Work in Progress: Engineering Design in Secondary Biology

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Abstract

Creating engineering design challenges is never easy. For seasoned engineers in academia, creating real-world context and content rich problems is difficult. For K-12 teachers, this task is even more challenging given their limited experience with engineering. However, initiatives such as the NGSS depend on teacher's ability to create and integrate engineering design as a topic. This Work in Progress paper evaluates engineering design challenges created by secondary biology teachers during a summer modeling based workshop.

During the summer workshop, secondary school teachers assumed the role of students and learned about engineering design by direct instruction in order to create engineering design challenges based in the life sciences. Teams of 3-5 teachers representing a variety of schools created the challenges and posted videos of their plans on an online web-based platform (Edthena, ©2017). Teachers from other teams and the workshop leaders provided feedback on the online platform about how well the proposed engineering design challenge would allow students to engage in engineering design practices. The teachers then revised their plans and uploaded new videos of their work for additional feedback. Both sets of videos were evaluated and scored using the same engineering design challenge rubric that included criteria such as the open-endedness of the problem, use of constraints and criteria, and the potential for iteration in the designs.

The initial results of our work show that teachers often struggle with making their design challenges open-ended as opposed to closed-ended single solution problems. Additionally, they view constraints and criteria as aspects of the educational experience instead of elements of the design problems (i.e., the students do not have access to computers instead of the solution can only use the materials provided). We are in the initial stages of analyzing this data for patterns of improvement. We plan to use the results to develop interventions targeting the engineering practices that teachers find challenging, thereby improving their ability to create engineering design challenges that can be integrated into existing science curricula.

Introduction

Concerns about STEM education in the United States are often linked to fears about maintaining and growing our innovative capacity and our competitive edge in the global marketplace (NAE & NRC, 2009). The National Center on Science and Engineering Statistics (NCSES) reported that in 2008 about 4% of the bachelor's degrees awarded in the USA were in engineering. In comparison, 19% of the bachelor's degrees in Asia and 31% of those in China were in engineering (NCSES, 2012). The NCSES also reported that disproportionately fewer women enrolled in engineering, computer sciences, physical science and economics (NCSES, 2012). At the graduate level, science and engineering program students from diverse backgrounds including blacks, Hispanics, and Native Americans make up only 12% of enrolled students. In contrast, Whites represent 48% of the students, and Asian/Pacific Islanders represent 6%. Temporary residents complete the remainder of the graduate science and engineering student population (NCSES, 2012). These statistics that show little pursuit of engineering fields may be demonstrating that our K12 students have little awareness of engineering as a future career choice. One strategy to promote future change in these statistics is to make sure that our K12 students are exposed to the engineering discipline. If diversity is increased, design capacity in engineering will be enhanced.

Literature

Several studies have shown little work being done on how to train K12 teachers of science to implement and design curriculum focused on the engineering design process (EDP) (ADE, 2014; Coppola, Madariaga, & Schnedeker, 2015; Cunningham & Carlsen, 2014; Katehi, Pearson & Feder, 2009; Smith, 2013; Trygstad, 2013; Weis, 2013). In general, this lack of work inhibits students to produce twenty-first century skills, many of which are essential for engineering. Twenty-first century skills such as application and synthesis thrive in settings that include hands-on project focused tasks. Collaboration, critical thinking, and communication skills are important in group design projects. Environments, which focus on collaboration, that deemphasize individual competition and allow students to have ownership for educational outcomes, have shown to be important for building educational resiliency and academic success of blacks, Hispanics, and women (Barton & Osborne, 1995; Borman & Overman, 2004; Brotman & Moore, 2008; Castro-Olivo, et al., 2013; Williams & Portman, 2014) all of whom are currently under-represented in STEM fields.

Specifically, the work being done in the field is not focused solely on biology (the context for the design challenges in this work). Unfortunately, statistics nationwide show that 81% of life science teachers do not feel very well prepared to engage classes in problem based learning activities (i.e., engineering scenarios), while 92% did not feel very well prepared to have students make the subsequent project presentations to peers (Lyons, 2013). These findings are troubling as recent evidence shows that embedding engineering challenges into curriculum can improve content knowledge and increase student motivation (Carr, 2011; Malone, Schuchardt, & Schunn, 2015; Potter, 2014; Schuchardt & Schunn, 2015). Our research study targets in-service engineering professional development for secondary level biology teachers through design.

