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A Synthesis

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Introduction

Since the inception of the National Center for Engineering and Technology Education in 2004, educators and researchers have struggled to identify the necessary components of a "good" engineering design challenge for high school students. In reading and analyzing the position papers on engineering design many themes emerged that may begin to form a narrative for engineering design in a high school setting. Before educators can provide a framework for engineering design in STEM courses, four questions need to be answered: (a) To what degree should engineering design challenges be open-ended or well-structured? (b) What are the relationships between engineering design experiences and standards –based instruction in STEM courses? (c) What is an effective sequencing of age-appropriate engineering design challenges? and (d) To what extent should engineering habits of thought and action be employed in resolving the challenges? (Householder, 2011)

Collectively, the six position papers (Carr & Strobel, 2011; Eisenkraft, 2011; Hynes et al, 2011; Jonassen, 2011, Schunn, 2011; Sneider, 2011) provide an intriguing foundation for answering these questions and forming a framework for engineering design in high school STEM courses. This synthesis paper discusses the most pervasive themes of the papers and provides a narrative for answering the question, "What are the requirements for a good engineering design challenge?" The following emergent themes provide some guidance to finding answers for that question: engineering design in the science curriculum; assessing the engineering design experience; sequencing the engineering design experiences; and choosing engineering design challenges. By addressing these areas of contention, the education community can begin to lay the curricular and pedagogical groundwork needed to provide successful engineering experiences for high school students.

Engineering Design in Science Curriculum

Most educators agree with the idea of teaching engineering design to high school students has merit. Engineering education in high school promotes engineering "habits of mind" (Carr & Strobel, 2011) and critical thinking skills, as well as providing a platform for the application of math and science (Hynes et. al, 2011). Recently, there seems to be a push by educators for the integration of an engineering design framework into the science setting (Sneider, 2011). Hynes et al.

suggest that infusing engineering design into the high school science curriculum would satisfy the need to provide engineering design with a set of standards that would serve as guiding principles for the competencies, skills, and knowledge that all students should develop. This push for engineering design in the science curriculum seems logical but comes without a convincing argument from the authors. It is true that science courses at the high school level, such as physics, provide an excellent milieu for the introduction of design problems. Though I agree with the idea of using the high school science curriculum as a setting for engineering design, this decision should be guided by research.

Although several states have established standards that follow a sequential implementation of engineering knowledge and skills from K-12, the community still lacks consensus on effective sequencing of engineering design challenges (Householder, 2011). Many learning progressions developed by educators for engineering design are based on the assumption that students are exposed to the engineering design process prior to high school (Hynes et. al., 2011). This may not be an accurate assumption. Hynes et al. do an excellent job of laying out a set of guiding principles that may be considered in the design of engineering coursework. This progression, however, is state-specific and it was not specifically created for high schools. The extent to which this learning progression will be transferable to other states is debatable. The relationship between the engineering design process and standards-based instruction is a burgeoning one, but one that lacks a sound research base.

Assessing the Engineering Design Experience

One of the most contentious areas of concern about infusing engineering design into STEM courses is the issue of assessing the engineering design experience. According to research, course instructors have struggled to provide timely and effectual feedback to students on their performance in engineering design challenges (Schunn, 2011). To address this issue, most scholars agree that students must take more ownership of their learning experiences, including developing experimental tests and criteria for their designs (Eisenkraft, 2011; Hynes et al., 2011; Jonassen, 2011). Schunn suggests that high school students engaged in a design challenge should be able to identify the constraints, conduct a needs analysis, and identify their goals in an engineering design experience.

Eisenkraft (2011) argues that students not only have to take ownership of their learning experience by choosing their own challenges and goals, he also proposes that students should be able to create their own assessment rubric. This will allow students to set their criteria of excellence, with teachers scaffolding their experiences along the way. Hynes et al. (2011), strengthen this argument by suggesting that students are capable of developing their own experimental tests to evaluate solutions. Though it is clear that high school students will have to take on more responsibility in assessing their experience, the authors neither provide a clear path toward addressing the problem of timely feedback nor suggest techniques for negotiating the vacillating responsibilities of assessment between instructor and students. With that said, having students reflect on their design experience and justify their own solutions provides a useful window into the effective evaluation of student performance.

Sequencing the Engineering Design Experience

Whether discussing the learner who evolves from novice to expert problem solver, or the structure of an engineering design problem that can exist in a well-structured to ill-structured design space, it is clear that the teaching and learning of engineering design problems comprise points on a continuum (Carr & Strobel, 2011). This observation emphasizes the importance of sequencing and correctly identifying the necessary skills and abilities needed to solve open-ended and well-structured problems. How to properly sequence the engineering design experience is a question that has yet to be adequately addressed. As instructors consider the type of engineering challenge to introduce (open-ended or well-structured), the skills and knowledge necessary to solve engineering challenges, and the most effective modes of assessment they will have to consider student competencies at that time of instruction (Jonassen, 2001).

