Developing Flexibly Adaptive Skills through Progressive Design Challenges

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ABSTRACT

This research study explores the potential of using a progression of design challenges in a studio setting to develop students’ ability to adapt to solving complex challenges. Engineering design blended with challenge-based instructions (a model of project based instruction) provides an excellent model of instruction for obtaining multiple learning outcomes associated with developing content knowledge, innovation skills, project management strategies, professional skills (communicating, teaming, leadership) and disposition for sustained inquiry. Many first year engineering programs provide design challenges for teams to work on during the term (for example). However, sometimes these challenges may be too large to allow all team members to engage in the design process deeply. Further, instructors cannot observe teams in action during their design process, which makes it difficult to provide feedback. Nor can they assess teams’ workflow process as they transfer what they learn into knowledge needed to define a solution. Over the past two years we have used a collection of small design challenges at multiple times of the year to help teams practice and reflect on their processes of design, teaming and project management. These two hour design sessions engaged learners in a short conceptual design around an interesting problem. After each session the students reflected on their process and then discussed as a class. A self-report survey was used to evaluate students’ perceptions of their process. Students report a positive increase in their team’s ability to manage their processes. In addition they report being more confident in approaching challenging design activities like the larger class projects. This paper outlines principles for constructing an effective design experience for undergraduate engineering education that co-develops design skills and the professional skills associated with a productive team’s workflow and effective communication of research finding.

INTRODUCTION

First year engineering students require multiple opportunities to test and refine their design skills as a team. ABET requirements¹, and many colleges of engineering, emphasize learning outcomes designed to prepare students for their academic and professional careers ²,³. These same requirements also identify specific engineering problem solving abilities involving the application of disciplinary knowledge to analyze systems being designed. Research on how students approach a design illustrate many challenges they demonstrate when engaging in design activities. For example, failing to identify the major requirements, define user needs, identifying appropriate measures of success, failure to identify to pursue alternatives ⁴,⁵. Also, as students transition from high school to college they are unaware of the increase in complexity of problems they will solve and their need to work interdependently with others to meet those complex alternative⁶. They may be overwhelmed with the experience and express great anxiety and frustration when faced with new experiences.
Many first year engineering programs find various methods to engage students in design activities as a method to introduce systemic design processes that support innovative solution and evidence based decision making. The process has the potential to develop students’ abilities to take the perspective of various stakeholders, work in multidisciplinary teams, and develop project management skills. These introductory engineering programs can be excellent methods to recruit students into engineering and develop their interests in various disciplines in engineering. For example, some first and second year undergraduate design courses introduce students to the practice of engineering by allowing student to identify clients with specific needs and then design projects that met those needs. Other programs like Engineering Projects In Community Service (EPICS) form teams with students from across the undergraduate years and disciplines. The EPICS team work with a project partner to identify needs and define problems to solve. Still other introduction to design courses define a single project for all the teams to complete and encourage them to identify innovative methods to solve them. Then students present their unique solution to their peers who critically evaluate the design solution and ask questions. This method is how we engage students in larger term project for a course.

Engaging students in authentic design practices builds on the constructivist theories of knowing that inform many problem and project based learning environments. By anchoring an entire class in a similar context the students all have a similar experience, but from different perspectives. This idea has been carried out in many different engineering disciplines in form of challenge based instruction. The instructional model uses a series of design challenges that engage learners in complex challenges that require multiple steps to solve, or multiple design constraints to consider. A key principle of this design experience involved created a challenge that is interesting and authentic to the learners. It is open ended enough that teams will generate variations on a theme. Further the challenges are complex enough that they require all the team members to engage in the activity and assume multiple roles. Each design challenge only lasts for a single class period and ends with deliverables in the form of a short presentation given to a peer team, potentially a physical prototype and notebook entries. Further, attempt to define an interesting engineering context that allow students to learn more about career options and the technologies associated with these careers. Successful teams will need to engage in project and team management skills to end with some.

