Fostering a Chemical Engineering Mind-set: Chemical Process Design Professional Development Workshops for Early Undergraduate Students

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Work in Progress:
Fostering a chemical engineering Mindset: Chemical process design professional development workshops for early undergraduate students

Despite the many efforts to propose renovations to the chemical engineering (ChemE) curriculum in the USA, the majority of the core course-sequence remains the same since 1905. Changes in industry trends are the primary cause for the addition of different areas in the ChemE curriculum such as the need for large-scale production of commodities chemicals, product development, pharmaceuticals, and bioengineering [1]. However, there are many hurdles to completely invigorate the ChemE curriculum. Some examples may include accreditation, course credit limits, maintaining consistency with the rest of the universities, among others. Many engineering disciplines have addressed these challenges by adding non-traditional learning experiences such as research experiences, cooperative learning, project-based learning, service learning, and experiential learning [2].

Conventional wisdom advocates that engineering student's involvement in extracurricular activities is one of the main factors for a fulfilling and beneficial college experience. Previous longitudinal studies have found that consistent extracurricular activity participation influences students' persistence during college years [3, 4] and improves the transition from higher education to the labor market [5]. Engineering literature shows that extracurricular activities such as professional organization and participation in design teams can positively impact undergraduate students, in particular, those from underrepresented communities [6-8]. Why can't universities foster the creation of well-designed extracurricular experiences that enrich the current curriculum while improving students' attitude and identity toward the engineering discipline?

The current work in progress looks for opportunities that can be offered to chemical engineering students without the need to immediately change the core curriculum. This work will build upon the idea that the purpose of engineering education is to graduate engineers who can design. Engineering design can be defined as "a thoughtful process that depends on the systematic, intelligent generation of design concepts and the specifications that make it possible to realize these concepts" [9]. In general, the design process must involve the designer understanding of the customer's need and wants to recreate a set of technical specifications, identification of design constraints, concept generation and selection, concept creation, economic feasibility, and concept validation. The design process is itself a complex cognitive process [9] and requires students to undertake deep approaches to learning [10].

Chemical engineering design experiences allow students to apply the design process to produce useful and profitable products to society. However, these experiences are traditionally offered during the senior year to meet their Capstone Design Project requirement. Some of the courses that may include design experiences are, for example, Process Design, Process and Plant Design, Product Design, and Process Design and Economics [1]. This leaves first-year, sophomore, and junior students without enough experiences to develop a chemical engineering mindset (attitude) while practicing in "actual" engineering work. Chemical engineering process design tools such as UniSim/HYSYS, ASPEN Plus, Capcost, and ASPEN APEA are generally introduced in senior-level design and unit operations courses. These tools are critical for the industry, but the students will only be familiarized with it upon graduation. Most of the times, students get trained in the tools, but not necessarily undertake deep approaches to learning or are able to transfer their design skills to other scenarios. Also, the incorporation of these tools earlier in the curriculum represents a challenge for instructors because it is expected that students have an idea of the mathematical methods and physical/chemical phenomena behind every unit modeled.

Traditionally, engineering educators have focused the assessments of student involvement around students' mastery of content knowledge [11] during lecture. However, previous studies suggest that student attitudes comprise another essential component of the evaluation[12]. The use of active learning strategies that encompass student-centered, inquiry-based instructional approaches seem to be more useful to inspire involvement and positive attitudes as compared to more passive methods such as attending a course lecture [13, 14].

The proposed work in progress will provide valuable information for understanding how measuring chemical engineering attitudes can impact curriculum, development, evaluation, and improvement. Future findings may help in creating discipline-specific experiences to improve student retention and program success. Also, the authors understand that sharing curricular content can be extremely valuable to other instructors/professors interested in providing different experiences to their students.

