Building Design Experience and a Greater Sense of Community through an Integrated Design Project

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***Abstract*— WIP: The Mechanical Engineering (ME) Department at Seattle University was awarded a 2017 NSF RED (Revolutionizing Engineering and Computer Science Departments) grant. This award provided the opportunity to create a program where students and faculty are immersed in a culture of doing engineering with practicing engineers that in turn fosters an identity of being an engineer. Of the many strategies implemented to support this goal, one significant curricular change was the creation of a new multi-year design course sequence. This set of three courses, the integrated design project (IDP) sequence, creates an annual curricular-driven opportunity for students to interact with each other and professional engineers in the context of an open-ended design project. These three courses are offered to all departmental first-, second-, and third-year students simultaneously during the spring quarter each year. Each course consists of design-focused classroom instruction tailored to that class year, and a term design project that is completed by teams of students drawn from all three class years. This structure provides students with regular design education, while also creating a curricular space for students across the department to interact with and learn from one of another in a meaningful way. This structure not only prepares students for their senior design experience, but also builds a sense of community and belonging in the department. Furthermore, to support the "engineering with engineers" vision, volunteer engineers from industry participate as consultants in the design project activities, giving students the opportunity to learn from professionals regularly throughout their entire four years in the program. This course sequence was offered for the first time in 2020, and while the global pandemic impacted the experience, the initial offering was by all accounts a success. This paper provides an overview of the motivation for the three IDP courses, their format, objectives, and specific implementation details, and a discussion of some of the lessons learned. These particulars provide other engineering departments with a roadmap for how to implement this type of a curricular experience in their own programs.**

***Keywords*— Engineering Curriculum, Engineering Education, Engineering Profession, Design, Mechanical Engineering, Professional Development, Industry Involvement**

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I. Introduction

In 2017, the Mechanical Engineering department at Seattle University (SU) was awarded a 5-year NSF RED (Revolutionizing Engineering and Computer Science Departments) grant. The goal of the grant was to create a "*program that fosters, in students, an identity of being an engineer by immersing them in a culture of doing engineering with engineers*" [1], [2]. To support this change, the department enacted a set of critical curricular changes that provided opportunities in every year of the program for students to interact with each other and practicing engineers. Engineering identity can be strongly influenced by having frequent and meaningful interactions with others who already identify as engineers [3]-[5]. To implement these changes, the department repurposed credits in the existing Bachelor of Science in Mechanical Engineering program (BSME) towards generating meaningful interactions between students and engineers [2].

II. Integrated Design Sequence Overview

Engineering design education is a critical aspect of any engineering program, as indicated by ABET(formally known as Accreditation Board for Engineering and Technology) requirement for programs to offer a culminating design experience [6]. Most undergraduate engineering programs meet this requirement via a senior design project [7], but how and when design should be taught in engineering programs is an open question in the literature. With several researchers suggesting that more design education is needed, many programs have opted for a "bookend" approach, teaching engineering design in the first and then again in the final year [8]. Because students in the middle years suffer from a lack of open-ended design problems, programs are continually searching for ways to expose students to the design experience more frequently [9]-[12]. In addition to the positive effects of project-based design education on student learning [7, 8], open-ended design projects offer an opportunity to expose students to industry-specific problems and practices [11], [12]. Design courses are also ideal curricular vehicles for engineering identity forming experiences. Engineering with engineers strengthens students' engineering identity and sense of belonging [13], [14]. To this end, the Department established a set of three interconnected courses, called the integrated design project (IDP) sequence designed to offer meaningful design experiences and create intentional and regular opportunities for interaction with practicing engineers and other engineering students.

Vertically integrated design projects (VIDP) [15] are known ways to bring together student engineers from various class years and experiences levels to work on projects to the educational benefit of all, and VIDP provided the basic framework for the new IDP sequence. Three new Integrated Design Projects (IDP) courses were added to the first three years of the program [2]. These courses, now required for the BSME degree, greatly increase the number and frequency of the design experiences and interactions with more experienced engineers, both in the form of professional engineers and more advanced engineering students.

The new integrated design project (IDP) sequence at SU consists of three coordinated courses taken by all department first-, second- and third-year students simultaneously in the spring term each year. Each of these courses includes two hours of classroom instruction and two hours of design project time each week. Classroom instruction is provided to each class year separately, while work on a term-long design project is accomplished in teams of 5-7 students with "integrated" members from all three class years (see Fig. 1). While the concept of vertically integrated design projects is well known, this experience is unique in that the program is a required curricular element for all students in the program and involves weekly mentoring by practicing engineers. As such, the entire department is effectively engaged in this experience, creating a greater sense of inclusion and community, and driving learning outcomes and professional growth.