**METHODS**

We have been developing a first year engineering course to support undergraduate engineering students transfer from high school to the rigor of college academics and their professional disciplines. Our focus is on introducing students to systematically design processes for generating innovative ideas, managing the complexity of the process, manage the dynamics of teams which are associated with the leadership skills they will need to employ in future projects in their academic and professional careers. In addition students’ should develop abilities to build computational models they can use to analyze systems. Like other programs the course engages students in several complex projects across the semester to develop these skills. The first project is a simple, and short, team building exercise to help new teams develop norms for engagement.
and level of social and intellectual cohesiveness. The second project is a several week project, where teams develop a computational model. Typically the model is tool to support a feasibility study of a client. The third project lasts the entire semester and involves developing an autonomous robotic system to serve a kind of seek and act type of mission (e.g. seek a location and deliver or pick up cargo, repair a subsystem, mark a location). The combination of these three projects in the fall and spring semesters provide an excellent opportunity for teams to engage in an authentic design process.

Table 1 – Overview of possible sequence of Design Challenges

<table>
<thead>
<tr>
<th>Week</th>
<th>Title</th>
<th>Description (main purpose)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Biomedical measurement device</td>
<td>A doctor has an idea for a simple device therapist can use to measure the progress of patients rehab after hand surgery. (Day 1 – initial attempt at engineering design)</td>
</tr>
<tr>
<td>4</td>
<td>Water horse system (temporary public drinking water system) during summer events on campus</td>
<td>Develop a computational model of a water delivery system currently being used and generate alternative solutions that increase performance of one or more functional requirements of a drinking water system. (modeling a system)</td>
</tr>
<tr>
<td>8</td>
<td>Solar panel tracking system</td>
<td>Develop an autonomous tracking system that keeps solar panels in line with the sun to maximize efficiency. (closed loop control using microcontroller system)</td>
</tr>
<tr>
<td>12</td>
<td>Modeling a sensor system</td>
<td>Design an experiment to evaluate the performance of a sensing system used in third project.</td>
</tr>
</tbody>
</table>

Spring semester

<table>
<thead>
<tr>
<th>Week</th>
<th>Title</th>
<th>Description (main purpose)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Most Beautiful Machines (MBM) (aka most useless machine proposed by Dr. Shannon – a machine whose only function is to turn itself off after it is turned on.)</td>
<td>Teams perform two roles – first as a client defining an innovative machine like the Dr. Shannon’s most useless machine that an engineering team is commissioned to build. The second role is as an engineering team that transforms a client’s MBM into a reality, ie a conceptual design. (Defining client’s needs and team building)</td>
</tr>
<tr>
<td>5</td>
<td>Analyze the feasibility of the proposed diagnostic medical device</td>
<td>Teams design and test a system that tests chemical strips that change colors as a reaction with biological materials. (Design of experiments)</td>
</tr>
<tr>
<td>7</td>
<td>Advanced cruise control</td>
<td>Develop a self-driving car prototype with the ability to adjust speed based on the speed of a car it is following. (closed loop control design)</td>
</tr>
<tr>
<td>8</td>
<td>Analyze undocumented C code</td>
<td>Evaluate C code to identify its functionality and develop a method to describe how it works to another team. (Analysis of another programmers algorithm design)</td>
</tr>
</tbody>
</table>
Teams must manage their design process outside of the class time which makes it difficult for the instructional team (instructor, graduate teaching assistance, and undergraduate peer teaching assistants) to observe and support the team’s design process and dynamics. Therefore, we introduce a series of smaller design challenges to provide students an opportunity to hone their design skills. Table 1 outlines some of the Design Challenges we have been using.

**Introducing a Design Challenge**

Teams are given a full 2 hour classroom session to complete a design challenge and communicate the results. Teams meet at their assigned table that already contains the challenge description, a notebook, building materials, and if appropriate for the task, a Mindstorm NXT microcontroller mini kit (containing sensor, motor and the NXT brick). Instructors may provide a very short introduction with background information and some logistical instructions to ensure an efficient process. The room is equipped with writable walls, small white boards, dry erase markers and erasers for students to easily share and explore their ideas. Students then have approximately 70 minutes to engage in a design process to generate a conceptual design and prototype of a system to meet the criteria of the challenge and a presentation to communicate their results. Then teams are given 5 minutes to present their design and results to other teams.

**Performing a Design Challenge**

The tight time constraints require teams to manage their process to ensure they meet the deadline. During the Fall semester teams are taught strategies for identifying needs and requirements of a client, project management skills for managing resources (time, personnel and materials), teaming skills (establishing rolls and procedures for managing work flow), and tools for managing their project and ideation. Further, they must document their design process in their notebook with sufficient detail to illustrate their understanding of the problem, generating alternatives, testing ideas, management of decisions made.

