a386/PS1301_ASME_Board_on_Education_Comments_on_the_Second_Public_Draft_of_the_Next_Generation_Science_Standards.aspx

Hutchison, M. A., & McKenna, A. F. (2008). The influence of problem structure on students use of innovative learning strategies. In *Research in Engineering Education Symposium 2008* (pp. 103–107), Melbourne, Australia: Research In Engineering Education Network.

International Technology Education Association. (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed.). Reston, VA: Author.

Jacobson, C., & Lehrer, R. (2000). Teacher appropriation and student learning of geometry through design. *Journal for Research in Mathematics Education*, *31*(1) 71–88.

Jain, V. K., & Sobek, D. K. (2003). *Process characteristics that lead to good design outcomes in engineering capstone projects* (Working paper). Retrieved from http://www.coe.montana.edu/ie/faculty/sobek/CAREER/VDOE_paper.DOC

Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments*. New York, NY: Routledge.

Jonassen, D. H., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2) 139–151. doi:10.1002/j.2168-9830.2006.tb00885.x

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., . . . Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting Learning by Design™ into practice. *The Journal of the Learning Sciences*, *12*(4), 495–547. doi:10.1207/S15327809JLS1204_2

Maryland State Department of Education. (2013). Teaching and learning: STEM education. Retrieved from http://mdk12.org/instruction/curriculum/stem/index.html

Merrill, C., Custer, R. L., Daugherty, J., Westrick, M., & Zeng, Y. (2008). Delivering core engineering concepts to secondary level students. *Journal of Technology Education*, *20*(1), 48–64. Retrieved from http://scholar.lib.vt.edu/ejournals/JTE/v20n1/pdf/zeng.pdf

Milano, M. (2013). The *Next Generation Science Standards* and engineering for young learners: Beyond bridges and egg drops. *Science and Children, 51*(2), 10–16.

National Academy of Engineering & National Research Council. (2014). *STEM integration in K–12 education: Status, prospects, and an agenda for research.* Washington, DC: National Academies Press.

National Research Council. (2002). *Technically speaking: Why all Americans need to know more about technology*. Washington, DC: National Academies Press.

National Research Council. (2009). *Engineering in K–12 education: Understanding the status and improving the prospects.* Washington, DC: National Academies Press.

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by state*s. Washington, DC: National Academies Press.

Ribeiro, L. R. C. (2011). The pros and cons of problem-based learning from the teacher's standpoint. *Journal of University Teaching & Learning Practice, 8*(1). Retrieved from http://ro.uow.edu.au/jutlp/vol8/iss1/4/

Sanders, M. (2009). Integrative STEM education: A primer. *The Technology Teacher, 68*(4), 20–26.

Silk, E. M., Schunn, C. D., & Cary, M. S. (2009). The impact of an engineering design curriculum on science reasoning in an urban setting. *Journal of Science Education and Technology*, *18*(3), 209–223. doi:10.1007/s10956-009-9144-8

Strimel, G. (2014a). Shale gas extraction: Drilling into current issues and making STEM connections. *Technology and Engineering Teacher, 73*(5), 16–24.

Strimel, G. (2014b). Authentic education by providing a situation for student-selected problem-based learning. *Technology and Engineering Teacher, 73*(7), 8–18.

Visser, W. (2009). Design: One, but in different forms. *Design Studies*, *30*(3), 187–223. doi:10.1016/j.destud.2008.11.004

Virginia Polytechnic Institute and State University. (2015). Integrative STEM education. Retrieved from www.soe.vt.edu/istemed/

Wulf, W. A. (1998). The image of engineering. *Issues in Science and Technology, 15*(2), 23–24. Retrieved from www.issues.org/15.2/wulf.htm

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