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Work in Progress: Implementation of a Curricular Development Project for Experiential Learning in a Senior Capstone Product-Design Course

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Introduction

In 2022, the National Academies of Sciences, Engineering, and Medicine released their report on New Directions for Chemical Engineering [1]. In this report, a section on curricular reform included recommendations "that would help students understand how individual core concepts merge into the practice of chemical engineering" and "include earlier and more frequent experiential learning through physical laboratories and virtual simulations" as well as other recommendations.

However, implementation of curricular reform can be challenging. A paper by Davis and Jacobsen, which focused on mentoring undergraduate research projects, provided faculty insights to barriers to curricular innovation [2]. This paper identified three main barriers: preparation, time constraints, and demands related to the promotion and tenure process. However, the barriers in this paper focus on faculty as being the only group who can inform curricular changes.

Several papers have advocated for inclusion of the student voice in higher education curricular development [3,4]. Upper-level students have a unique viewpoint, as they understand challenges that they and their classmates faced in understanding topics. Additionally, students intimately know the content and structure of courses taught in the department. At the authors' institution, some undergraduate chemical engineering (ChE) seniors have expressed the importance of the lab courses in their connection of theory to application and a desire for incorporation of earlier hands-on or other experiential learning experiences in core classes. With these viewpoints in mind, the authors have implemented a student design project focused on developing products/modules for hands-on or experiential learning. The final products from this project can then be integrated into core ChE courses.

This paper will discuss how a student-led curricular development project focused on hands-on or experiential learning was implemented in a year-long product design course. Additionally, this paper will present some information on the senior product design course as a whole to help situate the project. The presentation at ASEE 2024 will delve more into the student-developed project(s) and student feedback of the experience as it is still in-progress.

Course Background

Capstone product design courses are relatively rare with ChE departments, with less than 20% of institutions providing a product design course, according to a 2023 survey entitled "How We Teach: Capstone Design" which is similar to a 2013 survey on the same topic [5,6]. The 2015 NSF led study on Chemical Engineering Academia-Industry Alignment cited an integrated product-process design course as "very important for future innovations" [7].

Chemical product design, a full-year senior capstone course at the authors' institution, includes a prototyping lab and serves as an alternative to the traditional process design capstone course. According to ABET [8], a culminating major engineering design experience is defined as one that "1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work". The first semester consisted of product ideation, market research, consumer needs and development planning which targets the first part in ABET's definition. Second semester focused on development of a prototype(s) in a laboratory setting. For all the product design projects, students focused on a project which can be manufactured using principles of ChE including a minor manufacturing process design at the end of the second semester. Both semesters include additional lectures by instructors and guests (both internal and external), guided mentoring through design meetings, as well as student reflections [9] and other presentations [10]. Course outcomes for both semesters of the courses can be found in Table 1.

Table 1: Course Outcomes for Chemical Product Design Sequence [11,12]. Numbers shown in parenthesis correspond to ABET student outcomes [8]

Chemical Product Design I	**Chemical Product Design II**
Research and analyze technical and business-related information (1,7)	Research and analyze technical and business-related information (1,7)
Write, edit, revise, and critique technical memos and formal written reports (3)	Write, edit, revise, and critique technical memos and formal written reports (3)
Prepare and present effective oral reports (3)	Prepare and present effective oral reports (3)
Work as a member of a team (5)	Work as a member of a team (5)
Identify technology that meets the engineering and economic requirements defined by the marketplace (2)	Design a product that meets the engineering and economic requirements defined by the marketplace (2, 6)
Design a development program to enable and validate a design (2)	Determine a logical sequence of interconnected unit operations to produce the product designed, with consideration of global, cultural, economic, and public health factors (2)
	Assess the economic impact of a product and its related production process (2)
	Account for environmental, safety and applicable regulatory issues in designing a product (2)
	Recognize and analyze professional situations requiring ethical decisions with global context (4)

Teams and Project Support

At the beginning of an academic year, students were asked to rank preferences of ChE topics such as food, consumer goods, human health, energy, sustainability, etc. In the 2023-2024 academic year, a new type of project option was added: developing a new in-class demo and/or activity to help students learn ChE principles, supported by the fundamentals of engineering education research. Instructional faculty then formed the teams based on student preferences and other best practices for team formation [13], such as not isolating minoritized students wherever possible.

Projects were all internally supported. In other words, there were no external partners or mentors for the projects. Students on this project were mentored by the instructional team whose diverse backgrounds encompass instruction of several core ChE courses, research in the engineering education domain, and experience in experiential learning. Additionally, this semester a graduate student instructor was added to the instructional team for an additional project mentor.