Key Questions

The objective of this study is to determine the effects of video based professional development on in-service teachers' ability to create high quality bioengineering design challenges in a shortened time frame (e.g., a workshop). Specifically, this work aims to answer the following questions:

1) Can teachers produce a high quality bioengineering design challenge for secondary students with video based peer and instructor team feedback after learning about the engineering design process?
2) What issues and challenges do teachers face in creating design challenges?

Methods

The participants in this study (N=32) were enrolled in a three-week Modeling Instruction (Well, Hestenes, & Swackhamer, 1995) biology workshop held in the Midwest of the United States. The workshop introduced teachers to the Modeling Instruction pedagogical framework in the context of biology. The teachers assumed the role of students first, designing experiments to collect data that was utilized to produce models of the phenomena under study. The predictive biological models teachers produced included a number of multiple representations such as graphs and diagrams. As part of the workshop, participants deployed their newly constructed mental models to make predictions about biology phenomena. When their biological models failed to be predictive, they then refined their models. This approach to professional development is common in the K12 context (i.e., where teachers assume the role of students); however, the engineering design aspect of the workshop required participants to assume their normal teacher roles.

Recent work on in-service teacher engineering education in K12 has advocated that teachers must have hands-on experiences with engineering before writing well thought out engineering curriculum for their classrooms (Cunningham, & Carlsen, 2014; DeJong, Yelamarthi, & Kaya, 2016; Kukreti, Maltbie, Steimle, 2015). In our study, teachers did not initially work through a bioengineering design challenge in the role of students (as they did with the Modeling Instruction for experiments). Instead, they experienced engineering design in the role of teachers with the goal of designing an engineering design curriculum situated in a biological context for their students. Because the teachers had multiple backgrounds and experiences with engineering, but all were trained as science teachers, directed discussion was used to surface ideas and to develop key principles of the EDP such as solving a problem and iterative design. The EDP (brainstorming, asking questions, design solution, test solution, and improve solution) was compared to the modeling cycle (explore, develop model, deploy model, model failure, and model redesign) the teachers learned during the first part of the work. This directed instructional approach was chosen due to prior research that suggested that direct instruction of certain learning strategies such as control of variables can lead to greater conceptual gains as well as the ability to transfer to other contexts (Klahr, Chen and Toth, 2001; Bransford & Schwartz, 1999). We believe the same is true when teaching the steps of the EDP. The teachers were divided into groups of 3-5 to design the bioengineering design challenge problems. Groups selected a bioengineering design problem to work on and developed the resources, constraints, and criteria that students would apply to solve the problem statements.

The first Edthena video session occurred at this point in the workshop with groups sharing their initial project ideas as online videos. Video analysis was chosen because it has been shown to shift teachers' pedagogical practices in pre-service education (Abell & Cennamo, 2004; Santagata, Zannoni, & Stigler, 2007; Sherin & van Es, 2005; Star & Strickland, 2008; Zembal-Saul, 2005). Other teachers commented and provided feedback on the videos. In addition, workshop leaders, which included two biology science education researchers with experience in developing engineering curriculum in science and one engineering education professor, provided feedback focusing on how well the bioengineering design problem specifics met the criteria for an engineering design problem. The comments ranged from clarifying questions to suggestions for improvement. After teachers had a chance to review their video feedback, they revised their bioengineering design problem statements, planned a curriculum, and developed an evaluation and revision process for students. These final plans were shared via Edthena once more.

Analysis of Videos

The videos were analyzed using a rubric designed by the research team. The rubric can be seen in Appendix A. Since this is a Work in Progress paper, to date, the rubric has been used to analyze three sets of the videos (pre and post feedback) in Edthena out of the 7 pre and 8 post videos. Future papers from this work will include the full analysis. A Cohen's Kappa interrater check was performed and produced a score of 0.93. This score is considered large enough to allow for analysis of the rubric scores without concern that the scores could have occurred by chance (Fliess, 1981).

The pre and post average rubric scores can be seen in Table 1. The rubric scores for the first attempt at the bioengineering design challenge demonstrated that the teachers had major difficulty in the area of identifying constraints with none of the groups accomplishing this task. Only one of the three groups analyzed were able to earn an exceptional placement for stating criteria for student success, and application of EDP within the context of the problem. Their greatest successes were designing problems with engaging real world contexts that positioned students as engineers since two groups were able to accomplish this. Interestingly, only one of the groups designed problems that allowed for the students to deploy multiple biology models and all of the groups only seemed to be focusing on one biology model even though their design problem could be solved using multiple biology models. This finding was regardless of the fact that they had already had two weeks of a modeling biology workshop.