The design project experience is the centerpiece of the IDP. This project allows students to practice the engineering design skills in real-time, while also creating opportunities for organic interactions between diverse groups of engineers with different levels of experience. It is through this experience that our students are given a distinct, systematic, and intentional opportunity to do "engineering with engineers." Figure 1 shows the conceptual framework of the integrated design experience. The integrated design teams are made of students (depicted in red/green/blue icons) who work under the guidance of an engineering faculty (depicted with yellow icons), and in regular collaboration with one of several volunteer engineers from local firms (depicted with purple icons). The practicing engineers attend class sessions and operate in a consultant role for the design teams during project periods. This approach is sustainable since the volunteers need to be available for only one or two class periods in a term.

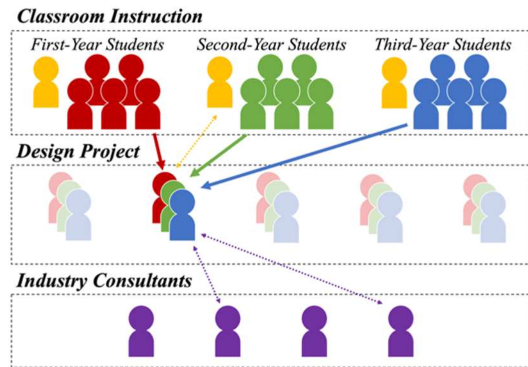

Fig. 1. The Seattle University Integrated Design Experience

Figure 2 depicts how a single student moves through a representative week in an IDP course. While each of the three IDP courses has its own class-year-relevant curriculum needed to achieve the specific learning outcomes (LOs), the outcomes for each course are interrelated and build upon each other as a student moves through the IDP sequence. Table I outlines the specific LOs for each of the IDP courses.

TABLE I. LEARNING OUTCOMES (LOS) FOR THE THREE IDP COURSES
(ASSIGNMENT TARGETING HIGHLIGHTED OUTCOMES ARE PROVIDED IN SECTION III)

Learning Outcomes	IDP 1	IDP 2	IDP 3
Understand the phases of the engineering design process	I	R	R
Understand the concept and usage of specifications in the context of engineering design	x		
Understand the concept of functionality within the context of engineering design	x		
Design a part or component needed for the fabrication of a design prototype	x		
Design and conduct an experiment to support an engineering design decision		x	
Understand the concept of uncertainty in the context of engineering design		x	
Understand the trade-offs between performance goals and non-technical design constraints		x	
Use computational tools to model a system or component to assist in design decision-making		x	
Manage conflicting engineering design requirements in the solution to an engineering problem			x
Understand the basic concepts of project management and critical path analysis			x
Understand the economic, ethical, legal, and regulatory aspects of engineering problems			x
Understand the tools and skills necessary for effective leadership of project teams			x
Use graphics and 3D models to communicate engineering design details	I	R	
Use oral and written communication skills to share engineering design decisions	I	R	R
Use practical software tools relevant to the engineering profession	I	R	R
Function as a member of a multi-disciplinary engineering design team	I	R	R

Note: "x" - included in course, "I" - introduced in course, "R" - reviewed in course

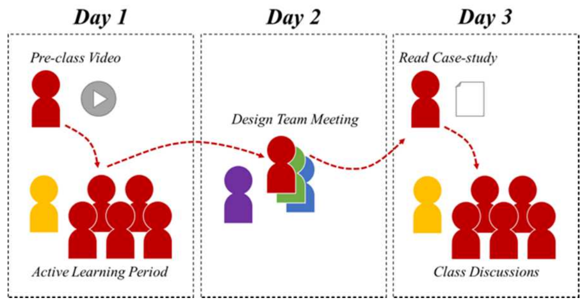

Fig. 2. A "Representative" Week in an IDP Course for a Single Student

III. Integrated Design Project Course Specifics

Each IDP course contains activities focused on technical writing, technical presentations, and other foundational professional skills that Department, University. and ABET deem critical and that need to be revisited by developing engineering students. Table II outlines the exact topics covered and the flow of activities in each of three IDP courses and the course project. The instructional periods for each IDP course cover the topics shown in the first three columns of Table II respectively, and the sequence of events and required weekly deliverables for the term project are shown in column 4. These IDP course activities are designed to provide repeated exposures to the seven student outcomes required by ABET [6], making this course sequence beneficial for driving continuous process improvement in other areas of the departmental curriculum. For further details and specific assignments, please contact the corresponding author via email.