Implementation of Experiential Learning Curricular Development Project

Before starting AY2023-2024 and implementing the new experiential learning curricular development project into the Chemical Product Design course, the instructors understood that certain deliverables for this project may slightly deviate from previous product design projects. This misalignment is due to the limited market for experiential learning in the core ChE curriculum. As such, the focus, goal, or method to obtain certain deliverables may be slightly different. Table 2 as well as the following paragraph explain some of the course deliverables and how the experiential learning team achieved them.

Table 2: Selected Course Deliverables for Chemical Product Design 1 and how an experiential learning development team achieved them.

Selected Course Deliverables	Experiential Learning Development
Initial Product Concepts Pitch and Decision Memo	• Pitched two courses and/or format of experiential learning for future development. • Research was based on *ASEE Proceedings*, *Chemical Engineering Education*, *Education for Chemical Engineers*, and other educational journals. • Researched groups that have done similar hands-on/experiential learning.
Market Research Strategy Memo and Findings Presentation	• Surveyed students who have taken the course for which the activity is being developed. • Surveyed and interviewed faculty who have taught the course previously.
Consumer Needs and Product Features Memo	• Explored topics in the chosen course that could be developed based on survey responses. • Investigated other universities that have hands-on or experiential learning in courses. • Researched companies that produce ChE educational equipment • Considered appropriate safety limitations for the activity. • Developed necessary features the team's research and surveys.

In the second semester of the Chemical Product Design course, students focused on iterative prototype development and testing in a dedicated laboratory. Students had to identify key product features and how to assess them. Additionally, students needed to determine the priority of testing parameter importance. Students in the experiential learning development project focused on development, construction, and testing of the activity/demo during this time which included:

- Constructing the physical prototype
- Testing to ensure the activity and/or demo physically acts as expected.
- Developing supplemental materials such as simulations and protocols to assist students in completion of the activity and/or demo.
- Completing focus groups with students not in the design group to see if their activity is pedagogically beneficial.
- Developing protocols for implementation of the activity and/or demo for faculty and graduate students to teach in their classes.

All teams presented their final prototype via poster and a demonstration at the College of Engineering's capstone design symposium as well as a final oral presentation in class.

Student Authors' Reflections

Our team was brought together in our senior Chemical Product Design course. We were joined by our collective interest in creating a product related to undergraduate chemical engineering academia. During initial brainstorming, we reflected on our individual ChE experience and decided that we wanted to create an experiential learning module for Material & Energy Balances (M&EB). At our university, M&EB is the first class in the ChE series and serves as a basis for all classes after. Due to a relatively large gap between the start of learning ChE concepts and having a hands-on application of them, our goal was to provide students with the opportunity to see theoretical concepts demonstrated and to work with equipment during their first semester of ChE.

Over the course of a little over a semester, our team encountered several challenges in developing our initial prototypes, such as the near-infinite options at the beginning and time constraints for in-class activities. Being the first team in this design course to be tasked with creating an educational learning module, our team did not have the benefit of seeing examples of our type of product in past years. Initially, we were discouraged during ideation due to the lack of previous examples. Many academic papers discuss the issues in engineering education without implementing change. However, our team was excited to set a precedent for other departments to create hands-on ways to teach chemical engineering.

Another challenge was creating an educational module that fit in the time constraints of a typical lecture or discussion section. Most laboratory experiments would take much longer than we could be allotted. Choosing an engaging and intriguing topic to present to students was not easy. Our team wanted to ensure that the topic would not only help students learn M&EB concepts, but also not be too overwhelming for students to tackle. In the first half of the design class, our team identified the topics that are most important for students to master. Our team then developed projects that work as a physical representation of those important concepts. Our team is excited to know that our projects could lead to students not only learning chemical engineering concepts, but also getting excited about the major.

Future Direction and Challenges

Upon development on hands-on activities or demos, the goal would be implementation in the targeted course during the 2024-2025 academic year. This implementation would most likely occur during the discussion (recitation) sessions of the courses and would be led by graduate student instructors. As such, some challenges are expected such as getting final buy-in from the instructor of the course as well as proper training of the graduate students for the actual implementation. This challenge is being addressed by minimizing workload for implementation. This includes development of SOPs for implementation by instructors as well as graduate students, learning outcomes from the activity, and development of any additional simulation or student handouts. Ideally, these activities and/or demonstrations could also be used by faculty, graduate students, and undergraduate students for outreach activities.

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