Creation and Implementation of a Project Framework to Improve Cornerstone Engineering Design

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Full Paper: Creation and Implementation of a Project Framework to Improve Cornerstone Engineering Design

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ABSTRACT

Introduction to Engineering Design (EDSGN 100) acts as a gateway engineering course for over 3800 students across 20 Penn State campuses each year. Recently, the course has incorporated six educational modules, which cover topics from creativity to professional communication to making. However, these modules require a unifying experience so that the students are able to perceive how the content from the individual modules coalesces to form the unique identity of an engineer. To address this need, a new framework is proposed to guide the creation and implementation of an 8-week long design challenge within EDSGN 100. This framework identifies a series of 8 project characteristics necessary to create a clear connection between the content from each of the individual modules and the successful execution of a world-class engineering design project. This ensures that faculty-developed design projects are of an appropriate scope and context in order to provide proper scaffolding to support the six individual educational modules. This paper demonstrates how such a framework can be applied to both create new projects for the course, as well as redesign existing projects to better meet course goals and incorporate module content.

1. MOTIVATION AND BACKGROUND

Introduction to Engineering Design (EDSGN 100) acts as the cornerstone engineering course for over 3800 students across Penn State's numerous campuses each year. This includes students from almost all engineering disciplines offered at 20 Penn State campuses. Each semester, the majority of students in EDSGN 100 are introduced to engineering design through an 8-week long design challenge of the instructor's choosing. During this challenge, instructors lead students through the problem definition, customer needs identification, concept generation, concept selection, prototyping, and iteration phases crucial to engineering design. In the course's current form, these steps are further augmented by the inclusion of six educational modules ("World Class Engineer," "Professional Communication," "Innovation Process," "Making," "Seeing the Big Picture," and "Grand Challenges"). However, as the modules were created after the majority of instructors had established their preferred design project(s) for the first 8 weeks, the modules and design activities are not closely aligned.

In order to create a more unified experience, this paper discusses a new framework to guide the creation and implementation of design projects for the first 8 weeks of EDSGN 100. This framework identifies project characteristics necessary to create a clear connection between the content from the modules and the successful execution of an engineering design project. Connecting the existing modules through carefully curated projects is intended to provide students with a more cohesive EDSGN 100 experience and allow them to clearly see how seemingly disparate elements form the unique professional identity of an engineer. The remainder of the paper is organized as follows. Section 2 overviews the process used to create this framework. Section 3 demonstrates how the framework can be used to either revise an existing design project (Section 3.1) or create a new design project (Section 3.2). Section 4 offers concluding thoughts and directions for future research and evaluation.

2. CREATION OF THE PROJECT FRAMEWORK

EDSGN 100 outlines specific student learning outcomes, or goals, that enable first-year students to learn the principles of engineering design through hands-on projects that address design opportunities for familiar or unfamiliar stakeholders. The learning outcomes are summarized into five main categories: i) Design Opportunities, ii) Systems Thinking, iii) Professional Skills, iv) Communication, and v) Hands-on Experience. As previously discussed, these goals are addressed through both long-form design projects, including learning of various design tools and techniques, and six supporting educational modules. Existing design projects include a 3D-printed prosthetic finger project, a project addressing the opioid epidemic, a vaccine refrigeration project, a zero-energy home (ZEH) project, a milk frother project, and a design for emerging markets (DEM) project. However, since the majority of design projects used in EDSGN 100 were created prior to development of the modules, alignment between the projects, module content, and course goals can be tenuous. As such, students may not be able to make a clear connection between the modules and the engineering design process followed during the design project.

2.1.Assessing Existing Projects With Respect to Course Goals

To identify how well the existing projects aligned with the course goals, a coding scheme—comprising the five course goals and sub-categories within each goal—was created. Each project was assessed by highlighting specific phrases in the project overview, description, and timeline that aligned with the sub-categories. The sub-categories helped identify which course goals were most heavily represented in the project descriptions (seen in Figure 1). In this way, projects which heavily focused on a specific element could serve as reference for implementation of that element into other projects. Relevant educational modules were next associated with each sub-category to assess how much of the existing module content was already integrated into the projects.

