EDSGN 100: A first-year cornerstone engineering design course

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Introduction

Introduction to Engineering Design (EDSGN 100) is the first-year cornerstone engineering course at The Pennsylvania State University that serves as the students' primary introduction to engineering and design. EDSGN 100 is taught to ~3600 students per year across 20 campuses (out of a total 24 campuses). At the University Park campus alone, 650–800 students take EDSGN 100 per semester, averaging 25+ sections per semester taught by ~15 instructors from a cadre of 20+ instructors drawn from the engineering design faculty, who are housed within the School of Engineering Design, Technology, and Professional Programs (SEDTAPP). At all Penn State campuses, there are over 50 instructors teaching 70+ sections annually. Over the past two years, the course has been significantly revised to reflect changing academic and industry needs. This paper describes the current state of the course, highlighting newly developed course materials that leveraged the expertise of a team of interdisciplinary instructors.

Prior to recent efforts, the curricular objectives for EDSGN 100 were formally updated most recently in 1995 when the course was changed from Engineering Graphics (EG 50) to Engineering Design and Graphics (ED&G 100), signifying the shift from a predominately graphics-based course to one incorporating team-based design projects. In 1998, the course won the Boeing Engineering Educator's Award, which recognized this significant shift and course innovations. In 2007, the ED&G course mnemonic was retired, and the mnemonic EDSGN was created to reflect the increased engineering design focus and new upper-division courses being offered through SEDTAPP.

The course curriculum has always been changing and new innovations developed by the faculty adopted, although not always uniformly throughout the course sections, particularly across the 20 campuses that teach EDSGN 100. Addressing the need to codify many of these innovations and to adopt more uniformity across offerings, between 2015 and 2018, the course curriculum was once again redesigned. This redesign reflects changing needs, standardization of course content across sections to provide a more consistent experience for students, and unification of core components to provide a cohesive course and address the misinterpretation (by students) that EDSGN 100 had three distinct parts (i.e., design projects, CAD, hand graphics). In 2015, eight EDSGN 100 instructors were interviewed with the intention of identifying themes and common practices. Broad objectives of these interviews were to identify resources needed by the instructors, determine the instructors' overarching vision for the course, collect information regarding the class structures established by the instructors, and identify the various, disparate branches of curricular materials being used within the course. Five general goals (i.e., broad, generalized statements about what is to be learned) for EDSGN 100 were identified from that work: engineering design process, systems framework, world-class engineer, maker culture, and communication. Based upon these findings, the course learning outcomes were redefined, and new educational materials were developed to meet the identified course and instructor needs.

Course Outcomes and Grading

During the Spring 2018 semester, EDSGN faculty codified student learning outcomes and grading schemes, standardized general course content, and documented best teaching practices. As a result of this redesign, the course title was updated from "Introduction to Engineering Design" to "Cornerstone Engineering Design" to reflect the importance of the course within the students' overall course sequence, beginning with a cornerstone design course and culminating with the capstone design course. Students in EDSGN 100 learn fundamental design skills, techniques, and tools that are built upon and applied throughout their engineering curricula. The updated student learning outcomes are as follows: Students will (1) apply engineering design to address design opportunities; (2) use systems thinking and apply it to engineering design; (3) develop professional skills necessary for becoming a successful engineer; (4) communicate engineering concepts and designs; and (5) gain experience in hands-on fabrication while developing a "maker" mindset.

A common grading scheme (Table 1) was adopted to ensure common expectations for students. Compared with prior incarnations of the course, more emphasis has been placed on the team-based design projects, as evidenced by 50% of the course grade being contributed by team work.

Table 1. Common grading scheme adopted for all EDSGN 100 sections.

<table>
<tr><th colspan="2">Assessment of individual proficiency (50%)</th><th colspan="2">Assessment of team work (50%)</th></tr>
<tr><td>20%:</td><td>In-class Assessments</td><td rowspan="2">25%:</td><td rowspan="2">Introductory Design Project(s) to support learning of design process</td></tr>
<tr><td>15%:</td><td>CAE Activities and Assessments</td></tr>
<tr><td>5%:</td><td>Making Activities</td><td rowspan="2">25%:</td><td rowspan="2">Client-sponsored Design Project to support application of design process</td></tr>
<tr><td>10%:</td><td>General Assignments</td></tr>
</table>

To assist in standardizing course materials and sharing best practices, educational materials (e.g., activities, projects, lecture materials) are uploaded to Box (a cloud-based file sharing system used across Penn State) for easy content sharing. In this way, faculty from all campuses can "crowdsource" and share new ideas and materials (e.g., teaching virtual product dissection as a concept generation tool). A tagging system was recently deployed to make finding materials as easy as possible. For instance, if an instructor is seeking a new hands-on activity, they would simply search the activities and materials tagged with "making." Additionally, new activities that are successful in the classroom are shared at weekly meetings with the EDSGN 100 instructors to supplement the online database.

