Board 125: Development of a Project Based, Differentiated Engineering Curriculum (DEC) for High School Students [Work in Progress]

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Jessica S. Ward serves as the Director of Development for the Center for the Advancement of STEM Teaching and Learning Excellence (CASTLE). During her tenure at Drexel University, Ms. Ward has successfully coordinated with multiple faculty members in the submission of approximately 700 grant proposals, including co-writing, editing and serving as the Program Manager for 9 awarded STEM education grants totaling more than $14M. She has collaborated with University offices, faculty and staff in the facilitation of recruitment strategies to increase the quality and quantity of undergraduate and graduate enrollment in STEM programs. Ms. Ward now manages the fundraising and grant writing for CASTLE, including assisting with hiring and overseeing awarded projects as well as coordinating program evaluation.
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Introduction

There is a need for more STEM workers and many solutions have been suggested and implemented since this problem was identified in the 2010 Report by the President’s Council of Advisors on Science and Technology [1]. Despite the 68% increase in engineering bachelor’s degrees from 2008 to 2017, large attrition rates continue to exist with only 14-17% of the students enrolled as engineering freshman graduating with a bachelor’s degree in engineering [2]. Introducing engineering in K-12 classrooms is thought to prepare college freshmen for engineering coursework by increasing students’ understanding of and affinity for science and mathematics concepts, college readiness, technological literacy and interest, and excitement and confidence in their ability to pursue engineering as a career [3].

Existing Highschool Engineering Curricula

Multiple initiatives have successfully incorporated engineering into either current science programs or as a separate subject in various high schools across the nation [4]. Well-known programs such as Next Generation Science Standards (NGSS), The Innovative Curriculum for Engineering in High School (ICE-HS) and Project Lead The Way (PLTW) are offered as four-year engineering electives [4-6]. Students in these four-year high school program embark on their engineering education with similar background knowledge in math, science and maturity level. However, taking four-year engineering electives makes it difficult for high school students to enroll in advanced math and science courses [7]. Studies show that some of these programs do not significantly improve students’ math and science abilities [8, 9]. In addition, only 19% of tenth grade students retain interest in engineering after the second ICE-HS program course, raising concerns about efficacy [10].

Programs such as the year-long ENGR 102 HS program developed by the University of Arizona have successfully increased students’ interest in becoming an engineer and their confidence in their ability to succeed in university-level engineering courses [7]. However, the ENGR 102 HS program cost additional tuition and require students to be a junior or senior and enrolled in pre-Calculus or higher math.

In this work in progress paper we report on a developing Differentiated Engineering Curriculum (DEC), which was created to expose students of varying knowledge backgrounds and interests to engineering while providing the flexibility in their schedule to take existing advanced mathematics and science courses. This paper will propose a new model of engineering curriculum based on a philosophy of differentiated curriculum, college readiness and career exploration through project-based learning and skill development.
Differentiated Engineering Curriculum (DEC)

History

DEC was created in response to feedback from recent high school physics graduates currently majoring in university engineering who stated they were overwhelmed by the rigors of university-level engineering. One author of this work and the creator of the DEC curriculum surmised that this was not due to a lack of ability but a lack of knowledge and preparedness. DEC was then developed with a focus on engineering design and a mission to educate students about the engineering profession in order to prepare them to succeed at the university level. Similar programs that focus on introducing engineering at any high school level do exist [11]. However, non-DEC programs do not address varying levels of familiarity in math and science among the students within the classroom.

Development of the Differentiated Engineering Curriculum

DEC is a three-course elective sequence open to all honors-level students in grades 9 through 12. With no specific science or mathematics pre-requisites, curiosity and interest are the primary drivers for student enrollment. Since students enter DEC having varying levels of mathematics and science backgrounds as well as variable skill levels in technical communication, computer programming and material processing, differentiated instruction is critical to the success of the program.

Differentiated curriculum is aimed at creating, “greater academic success for the broadest possible student population” [12]. One characteristic of a differentiated curriculum is filling in gaps in students’ knowledge without the more advanced students having to wait for others to catch up. The instructor achieves this by learning and familiarizing themselves with the background and skillset of each student. Based on this information, the instructor can assign specific tasks or create teaming scenarios that take advantage of students’ various levels of knowledge for projects and assignments.

DEC focuses on five core engineering themes: the engineering design process, engineering analysis, technical communications, prototyping and fabrication and project management (Figure 1). These five categories overlap with the engineering skills outlined at the first annual High School Engineering Education Symposium [13]. DEC does not cover as much content from each engineering subdiscipline as outlined in that workshop; however, these topics overlap with content found in other advanced science and mathematics courses available to students.
Each DEC course consists of two major projects (8 weeks each) and several minor ‘quick build’ modules (1 class session). These modules were developed and implemented in conjunction with engineering PhD students and have been discussed in an earlier paper [14]. As shown in figure 2, students practice the embedded skills in the five core themes multiple times per course. The final course of the sequence allows students to select a capstone project. The five core engineering themes are the underlying structure to all major projects, quick builds and capstone projects.