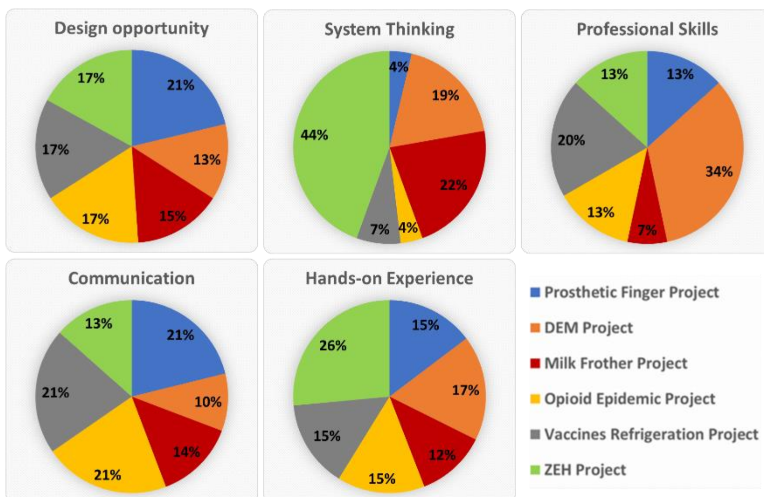

Figure 1. Results of Coding Existing Projects to Course Goals

2.2.Establishing Key Framework Criteria to Support Project Development

After assessing existing projects against the course goals and modules, common best practices were identified, which manifested as eight characteristics. These characteristics form the backbone of the proposed project framework. With each characteristic, specific opportunities for successful implementation of the characteristic were derived based on the current best practices (from Figure 1). The result is a "field guide," which guides EDSGN 100 instructors in the creation (or revision) of engineering design projects that more meaningfully address course goals while incorporating the content from the modules. The eight characteristics are detailed as follows:

- <u>Encourage a Realistic Engineering Design Process</u>. One goal of EDSGN 100 design projects is to introduce students to the use of an engineering design process. To this end, it is crucial for instructors to scaffold the project so that students develop a connection between the engineering design process and the activities, lessons, and modules in the course. This can include i) working from an explicit design process and ii) demanding iteration. Previous research has demonstrated the importance of connecting engineering education with professional practice to form professional identities and enable students to see themselves as future engineers [1].

- Engage Multiple Disciplines within a Project. Design projects are an opportunity for students to interact with other students interested in different engineering disciplines. Having a project statement that encompasses many engineering disciplines is more likely to connect with each student, and help them to see the utility of different engineering disciplines. This can include i) encouraging collaboration across interest areas and ii) developing a project that is non-disciplinary or multi-disciplinary.
- Provide Opportunities for Hands-on Experiences. Hands-on experiences help students develop a deeper understanding of complex engineering concepts and gain confidence in their own engineering abilities. It is important for instructors to provide students with multiple opportunities to engage physically with engineering design over the course of a project. This can include i) modeling, ii) building, and iii) testing. Previous research has demonstrated the benefits of hands-on making skills; this includes visualizing problems and highlighting incorrect design assumptions [2], as well as realizing critical differences between the real behavior of systems and the conceptual models used to predict that behavior [3].
- Allow for Flexibility in the Problem Space. The scope of a project sets the context for how students will demonstrate their learning and can affect their engagement. If the problem is too open, they may become overwhelmed; too narrow and they may see the solution space as trivial or uninteresting. Well-scoped design projects encourage students to solve a need, not design an object or widget. This can include i) encouraging students to reframe the problem and ii) creating a project that has the potential for real-world impact.
- Identify and Design for Specific Groups of Stakeholders. A good design project should encourage students to identify the affected stakeholders and their needs, and incorporate those needs into the project description and design goals. Projects should highlight specific stakeholders that students might not be as familiar with, encourage students to explore cultural differences, varying age groups, etc. Pushing students to consider extreme users and less familiar stakeholder groups will help them to explore alternative use cases and develop a broader perspective on engineering design challenges. Designing for “extreme” or “lead” users is common practice in professional engineering design, and designing for such users can lead to increased empathy and improved design outcomes [4,5].
- Incorporate Reflection on Big Picture Concepts. As part of EDSGN 100, students should come away with a holistic understanding of what it means to be a practicing engineer in an age of increasing globalization and project scale. A successful engineering design project should encourage students to consider the “big picture” impacts of engineering design. This can include consideration of the i) people, ii) planet, and iii) economic impact. Engineering education researchers often use theories of reflective practice to motivate the use of written or verbal reflection during activities such as problem solving [6,7]; engineering design [8,9]; and engineering professional development overall [10,11] since reflection-in-action and reflection-on-action are both critical to learning.
- Constrain the Project Space. Research in creativity and engineering design points to the dual relationship between creative output and problem constraints [12]. As such, the aim of this characteristic is to encourage flexible project spaces that strike a balance between over defined