Course Framework

EDSGN 100 is a 3-credit course that meets for three two-hour sessions per week that are dominated by interactive lessons and hands-on activities. At University Park, the sessions are held in different rooms (what we refer to as "Make Spaces") to support learning and application of different design tools. For instance, computer labs support learning and use of computer-aided engineering (CAE) software; flexible teaming spaces with and without computers support various design project activities (e.g., low-fidelity prototyping, sketching lessons, concept generation and selection). Students have access to a shop-based Make Space in which they construct design artifacts out of wood, cardboard, plastics, and other miscellaneous materials. In addition to the instructor, each class is allocated Make Space Assistants, typically undergraduate students who have excelled in the course. These peer mentors interact with the students, assisting with CAD designs, design project work, and Make Space projects.

The core of EDSGN 100 is the application of engineering design methods through team-based design projects. For the first half of the semester, instructors are provided flexibility in how they introduce an engineering design process, whether through a single half-semester project or a series of "mini" design projects. These design projects should present some ambiguity in the problem space, requiring that the students practice the difficult, but necessary, step of problem framing. Two examples of such projects are displayed in Figure 1. During the second half of the semester, all EDSGN 100 sections at the University Park campus address design opportunities through a sponsored design project presented by a client, most often an industry partner. Since the client-sponsored project nominally benefits from a systems perspective (e.g., addressing the negative impacts of agricultural runoff into the Chesapeake Bay), the students are afforded the opportunity to learn and practice systems thinking skills, which are vital to the practice of engineering. Standard deliverables for these design projects include a combination of the following elements: physical low-fidelity prototypes, functional prototypes, CAD models, testing and evaluation of designs, formal oral or poster presentations, and written design reports.

Food insecurity	**Background:** Across the world, lack of food security—i.e., availability, accessibility, and affordability of nutritious food—affects nearly 800 million people. Food insecurity has a number of causes, including climate, conflict, unstable markets, food waste, and lack of investment in agriculture. For many living in developing countries, there is an unavoidable link between food insecurity and poverty, as those who are in poverty cannot afford nutritious food, leaving them in a cycle where they become less able to earn the money to buy the food. **Task:** Design, prototype, and evaluate the impact of an inexpensive, context-appropriate and sustainable solution to the specific design challenge that your team has selected using materials that would be widely available in your selected country.
Opioid epidemic	**Background:** On January 10, 2018 Governor Tom Wolf issued a formal disaster declaration regarding the opioid epidemic. This action is supposed to "waive statutory regulations that create barriers to treatment and prevention, prevent first responders and others from saving lives, and reduce efficiency of our response." Opioids are a class of strong painkillers. Because opioids act as a strong sedative, overdoses can result in respiratory depression and death. Although many overdoses are the result of illegal opioids, the misuse of legal prescriptions is also a contributing factor. **Task:** Design and prototype a product or service that resolves difficulties associated with ensuring that prescriptions are consumed at the right time, at the right dose, and by the right person.

Figure 1. Example design project prompts for EDSGN 100.

To support the execution and communication of their design projects, EDSGN 100 students learn a series of design tools and techniques, such as hand graphics (e.g., multiview sketching, dimensioning, and isometric sketching) and CAE software (e.g., spreadsheet and 3D modeling software). The students are exposed to SolidWorks through a combination of faculty-led introduction projects, Lynda or SolidWorks tutorials, quizzes, and student-led projects. Through these mechanisms, students reach a minimum level of proficiency in CAD modeling to enable them to model 3D objects from dimensioned 2D sketches, from an image, or from their imagination. Within the SolidWorks environment, students become comfortable with 2D sketching, using relations and dimensioning, developing 3D features, assembling components, and composing technical drawings. Additionally, the connection between CAD modeling and prototyping of physical artifacts, i.e., making, is realized through activities whereby students 3D print their models through on-campus services.