Figure 1. Core engineering themes and focus areas within DEC

Figure 2. Design challenges covered within the 3 courses
A project is a mousetrap vehicle design. In a classic physics design challenge, students must design a vehicle powered solely by the energy of a common mousetrap. As an example, Figure 3 demonstrates how to differentiate for three different types of students: a novice, a tech savvy student and a student with advanced coursework in mathematics and science. When these students are together on a project team, they each have responsibilities appropriate to their skill level while at the same time contributing to the overall project success. Each class has a combination of students with specific skills upon entry. It is the instructors’ challenge to shape both the project itself and the composition of the student project teams in order to take advantage of these factors.

<table>
<thead>
<tr>
<th>Engineering Analysis</th>
<th>Novice Student</th>
<th>Tech Savvy Student</th>
<th>Experienced Math/Science Student</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calculate distance traveled based on wheel/axle geometry.</td>
<td>Utilize assembly drawing to analyze motion and interference of parts.</td>
<td>Design an experiment to determine the variance of spring energy in various style mousetraps.</td>
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<tr>
<td></td>
<td>Calibrate vehicle stopping-distance based on testing.</td>
<td></td>
<td>Collect and analyze run data to create a stopping-distance calibration tool.</td>
</tr>
<tr>
<td>Technical Communication</td>
<td>Create isometric conceptual design drawings.</td>
<td>Create functional assembly drawing in 3D modeling software.</td>
<td>Explain how energy, friction, rotational inertia and other physical concepts influenced design details.</td>
</tr>
<tr>
<td></td>
<td>Create basic parts in 3D modeling software.</td>
<td>Generate drawing files in 3D modeling software.</td>
<td></td>
</tr>
<tr>
<td>Prototyping &amp; Fabrication</td>
<td>Use basic tools and techniques to process materials.</td>
<td>Utilize laser cutter and/or 3D printer to manufacture parts.</td>
<td>Use basic tools and techniques to process materials.</td>
</tr>
</tbody>
</table>

_Figure 3. Example - Differentiation in a Mousetrap Vehicle Design Project_

**Implementation of Interest and Confidence Survey**

In our work to improve the DEC program and understand its impacts on students, we have so far received the approval of the Institutional Review Board of the university to examine the efficacy of DEC to increase the level of interest, confidence and intention to pursue engineering. This is assessed through pre- and post- surveys developed by the Center for Advancement of STEM Teaching and Learning Excellence (CASTLE) and administered at Plymouth Whitemarsh high school to research the impact of the Experiential Practices in Education Research and Teaching in STEM (ExPERTS) program. The ExPERTS surveys seek to understand the high school students’ experience with the graduate fellow who develops some of the design challenge modules and whether their overall engagement in STEM topics and disciplines was increased. Among the 21 questions of the survey, three questions specifically targeted students’ interest and confidence in various STEM fields and their choice of a career was also asked.
Results and Discussion

There were low response rates during the first term of data collection due to the voluntary nature of the survey, and no meaningful statistical analysis could be performed at this point. The authors will receive additional survey responses at the end of the current semester. This will allow for a meaningful comparison of the responses as will future repetition and surveying of this program within this one high school.

Next Steps in DEC development

The differentiated nature of this unique curriculum could not be assessed by current high school engineering assessment tools. Therefore, our team is in the process of creating a system of performance rubrics for each focus area in all five engineering themes that is similar to the progression of learning in engineering [13]. The rubrics will concentrate primarily on advancement as opposed to overall achievement level because students enter at different grade and experience levels. Students will be able to utilize these rubrics as self-assessments that guide their work, and instructors can use the rubrics to provide both formative and summative assessment data on student performance. Additionally, a system of rubrics will allow for more detailed curricular analysis over time as data is accumulated.

Conclusion

DEC is a framework of engineering skills and practices designed to teach students what it means to be an engineer, while at the same time preparing them for post-secondary engineering education. DEC allows students to enter the program at any point in their high school career to both explore the profession and immerse themselves in detailed engineering practice. DEC meets students at their given skill level upon entry through differentiation and advances them forward through each identified focus area. In future work, a more detailed system of rubric assessment will provide students valuable feedback. Instructors will gain information regarding student and curricular success. Full survey results at the conclusion of the semester will provide additional information regarding student interest and confidence as well.
References