A. Project Details

The integrated design project is at the core of all three IDP courses. This project is a term-long scaffolded experience where faculty guide student design teams through the design process. This process starts with need identification and problem definition, and progresses through to the development and presentation of a fully realized prototype solution, which can be physical or virtual. Student teams keep a design journal in the form of a website/blog, and design team progress is tracked through deliverables and milestones as outlined in column 4 of Table II. Project topics are driven by an initial problem statement (or project prompt) provided to design teams by the faculty, and they could be motivated by an industry driven problem, could be inspired by an engineering society design competition, or could simply be generated purely by the faculty. They are open-ended and don't have specific criteria for completion. The design projects vary year to year, but the framework of the project, the deliverables expected, and the timeline of the project stays consistent to emphasize the iterative nature of the IDP experience. As students progress through the IDP experience (year-to-year), they become more familiar with these deliverables and are able to provide context and experience to the other members of their teams, helping all students in the program to better identify as engineers by seeing their peers demonstrate comfort with engineering skills and judgement.

An example of a significant project deliverable is the preliminary design review (PDR) presentation teams must give to departmental faculty during Week 4 of the course. At this point, all IDP classes will have worked on issues associated with defining design problems, conducting background research, developing conceptual solutions, drawing hand or computer sketches, and presenting technical information (as seen in Table II). During the PDR, student teams formally present to the faculty: a) the exact need their design must meet, b) the background research they have conducted, c) the design specifications identified, d) the design concepts considered, e) the chosen "best" concept, f) the rationale for how the selected concept was chosen and g) plans for the next phase of the design process. The PDR presentations are evaluated based on the quality of the information provided, and the presentation.

B. IDP 1

The first IDP course, required of all first-year students, is focused on integrating students into the department community, building an understanding of the engineering design process, and introducing students to professional skills essential to the engineering profession. The LOs (see Table I) for this course are addressed via a series of independent classroom instructional periods. Each of the topics covered during these instructional periods (column 1 in Table II) address the learning outcomes that build first-year students' skills and confidence so that they can participate fully with skills and confidence in their design project teams. For example, IDP 1 students are taught computer drawing tools (e.g., Inkscape [16]) during the week of the term when the rest of their design teams are working on developing conceptual design solutions for their projects.

TABLE II. Schedule of Topics for the IDP Courses

<table>
<tr><th>Week</th><th>IDP 1</th><th>IDP 2</th><th>IDP 3</th><th>Project Time</th></tr>
<tr><td rowspan="2">1</td><td colspan="3">Course Intro and Inclusivity Workshop</td><td rowspan="2">Team Formation</td></tr>
<tr><td>Problem Definition</td><td>Design Objectives</td><td>Leadership</td></tr>
<tr><td>2</td><td>Concept Design/Project Time</td><td>Decision Tools/Project Time</td><td>Project Management/ Project Time</td><td>Specifications</td></tr>
<tr><td>3</td><td>MS Word/Sketching/Graphics</td><td>Tech. Writing 1/Tech Research</td><td>Tech. Writing 1/ Patents & IP</td><td>Conceptual Design</td></tr>
<tr><td>4</td><td>Writing Rev./ MS PowerPoint</td><td>Writing Rev./ Slide Design</td><td>Writing Rev./ Elevator Pitches</td><td>Preliminary Design Reviews (PDR)</td></tr>
<tr><td>5</td><td>Embodiment Design/Excel</td><td>Design Models 1/2</td><td>Engr Standards/ Data Visualization</td><td>Embodiment Design</td></tr>
<tr><td>6</td><td>Tech. Writing/ Digital Manuf. 1</td><td>Tech. Writing 2/ Uncert. Analysis 1</td><td>Tech. Writing 2/Engr. Ethics</td><td>Embodiment Design</td></tr>
<tr><td>7</td><td>Writing Rev./Digital Manuf. 2</td><td>Writing Rev./ Uncert. Analysis 2</td><td>Writing Rev./ Design Tradeoffs</td><td>Embodiment Design</td></tr>
<tr><td>8</td><td colspan="3">Project Time/Project Time</td><td>Design Review</td></tr>
<tr><td rowspan="2">9</td><td>Specification Review</td><td>Requirements Verification</td><td>Design Documentation</td><td rowspan="2">Critical Design Revisions (CDR)</td></tr>
<tr><td colspan="3">Resumes and Portfolios Workshop</td></tr>
<tr><td>10</td><td colspan="4">Final Design Evaluations</td></tr>
</table>

The assignment tasks for this activity, which specifically targets the LO highlighted in Table I, are to:

a) View the "Drawing" video prior to class, b) participate in the in-class demonstration of various software packages to make drawings, c) locate a photo or image online of a mechanical object and produce a graphical sketch of the object using Inkscape, d) make a sketch of one of possible design solution under consideration by your team using Inkscape or Powerpoint as desired, e) export your produced drawings as image files (e.g. .jpg or .png files) and insert those images into a Word document, f) produce a descriptive caption for each image that describes what the image is and how it was produced in your document, and g) submit your produced document file (with images) for evaluation.