**Metacognition: Self-Reflection of Performance on a Design Challenge**

Team members typically can recite all of the strategies we recommend for managing their process. However, early in their design process they are uncertain how to implement these skills. Therefore, the next class session after a design challenge includes a short self-reflection on their performance during the design challenges. Individually students are asked to write down record what they believe the team did well and what they think the team could do to perform better next time and what they can do individually to perform better. The team members share their thoughts with each other on the team. Finally, through a large class discussion, the instructor helps the class identify the strategies teams used to ensure success.
Evaluation Instruments

Teams are graded on their notebooks and presentation. Rubrics are used to evaluate the content of each work product by Peer Teaching Assistants (PTA) on the instructional team. PTA’s are trained on the scoring rubric during regular meetings associate with course planning. The goal for the grades are mainly to provide motivation to engage in the task and to receive some level of formative feedback on their work products. Therefore, the scores are relative to where they are in their development as a design team and do not provide a strong indicator of a learning progression. A separate analysis of these work products is underway to determine a team’s progression from novice designers with weak performance to highly functional design teams. An in-depth analysis is currently underway and will be reported in future publications.

At the end of each semester students completed an exit survey targeting individuals’ perceptions of the effectiveness of the design challenge interventions and their change in confidence to adequately perform these design tasks compared to their performance in the beginning of the Fall semester. The survey consists of statements associated with our intent for improving the course and students are asked to identify their agreement with the statement on a scale of strongly disagree to strongly agree. Some questions were worded in the negative to counter balance students response which insures students are reading the question and not just giving high or low scored.

RESULTS

The results for this study focus on the exit survey students complete at the end of each semester. Analysis consisted of assigning a number to the category of response (1= strongly disagree and 5 = strongly agree). Figures 1 and 2 summarize key questions associated with the study. The centers of the bar is designed to illustrate the magnitude of the percentage of students who agreed with a particular statement on the survey.

DISCUSSION

Overall the students responded positively to all items on the exit survey. They overwhelmingly agree the design challenges increase their ability to manage complex problems and they are significantly more confident in these skills. They recognize that these experience help them practice the skills they need to work on the larger challenges they must solve outside the class sessions. Further they have increased their comfort with presenting their ideas to their peers. Both semesters revealed similar trends. However, the only change is their perception of the utility of the reflection activities to support an increase in their team’s performance. This could be a factor of the quality of the reflection activities in the various section or the students may be increasing their ability to self-regulate their process in the Spring and already do the reflection on their own. This kind of metacognition on their process is the subject of future studies.
increased our team’s ability to manage the complexity of the problem.

The Design Challenges were too hard and difficult.

We did too many Design Challenges during the semester.

Presenting to my peers increased my comfort with communicating my ideas orally.

The Design Challenges provided excellent practice for working toward our larger term projects.

Design Challenges felt like authentic engineering activities.

Reflection Activities provided useful feedback for increasing our team’s performance.

I feel more confident in my ability to analyze a complex system compared to when I started this course.
**Future Analysis**

Additional analysis of the data set needs to be complete to explore the relationship of gender and individual sections. Also, video recording were made of various teams working on the problem across each of the design challenges. These recording may provide case studies of how teams approach these design challenges and how they refine their process over time.

**Conclusion**

The use of a series of small Design Challenges can be an excellent method for increasing team’s ability to simultaneous develop their design process, project management skills, teaming abilities and communication skills. The short time line force students to engage in a systematic process and maintain a sense of urgency that they may not feel when they are working on their larger
project outside of class until the deadline is upon them. It helps them better evaluate their team’s ability to function as a team and leverage a metacognitive process of self-reflection to identify opportunities for change. Further the design challenge experience gives the instructional team an opportunity to observe the teams’ process first hand. Therefore, they increase their opportunities to anticipate if a team is having difficulties in their process and step in to assist.

Design challenges provide a safe environment for students to feel the pressure of working on a challenge problem with a tight timeline. However, the stakes are not so high that failure is catastrophic. In addition, they see where they are failing and work to develop methods to anticipate failure conditions and avoid them. Further studies need to be performed to determine if students’ increase in skills and confidence transfer to their other design experience in their academic and professional careers.

REFERENCES