and over ambiguous project statements. Including constraints in the project statement can challenge students and encourage more creative or innovative solutions [13]. While care must be taken to avoid over-constraining the project space [14], carefully selected constraints can push students past the “easy” or “obvious” design solutions. This can include i) specifying resource constraints and ii) specifying project constraints.

- Emphasize Effective Communication of the Design Process and Product. A project statement that requires written reports, presentations, and graphical representations will expose students to various opportunities for communication. Such forms of communication should be emphasized throughout the project, so that students learn how to effectively communicate concepts and final results through formative feedback. This can include i) written reports, memos, and emails, ii) oral presentations, and iii) visual artifacts.

3. APPLICATION OF THE FRAMEWORK: CASE STUDY EXAMPLES

A successful EDSGN 100 project is one that is carefully curated to integrate the field guide’s key characteristics with the content from the course modules. Such a project will expose first-year students to a comprehensive learning experience where they can develop their professional engineering skills. The proposed flow for applying the framework is shown in Figure 2 and is demonstrated in the revision of (Section 3.1) and development of (Section 3.2) design projects.

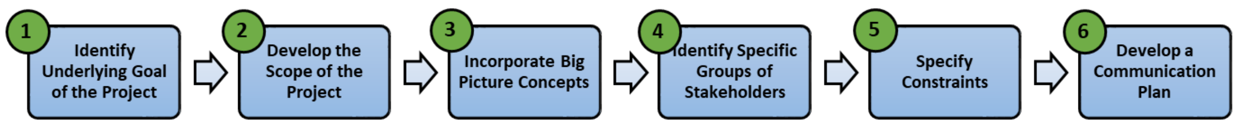

Figure 2. Recommended Steps for Creating or Revising a Project According to the Framework

3.1.Cast-Off Material Re-Use

To demonstrate how the project framework can be used to revise an existing project, a relatively simple cardboard furniture project is deconstructed and reframed to provide students with a more authentic design challenge that better reflects the content of the modules. In the original cardboard furniture challenge, students were tasked with designing a personal-sized desk made entirely from cardboard, without the use of adhesives, and which can fold down to fit in a backpack. While designing a piece of furniture using a novel material may be appealing to students, it can also come off as inauthentic. Besides specifying a desire for students to recognize the role of design, this challenge does not provide a compelling goal with a real-world context. This may limit the need for the students to follow a systematic design process. The task is also very narrowly scoped with a clearly defined problem and specified customer with which they are very familiar. With such a narrow scope, the end products may all look and behave similarly, limiting creativity, and meaningful incorporation of "big picture" concepts is likewise limited. While there is an element of environmental consideration to the challenge, the overall impact of the challenge is too narrow, affecting only an individual. The targeted customers are ones that the students are already intimately familiar with – “individuals between the ages of 18-25 years who attend a 4-year university.” This may trivialize gathering customer needs and, additionally, limits the need for the students to identify the customer for themselves. Regarding constraints, while the functional constraint of "folds down in a backpack" and the material constraint of "no adhesives" are novel, the project as a whole may be over constrained. This results in students developing similar solutions for the challenge. Physical, oral, and written communication are only emphasized at the end of the challenge when students present their final PowerPoint presentations and their physical prototypes are tested.