Similar targeted activities have been developed and implemented for every other instructional period in this course. These activities build student's skills and confidence in practical tools they can then immediately put to use in their integrated design team activities.

C. IDP 2

By the time students take the second IDP course they are ready to work on improving their design thinking, and to take on more responsibility in their integrated design teams. While the LOs for this course (see Table I) reflect this increased technical maturity, they are closely aligned with the outcomes from IDP 1, emphasizing the iterative nature of the IDP experience. The IDP 2 classroom activities, as shown in column 2 of Table II, are focused on thinking more deeply about how to apply what they have learned in classes like statics and dynamics to open-ended problems with no concrete answers. Much like the IDP 1 activities, the IDP 2 instructional periods are self-contained (i.e., each class period focuses on a single topic). Each topic targets a specific LO relevant to the work students will engage with during their design project periods. For example, following the project teams PDR presentation, IDP 2 students start a week-long activity that challenges them to build a design model for an element of their project. The form of their model is up to the students, but the activity forces them to build the model in such a way that it can be used to answer a specific design question of interest to their team. The assignment details for this activity are as follows:

a) View the "Design Models" video before class, b) identify a question about your IDP project that can be solved with a design model, c) develop a simple model of the system, component, or behavior that you wish to study using Excel, Python, Solidworks, or any other software package that you are comfortable with and feel is relevant, d) develop a small experiment that attempts to answer the question you are focusing on using your model, e) run an experiment relevant to your design problem using your developed model f) draw a conclusion about the question you are focused on, and f) write a 1-page summary document that summarizes your experiment and finding to submit for evaluation.

D. IDP 3

By the time students enroll in the IDP 3 course, they are ready to learn the skills needed to manage project work, and to think more broadly about issues related to engineering design. Conceptually, IDP 3 can be thought of as a dress rehearsal for the senior design project experience they will embark on the next academic year. As with the IDP 1 and 2 courses, the instructional activities in IDP 3 are focused on a single topic for each period (as detailed in Table II). These activities are designed to expand on how the students think about the greater contextual issues and challenges around engineering design activities. The LOs for this course build on the outcomes for IDP 1 and 2 (as seen in Table I), but are geared more towards synthesizing engineering design issues with the broader factors that engineers must consider when engaged in design activities. These more subjective issues are addressed during class periods via small group discussions and written reflections. For example, when discussing engineering ethics, students are asked to review the National Society of Professional Engineering (NSPE) code of ethic prior to class, and to engage in group discussions on ethics case studies during class [17]. Having the IDP 3 students thinking more broadly about engineering design and teamwork sets an example to the other members of their IDP teams and helps the third-year students drive the cultural changes in the department that are at the core of the RED grant experience.

IV. Lessons Learned and Future Work

The IDP sequence at SU has been offered twice as of the time of this writing with 90-100 students working in 15-16 integrated design teams per offering. Three faculty members are responsible for organizing and teaching these courses, with each faculty member leading the classroom activities for one of the three IDP courses and also advising one third of the IDP teams on a weekly basis. There has also been strong involvement from industry partners and volunteers with approximately 10-20 individuals participating each year, many of them multiple times per term.

The department has much to learn in the coming years regarding the effectiveness of this new approach. However, after two offerings, several promising observations can be made. First, the department was able to offer this set of courses for the first time virtually during the COVID-19 pandemic, and based on the course evaluations submitted, the students appreciated the experience and learned a great deal. Although the learner-to-learner communication was intended to take place in-person during class, the pandemic drove it to digital platforms and made communication to be more intentional. Second, students reported in their course evaluations that the class activities proved valuable and relevant to the design project work. Third, all faculty involved in the second offering noted that the second- and third-year students immediately displayed comfort in their integrated teams, and as a result, all design teams were able to navigate the course deliverables much more effectively. Fourth, in both offerings of these courses to date, students from all class levels were observed engaging in the project work with enthusiasm and reported getting to know other members of the department better through this experience. Quantitative data showing how the IDP experience improved team and program belonging have been collected and will be shared in a future paper. The Department will continue to improve the IDP sequence and collect additional data in the years ahead. These data should demonstrate the positive effects this new curriculum has on department culture and on engineering identity.

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