Development of Interdisciplinary Learning Modules

With funding from the College of Engineering's Leonhard Center for Enhancement of Engineering Education, six learning modules focused on the identified student learning outcomes were developed by a team of 21 multidisciplinary faculty members across six campuses. Through a framework of world-class engineering, the overarching goal of these modules is to reinforce the attributes of, and assist our students in identifying as, world-class engineers. These learning modules focus on the following topics: (1) world-class engineering attributes; (2) systems thinking and sustainability; (3) innovation processes; (4) making; (5) professional communication; and (6) grand challenges. Each of the modules is comprised of two or three lessons that introduce each topic, with lessons accompanied by hands-on activities and in- and out-of-class reflections to actively engage the students.

World-Class Engineering Attributes: This module is comprised of three lessons—world-class engineering attributes, teamwork, and leadership and ethics—that are broadly applicable to any engineering discipline. These lessons invite the students to reflect on their own experiences, their own motivations for pursuing engineering, and to think more broadly about the role of engineering and engineers in society.

Systems Thinking and Sustainability: This module incorporates core lessons on seeing the "big picture", i.e., systems thinking via concept maps and life-cycle assessment. Students are introduced to systems thinking via the "Draw How to Make Toast" [1] activity followed by construction of a mobile phone concept map using post-it notes and online Cmap software [2]. The SolidWorks Sustainability tool introduces students to the concept of life-cycle assessment through analysis of a simple water bottle or a model of their design project solution.

Innovation Processes: This module incorporates best practices related to key components of the design process, namely concept generation (which includes innovation methods), concept selection, low-fidelity prototyping, and design reviews. To support low-fidelity prototyping, classrooms have been equipped with carts that house various common low-fidelity prototyping materials, such as various papers, markers, pipe cleaners, craft sticks, plastic building blocks, and various fasteners. Students also have access to microprocessor kits and littleBits electronic building blocks to further develop their design concepts.

Making: This module comprises lessons on maker culture, traditional manufacturing processes, and additive manufacturing (aka, 3D printing) techniques. As a part of the lesson on maker culture, students are directed to explore and visit several maker spaces on campus and in the local community. It is suggested that students visit different types of maker spaces to understand the types of "making" that they support (e.g., 3D printing facilities, crafts, etc.). The third lesson of this module introduces the concept of 3D printing and design for additive manufacturing. To support this lesson, several "Nittany Build Boxes," or mobile 3D printing carts, were developed and constructed [3] and deployed in key classrooms. Each Nittany Build Box contains a 3D printer, a 3D scanner, 3D printing pens, and a laptop with software for slicing and controlling the 3D scanner. In addition to the equipment, the mobile cart contains a display box with 15 3D printed components to highlight key opportunities (e.g., 3D-printed assemblies and complex parts) and restrictions (e.g., warping and minimum feature size) of the technology. This mobile station actively engages students in the lesson about additive manufacturing and supports their understanding of the practical application of 3D printing.

Professional Communication: This module comprises a series of activities that support verbal, non-verbal (drawing, modeling, acting) and written communication forms. A sampling of activities is found in Table 2.

Table 2. Example activities detailed within the Professional Communication module.

Celebrity	Teams progress through three rounds (Taboo, Pictionary, Charades) with the goal of learning the importance of different communication styles.
Paper Tower	Teams design and construct a tower out of newspaper and tape without speaking (i.e., write and/or sketch).
Team Contract	After completing an individual worksheet, the team collectively discusses their answers to develop a team contract.
PBJ	Each team produces instructions that guide an undefined user to produce a peanut-butter-and-jelly (PBJ) sandwich. The instructor will redistribute the instructions so no team has their own. Teams use the instructions to the letter to produce a PBJ.
Presentation Techniques	Provides overviews of and activities related to the following: elevator pitches, assertion-evidence and Pecha Kucha style presentations.

Grand Challenges: This module introduces students to grand challenges, particularly focusing on the National Academy of Engineering (NAE) Grand Challenges for Engineering and the United Nation (UN) Sustainable Development Goals. An overview lesson encourages students to explore the concept of a "grand" challenge and a selection of challenges; a second lesson focuses specifically on the "Clean Water" grand challenge, identified in both the NAE and UN lists. In the "Clean Water" lesson, teams are provided with a simple, low-cost water cleaning technique (e.g., coffee filters; various combinations of sand, gravel, and activated carbon; boiling; and distillation) and "dirty" water samples. Students compare techniques by analyzing water quality before and after, using optical measurements, TDS and EC meters, and other techniques.