ChemE Design Workshops Curriculum Development

The current proposed work intends to create a fun extracurricular design experience for early undergraduate students and explore how their participation may affect their attitudes towards being a chemical engineer and their perception of ChemE design. The ChemE design workshops will be created to explore the following preliminary research questions using a mix of quantitative and qualitative approaches: (1) What are the possible reasons students want to be involved in discipline-specific extracurricular activities? (2) What are their attitudes towards being a chemical engineer and their perception of ChemE design? (3) To what extent do student attitudes change before and after their participation in the workshop?

As an overview, the students will be invited to voluntarily apply to the workshops and selection will be based on different factors such as academic year, gender, and previous experiences. Only 20 students will be accepted in the first cohort. As shown in Table 1, students will participate in online instructional videos independently [15] and then partake in design tutorials/challenges in a collaborative setting[16]. Online training videos will be watched individually to help students get the necessary competencies and confidence on the topics to be discussed in the workshop. Workshops will last 10 weeks and will be mostly guided by senior peer-mentors in an active learning classroom.

As shown in Table 1, video lessons will focus on completing simulation exercises that introduce unit operations (e.g., Reactors, Pumps, Heaters, Coolers, Mixers, and Tees), common industry equipment, and processes. Modeling and simulation of these processes are facilitated by using available UniSim simulation tool. Videos will be mostly designed and recorded by senior peer-mentors. Students must submit evidence of important mastery milestones from the assigned online tutorials. Their submissions are not graded but rather verified for completion and overall understanding.   Each face-to-face workshop will require students to work on team projects using their applied knowledge to solve simulation exercises at a higher level. To foster a real design experience, they must use introductory concepts of process economics and level appropriate optimization techniques to make recommendations about their work.

Table 1. Overview of the proposed curriculum during the ChemE Design Workshops

Week	Topic	Face-to-face Team Activities	Individual Activities at home
1	Introduction to Workshop structure and teambuilding exercises	• Software installation • Professional Topic: Team Building Activities (Team, name and Logo) • Team Challenge #1: Flowsheets	• Training 1: Introduction to Unisim • Pre- Attitudes Survey
2	Styrene Monomer Production: Flowsheet design, economic evaluation, and optimization	• Professional Topic: Present Team Name and Logo • Introduction to Process Design case studies	• Training 2: Heater Design and Case Studies
3	Heater Design	• Team Challenge #2: Heaters and Coolers	• Training 3: Conversion Reactor and Reactions
4	Mixer and Tee Design	• Team Challenge #3: Mixer & Tee Team Challenge	• Training 4: Gibbs Equilibrium Reactor
5	Equilibrium Reactor: Gibbs vs Data Driven Reactors	• Introduction to Separations: Phase diagrams and separation strategies	• Catch up week on videos from Trainings 1-4
6	Final Project Disclosure	• Understanding the Scope of Work • Assumptions and Heuristics • Building process flow diagram using base case	• Catch-up PFD started during face-to-face • Answer follow up questions
7	Final Project Support	• Building process flow diagram using base case • Professional Topic: Resume Basics	• Catch-up PFD started during face-to-face • Answer follow up questions
8	Excel for Cost Calculations	• Team Challenge: Optimizing Base Case PFD • Professional Topic: Resume Basics	• Catch-up PFD started during face-to-face • Answer follow up questions • Resume Feedback
9	Final Project Support	• Team Challenge: using Base Case • Professional Topic: Technical Oral Presentations and Reports	• Get ready for final presentations and submit Design report.
10	Final Presentations and Networking Event	• Presentations with invited judges • Recognition Ceremony	• Post- Attitudes Survey • Workshop Evaluation

The proposed professional development workshops will have the following student-centered objectives:

1. Create an environment for chemical engineering students to learn, design, and optimize a chemical process, without the pressure of grades, and with the guidance of senior peer mentors.
2. Build confidence in design skills and reinforce/ learn interesting topics in chemical engineering.
3. Be able to improve skills useful to increase your participation in student engineering societies, job/internship opportunities, and engineering design teams.
4. Increase teamwork, professional networking and design skills for early chemical engineering undergraduates.