Though most agree with the importance of teaching engineering prior to reaching college (Carr & Strobel, 2011), there is currently a lack of research regarding what this experience should look like. Sneider (2011) lays out an effective plan for sequencing age-appropriate engineering design challenges starting in the fourth grade. By using the science framework, he does an excellent job of addressing this quandary by using standards-based instruction as guiding principles for an engineering framework. However, he correctly notes that the sequence specified is not based on research. As we look to develop and select age-appropriate engineering design challenges, researchers and engineering educators will have to work hand-in-hand to develop standards that are appropriate for the age and skill levels of learners. In the interim, researchers and educators can look toward the National Research Council and the National Assessment of Educational Progress (NAEP) for guiding principles to help in identifying age-appropriate knowledge and skill.

Choosing Engineering Design Challenges

The authors all seem to realize the importance of introducing real-world challenges that appeal to the humane sensibilities of students (Carr & Strobel, 2011; Schunn, 2011). In order to increase motivation and interest in solving engineering challenges, teachers should provide students with an opportunity to choose their own challenges and set their own goals (Schunn, 2011). Eisenkraft (2011) even provides the opportunity for students to promote their culture or other cultures of interest within the design challenge. Allowing students to pick their own challenges and set their own goals enables them to set the standards of excellence and take ownership of their problem.

When developing engineering challenges I am in agreement with Carr and Strobel (2011), who argue that instructors should focus on the intertwinedness of real-world problems when developing engineering design challenges for high school students. Ideally, engineering design challenges for high school students should be open-ended problems with a plethora of different solutions where the students identify the necessary constraints, conduct a needs analysis and identify their own goals (Hynes et al., 2011). Such an approach would allow students to develop critical thinking skills, acquire engineering habits of mind, and engage in deeper learning. Unfortunately, studies have shown that high school students are ill prepared to solve ill-structured problems (Jonassen, 2011). This finding does not necessarily mean that high school students should not engage in open-ended problems. In fact high school students should experience *both* open-ended and well-structured problems throughout their learning progression. Carr and Strobel (2011) make the case that ill-structured and well-structured problems both have a place in engineering education but should be represented by points on a continuum. So the question is not a dichotomous one of either/or but one of when a particular design problem is appropriate.

Conclusion

This synthesis paper postulates that the question of age-appropriate sequencing of engineering coursework may hold the key to proper development of engineering design challenges. This is a question that will need the input of the whole learning community in order to answer it effectively. If students should have engineering design experiences before high school (Carr & Strobel, 2011) there is a need for collaboration and consensus across the board on the skills and abilities to be taught in pre-high school experiences. Proper attention to the sequencing of engineering design coursework and astute understanding of the design space will lay the groundwork for investigating successful design experiences. If a theory of a spiral curriculum for engineering education is widely accepted for the teaching of engineering design, then it should be considered in the design of curriculum and teaching strategies (DiBiasio, Clark, & Dixon, 1999). More empirical research is needed to identify the age-appropriate skills and abilities needed at each grade level in order to properly sequence engineering design experiences.

There are procedural questions that still need to be answered that were not adequately addressed in the compilation papers. As an example, Jonassen (2011) asserts that the goal of design is not optimization but satisficing. This runs contrary to Hynes et al. (2011) who argue that redesign and *optimization* is an essential guiding principle for engineering design in high school. Answering this question will go a long way toward the development of appropriate assessment strategies. There is also the growing expectation for students to develop their own experimental tests and grading rubrics. (Hynes et al., 2011; Schunn, 2011). Though the authors make a compelling case for students taking more responsibility for assessing their engineering experiences, they do not account for the time and the acquisition of skills necessary for the development of rubrics and other assessment tools. Neither do the papers defend the infusion of engineering design into science settings in lieu of mathematics or technology courses. Though it seems to be widely accepted that engineering design will be infused into science at the high school level, research findings should guide that decision. With that said, I believe that the goal of the position papers was to begin to develop guidelines that would allow for the integration of engineering design experiences in high school settings. The submitted papers are effective in providing a framework that will allow for an investigation of these guidelines and strategies at the high school level.

Future Work

Words like "little" and "more" dominate the conversation of research as it relates to engineering design experiences in high school. This is a testament to the nascent status of engineering design in high school classrooms. As researchers go forward with their investigations of engineering design experiences in high school settings, they should pay special attention to *decision-making.* Decision-making and improved decision-making seems to be an overarching theme in the design process. According to Jonassen (2011), design problem solving can be represented by a series of decisions made by students. The study of students engaged in the engineering design experience should focus upon how students make decisions during the design process. As we consider how students approach problems and narrow the problem space it would behoove us to investigate the reasons students make specific decisions.

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