To revise the existing project, the fundamental underlying goal of the original challenge must be identified. The original challenge is not necessarily about designing a desk from cardboard; it is about teaching students to consider the reuse of traditional waste materials to impact the environment. By identifying this fundamental goal, we now have a compelling reason for the existence of the design project; one that merits a deep dive into a systematic design process over 8 weeks. Several alternative problems are also identified and incorporated into the project. While the problems deal with the same underlying goal (i.e., reusing cast-off materials), the contexts are significantly different. This may serve to engage a larger range of students in the project. The reach of the problem was expanded to a global scale and includes pressing issues facing the global community (e.g., health, poverty, extreme weather). By framing the problem in terms of ongoing societal, environmental, and economic challenges, the "big picture" pieces of the design project become much clearer. Different groups from different regions around the world were highlighted as potential customers, which challenges students to discover additional information regarding the users' lives and the specific problems they face. Novel and challenging functional constraints can still be implied (e.g., accommodating individuals with disabilities), but incorporating too many artificial constraints was avoided. Instead, the use cases for each problem will lead the students to organically discover relevant constraints for their target users, such as the types of cast-off materials typically found in that context. Finally, emphasis was placed on different forms of communication throughout the project. For example, while students will still have a final presentation and prototype, they also now engage in "elevator pitches" and low-fidelity prototypes at multiple points within the design process.

3.2.Global Health and Wellness

While the proposed framework can be used to improve existing design projects such as the cardboard furniture challenge, it can also be used to create new projects within the course. As an example, in Fall 2018, the framework was used to establish and pilot a new project centered on the United Nations' Sustainable Development Goals. Specifically, students were tasked with addressing challenges related to Sustainable Development Goal 3 (SDG3), which is to "ensure healthy lives and promote well-being for all at all ages." Students were given the option of working in one of four topic areas related to SDG3: (1) access to safe water, sanitation and hygiene services in sub-Saharan Africa and Central/Southern Asia, (2) global coverage of Hepatitis B vaccinations for children, (3) improving air quality or reducing exposure to either household or ambient air pollution, and (4) reducing the frequency or deadliness of road traffic injuries. By leveraging the global challenges addressed by the SDGs, the design project is naturally suited to incorporating "big picture" engineering concepts (e.g., societal or economic impacts). Further, students are offered a choice of problem topics within the lager umbrella of SDG3; this serves to expand the scope of the project to encourage different design solutions. Additionally, by specifying stakeholders from across the globe, the project guides the students away from customer groups with whom they may already be familiar. This can serve to expand their cultural awareness and help them better understand the role that geographic concerns can play in engineering design.

4. CONCLUSIONS AND FUTURE WORK

In this paper, the authors have presented the creation and implementation of a framework to support project development in a cornerstone engineering design course. The framework was derived from an analysis of best practices already in-use within the course. The resulting eight characteristics will ideally provide greater cohesiveness between the course's module content and the scaffolding design projects. While projects that leverage the framework have been piloted, additional evaluation is still needed, such as assessing changes in engineering design self-efficacy during the design project. Additionally, engagement with curriculum can be measured with a pre and post open-ended survey asking students to describe the engineering design process; coding of responses could provide insight into how much or how little students understood and engaged with course content.

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