An important motivator for student's participation in the workshops is the possibility to become part of the Chemical Engineering Design Team that will compete for the first time at AIChE national conference.

Quantitative assessment of student's attitudes

To explore students' attitudes toward chemical engineering, students were asked to complete a modified version of the PFEAS (Pittsburgh Freshman Engineering Attitude Survey) developed by Besterfield- Sacre et al. [12]. It was necessary to reword the original questions as appropriated for the context of chemical engineering students. For example, "I expect that engineering will be a rewarding career" was reworded as "I expect that chemical engineering will be a rewarding career.

The self-report instrument includes 50 Likert-style questions items related to: 1) overall impressions of chemical engineering; 2) enjoyment of chemical engineering courses; and 3) confidence in computer, calculus, and design skills. All items are rated on a 5-point Likert-type scale ranging from *strongly disagree* to *strongly agree.* While the reliability and validity of this instrument in previous research contribute to the current validity and reliability of the survey, additional tests will be run to ensure the reliability and validity of the specific instrument and its use in the context of this study.

Preliminary Data:

Why are students applying to technical extracurricular experiences?

After sharing the workshop application to faculty and academic advisers, 35 applications were received in less than 2 days. Application process provides insight into what are the possible reasons students want to be involved in discipline-specific extracurricular activities. Figure 1 shows the distributions based on gender and academic year of the workshop applicants. Having a diverse pool of students was an important goal to form the first cohort for the workshops. For the academic year, we were expecting to have more participation from sophomore students because we were able to market the program more efficiently via their first chemical engineering classes.

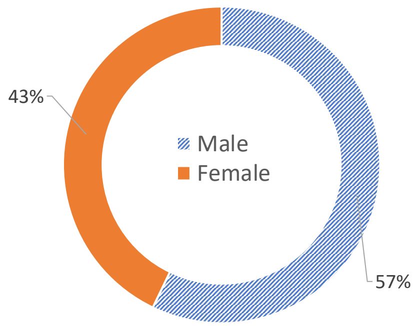

Figure 1a. Gender Distribution of Workshop Applicants (N=35). Gender; Middle: Year of study; Bottom: Specified experiences (N=35). Note: Only one student didn't answer about experiences.

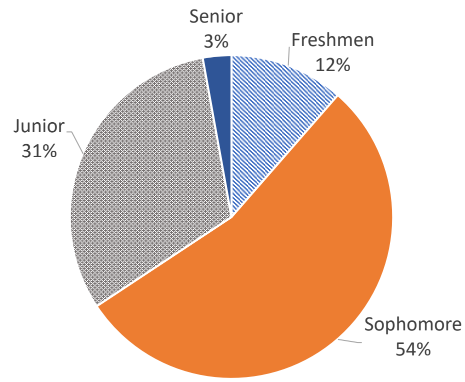

Figure 1b. Year of study Gender Distribution of Workshop Applicants (N=35)

Students were also required to indicate if they had previous extracurricular experiences and, if any, to describe what type. To minimize dishonesty in their answers, the application stated that teams will be built using a mix of students with zero experience and with previous experiences. Table 2 summarizes this information.

Table 2. Academic year distribution of student self-reported previous experiences. (N=34)

	First-year	Sophomore	Junior
No Experiences (n=12)	17%	50%	25%
Some Experiences (n=22)	9%	55%	36%

Data shows that 12 out of 34 applicants (35%) reported not having previous experiences to participate in the workshops with Sophomore leading this category. This information was essential to decide the cohort distribution for the workshops. These results may suggest that students are applying voluntarily to these workshops because they want to have more experiences before graduation.

On the other hand, it is interesting to see that most of the applicants (~65%) reported having previous extracurricular experiences. Further analysis of the students that answered having previous experiences in their applications is shown in Figure 2. This figure shows a preliminary analysis of the frequency of mentions of the different categories identified by the authors. One student may have mentioned more than one extracurricular experience.