Deployment of Learning Modules through Online Systems

To simplify integration of the learning modules and to enable broad deployment to all campuses teaching EDSGN 100, the module materials were uploaded to Box and Canvas (Penn State's Learning Management System). An example of the faculty view of one of the six modules is shown in Figure 2.

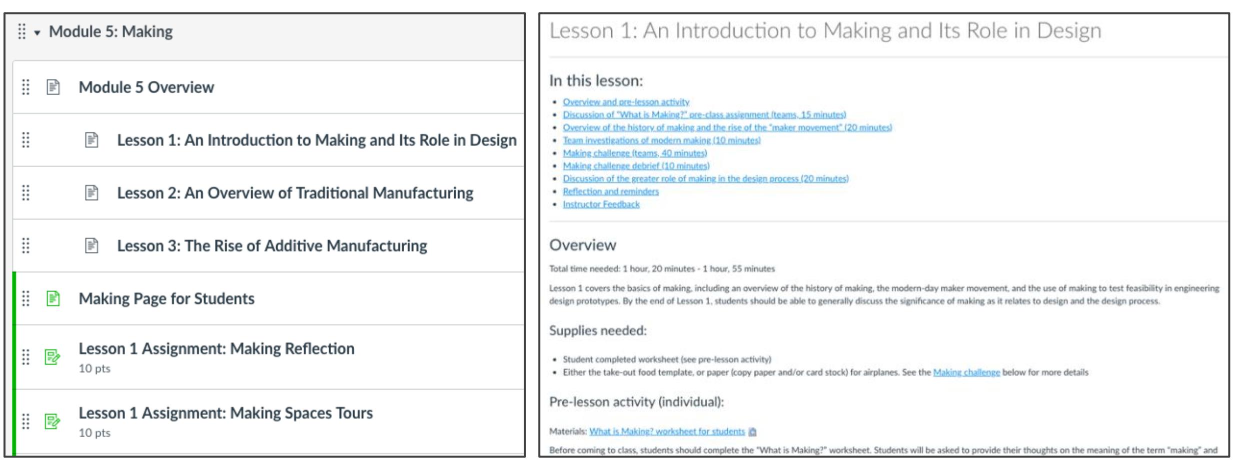

Figure 2. Example overview pages for Canvas deployment of EDSGN 100 modules.

All faculty teaching EDSGN 100 across the 20 campuses have access to the shared Canvas site; to incorporate into their own Canvas course page, they simply import the desired modules from the shared site. Each Lesson page is accompanied by a short feedback survey enabling the instructor to provide feedback on appropriateness of timing and content as well as which activities they did and did not use. The shared Canvas site and Box are kept up-to-date with changes as well as improvements based on instructor feedback. The grey Overview and Lesson 1–3 pages in Figure 2 are viewable only by the faculty and contain instructions and materials necessary for the lesson (e.g., slide decks, activity sheets, links). The green pages are viewable by the students and include an overview page that summarizes the lessons and provides necessary materials as well as pages where students upload completed assignments.

Summary and Lessons Learned

The new course outcomes and content mirror several of the recently updated ABET student outcomes [4], further supporting their importance within engineering curricula. For instance, ABET articulates the following student outcomes: (1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics; (2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors; (3) an ability to communicate effectively with a range of audiences; (4) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.

While this paper has outlined the cornerstone engineering design course at Penn State, many of the characteristics are widely applicable to other design programs. EDSGN 100 focuses on hands-on, team-based activities that strengthen the connection between coursework and the practice of engineering. The incorporation of ambiguity into the problem space of the design projects helps students to understand that real engineering problems are complex and often lack a single “right” answer. The flexibility afforded to faculty within the course framework allows them to try new approaches and activities, which serves to enrichen the materials available to all instructors. Additionally, sharing of materials between instructors at University Park and across all campuses helps to ensure a more common experience for our students. Finally, incorporating the expertise of an interdisciplinary team of faculty in curricular development has provided a rich, diverse, and relevant set of educational materials.

References

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