Table 1: Average Pre and Post Rubric Scores by Topic (Range 0 to 2)

Rubric Topic	Pre average score	Post average score
Design Problem Statement and Boundaries	1	2
Design Problem: Real World Context and Attributes	1.33	1.7
Identifies Relevant Problem (opposed to implementation) Constraints	0	1
Criteria for Judging Student Projects	0.33	1
Alternative Designs	1.33	2
Opportunities to Deploy Multiple Science Models in the Engineering Problem Solution	1	2
Teacher Biology Model Focus	1	1.7
Application of Engineering Design Principles	0.33	1

The post scores demonstrate a shift towards a clearer bioengineering design challenge statement. All the teacher groups were able to produce exemplary statements in the areas of a real world statement that positions students as engineers; a statement that allowed for alternative designs as well as deploying multiple science models. Only one group still focused on only one biology model for the final design challenge statement. All of the groups improved in the area of constraints, but one group was still either including inappropriate constraints (such as no computer at home to search the internet) or only a few appropriate constraints (such as only economic and environmental ones but nothing about sustainability and resource conservation).

Conclusions and Implications

This Work in Progress paper demonstrates that the most troubling area for teachers to grasp is the need for constraints in an engineering design statement. It seems that they might be confusing the idea of engineering constraints with that of curriculum or school constraints, such as no internet connection available. The use of the online platform to obtain peer review of their project produced very satisfactory results with all groups showing substantial improvement in their designs in all areas except for constraints. Thus, extra time should be spent during professional development to unmingle the use of constraints in the context of engineering from that of its use in curriculum design when dealing with in-service teachers. In addition, this study demonstrates that the use of an online platform, such as Edthena, could lead to substantial understanding of design challenges within the short amount of time allotted during workshops.

The results of this work will better inform future iterations of this workshop, but more importantly, the results will aid teachers in developing design challenges that will be integrated into their science classrooms. The rubric was developed to be broad enough to be used for other contexts where teachers are developing design challenges. We already have plans to implement the rubric in other programs that teach K12 teachers about engineering design. We hope that the rubric and our approach can be a template for others wishing to extend engineering design to K12 classrooms.

Acknowledgements

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Appendix A: Engineering Design Assessment Rubric

Topic (Points)	Unacceptable (0)	Acceptable (1)	Exceptional (2)	Points
Design Problem Statement and Boundaries	Little or no problem focus. The central problem does not include a driving question and appropriate focus to the grade level	Some problem focus. The central problem does not include a driving question or appropriate focus to the grade level	Clear and complete understanding of design goal. The central problem includes driving question, and appropriate to the grade level	
Design Problem: Real World Context and Attributes	The problem context is likely not to be engaging for students, lacking a real world context, nor positions students as engineers	The problem context is lacking at least 1 of these attributes: problem task is likely to be engaging to students, problem task contains a real world context, or problem task positions students as engineers	The problem context is likely to be engaging to the majority of the students, contains a real world context and positions students as engineers	
Identifies Relevant Problem (opposed to implementation) Constraints	No appropriate constraints are identified (0-2) or constraints are inappropriate (mostly about implementation)	Few appropriate constraints (3) are identified or some constraints are identified and some inappropriate constraints are also included	Most relevant constraints are identified.	
Criteria for Judging Student Projects	No criteria are included	One to two criteria are specified	Most relevant criteria are included including constraints met	
Alternative	Only one design possible	---	Multiple design paths	
Opportunities to Deploy Multiple Science Models in the Engineering Problem Solution	No models	One model	Two or more models	
Teacher Biology Model Focus	No models	One model	Two or more models	
Application of Engineering Design Principles	Deficiencies in problem statement with 0-1 steps in the EDP included	Deficiencies in problem statement with 2-3 steps in the EDP included	Includes nearly all steps (4-5) of the EDP: brainstorming, asking questions, design solution, test solution, and improve solution	
Overall Project Statement	Not capable of achieving desired objectives	Design barely meets desired objectives	Engineering problem meets or exceeds desired objectives	
OVERALL PERFORMANCE	**Unacceptable**	**Acceptable**	**Exceptional**	**TOTAL**
POINTS				