Student organization (Student Org) was divided into two groups: leadership and membership to have more resolution on the level of participation. Preliminary results indicate that student organizations membership seems to be the experience with the highest frequency of mention followed by design teams and non-chemical engineering related part-time jobs. It is important to mention that there is no Chemical Engineering Design Team on campus. Only two of the students reported being part of the ChemE Design team that competes at AIChE. This suggests that chemical engineering students are currently seeking design opportunities outside their discipline.

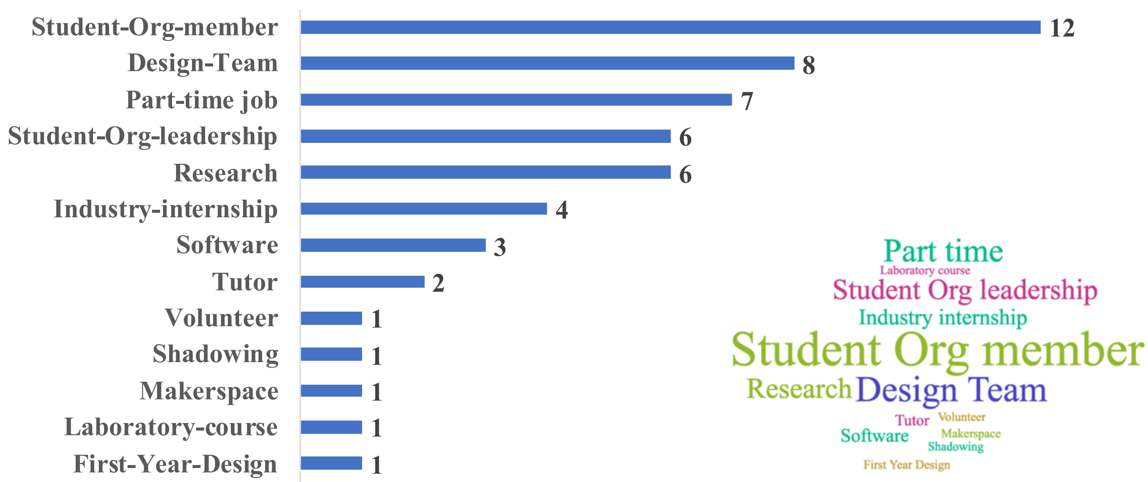

Figure 2. Frequency of workshops applicants' responses about their previous experiences and word cloud representation of the data.

Open-ended questions were gathered to help the authors get additional insight into the students' reason why they want to participate in the workshops even if it is not for a grade. Understanding student's motivation to participate can help to understand why they decide to stay during the 10-week workshops. Some preliminary trends were found from students' responses to the reasons why they want to participate in the workshops:

- Opportunity to have exposure to Chemical Engineering software
- Opportunity to have exposure to equipment that is typically used by a Chemical Engineer in industry
- Working in a design team seems like an interesting alternative way to learn the material in chemical engineering
- A fun extracurricular activity in a stress-free environment that will help them academically
- Form relationships with peers and professors

The following is an example a First-Year student response:

I want to participate in the ChemE Design Workshop because I want to gain some insight into the field of chemical engineering. Even though it is my major, I am not completely aware of what the job of a chemical engineer entails. Also, I would love to gain design experience so that I may be more comfortable with working in a design team and have some direction in the workshop setting.

Final Remarks:

The current work in progress looks for opportunities that can be offered to chemical engineering students without the need to immediately changing the core curriculum. This is an exciting opportunity to share findings on the role that well-designed extracurricular experiences have on the attitudes of chemical engineering students. Authors will be using the preliminary results to identify trends (using qualitative and quantitative methods) and identify theoretical frameworks that can help to understand the impact of this work. It is expected that the proposed workshops will be offered every semester to support the efforts of the recently formed Chemical Engineering design team at our institution. This provides a potential for longitudinal studies within the chemical engineering education community.

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