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Impacts of implementing up-to-date industry problems on engineering identity development

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Abstract

The chemical engineering curriculum has not evolved as fast as the expansion of the chemical engineering field into very diverse areas such as pharmaceuticals, renewable energy, nanoparticles, and food products. Practicing engineers need to acquire knowledge and broader skills that go beyond what is typically taught in chemical engineering (CHE) programs. To adequately address this problem, we aim to bridge the gap between academia and industry by implementing up-to-date industry problems into a sophomore course on "*Mass and Energy Balance*" and introducing industry mentors to students.

Through this proposed intervention, we explore the broad research question: How effective is the proposed approach in impacting professional identity formation and promoting industry-related competencies? Doing so involves addressing related questions such as: (1) what is the understanding of these applications and their impact on students in terms of interest, knowledge of applications, and professional identity formation? (2) What is the relationship between students' identity and course performance and assessments? (3) Is there a significant impact of the proposed approach on underrepresented groups especially women?

We worked with four industry mentors from various areas of chemical engineering to design up-to-date industry problems. During the Spring 2021 and Fall 2021 semesters, the mentors were introduced to the students and gave background about themselves and their industry-related problems. Aspects of the problems were systematically introduced into the course as homework assignments. Students were surveyed at the beginning and the end of each semester to measure engineering identity and self-efficacy. Randomly selected students were interviewed before and following the course integration activities, to determine engineering identity development and benefits and challenges of the implementation. Mentors, course teaching assistants, and the course instructor were also interviewed to capture their perspectives on the effectiveness of the implementation.

This paper describes the integration efforts, the data sources, and results from two different semesters: Spring 2021 and Fall 2021. Our preliminary results suggest that the intervention has an impact on engineering identity development and broadens students' understanding of what chemical engineering is. The findings of this study will help to reveal effective principles of industrial engagement for the evolving field of chemical engineering. The results can help other institutions to build and maintain industry-faculty relationships that assist in the professional formation of engineers.

Introduction

With the broadening of the chemical engineering field, the gap between academia and practical understanding of the industry has increased [1-3]. This gap was recognized by John Chen who organized a session at the 2013 American Institute of Chemical Engineers (AIChE) annual meeting revealing that growth areas in engineering research and faculty development are often very different from the areas that require the greatest number of new workers in engineering fields [4]. Three main areas need to be worked on to bridge the gap between academia and industry: (1) course content, (2) faculty development, and (3) teaching methods. (1) Many of the courses in the chemical engineering curriculum focus on delivering fundamentals and lack an introduction to real-world up-to-date industry applications. In addition, interpersonal and intrapersonal skills are assumed to be acquired in activities that occur as late as the senior year such as senior design and unit operations lab. (2) Faculty teaching courses are not trained in multiple areas of chemical engineering. They develop expertise in their research areas; however, they do not develop knowledge and skills in different areas of chemical engineering nor update themselves in up-to-date practices. (3) It has been shown that traditional lecture-based instruction is ineffective at promoting engineering problem-solving, self-learning, and high-level skill development [5-7]. An emerging paradigm in engineering education is design thinking including integrated or inductive-learning models and abductive-thinking [8-13]. Inductive learning is a needs-based or problem-based learning (PBL) instructional model. Fundamental principles are introduced in the context of solving a given engineering problem, and other skill sets such as communication, economics, safety, and ethics can also be introduced to add depth and meaning to solving the problem. As Felder states, “students learn best when they perceive a clear need to know the material being taught” [11]. PBL creates learning environments with rich extended problems that, when carefully designed and implemented, can engage learners in challenging tasks (problems) while providing guidance and feedback [12, 13]. Moreover, there have been many active learning strategies like cooperative learning, guided design, problem-based learning, hands-on learning and computer simulation, “clickers”, gamification, etc. that have been proven to impact student learning and student engagement [14-19]. In summary, there are many research findings and proven methods of teaching that are effective in achieving deeper learning and competency development. However, many chemical engineering faculty members are not trained in pedagogy and are not aware of these educational methods and tools and their implementation in today’s engineering education.

In summary, with the broadening of the chemical engineering discipline, the gap between industry and academia has grown. Faculty with limited experience in the industry struggle to update themselves and design their courses to reflect current industry practices. The development of interpersonal and intrapersonal skills is not systematically introduced into courses and programs. Therefore, students are disengaged and do not develop the knowledge, skills, and abilities that the industry needs. This gap is especially large for first-generation college students. Studies have shown that students who “know where they are going” are more likely to persist in engineering [20-23]; students whose parents or family members are engineers are more likely to have a better understanding of engineering practice. For those without such connections and role models, it is harder to develop a professional identity and a sense of belonging to the engineering community, which results in a lack of confidence when they start in the workforce. Research shows that identity and fit are determining factors in choosing, retaining, and pursuing the engineering profession [24-26] and better predict the long-term persistence of freshman students [27]. Underrepresented groups like women, who often perceive engineering as a male field, especially experience an identity conflict and gender roles affect their retention in engineering [28,29].

The Current Study

The current study aims to bring up-to-date industry-relevant problems into the classroom and do so by having students interact with industry professionals who pose the problems for students to solve in a scaffolded manner. It employs design-based research (DBR approach) [30-33] with multiple cycles of implementation. Our research plan includes one baseline condition (Spring 2021) and two cycles of enactment (Fall 2021 and Spring 2022). The iterative cycles pursue an answer to the following overall research question:

How effective is the proposed approach in impacting professional identity formation and promoting industry-related competencies?

Answering this overall research question requires that we also address a series of related and precursor questions associated with the design, implementation, and evaluation of the proposed components of the proposed approach in the *CHE 210 "Mass and Energy Balance"* course. Among these are the following:
(1) what are the students' understanding of these applications and their impact on students in terms of interest, knowledge of applications, and professional identity formation?
(2) What is the relationship between students' identity and course performance and assessments?
(3) Is there a significant impact of the proposed approach on underrepresented groups especially women?

Theoretical Framework

The proposed research is grounded in an engineering identity framework developed by Godwin and based on Hazari's quantitative measure of physics students' identity [34, 35]. This theoretical framework defines engineering identity as a particular type of role identity; students describe themselves and are positioned by others in the role of engineering. Engineering identity can be understood through three complementary dimensions: personal **interest** in engineering, perceived **recognition** by others, and belief in their **performance/competence** in disciplinary tasks [34, 35]. This type of engineering identity framework has been used to measure engineering identity in many studies, especially for first-year engineering students [36].

Methods

To understand the impacts of the intervention on self-efficacy and engineering identity, up-to-date industry-relevant problems were designed and introduced to the targeted course. Instruments for assessing self-efficacy and engineering identity were developed and employed. Each of these is further explained below:

Up-to-Date Industry Problems Design

During the Fall 2020 semester, the PI and project team reached out to industry mentors, and many industry mentors graciously agreed to volunteer for the project. Although other mentors were willing to volunteer for the project, we chose two industry mentors to work on industry-relevant problem designs due to time constraints. Industry mentors, course instructors, and the project team met and brainstormed the design criteria for the problems. It was decided that each problem should have multiple stages with increasing difficulty. The first stage is a basic economic calculation, the second a reactor mass balance, the third a separation mass balance, the fourth a recycling loop, and the fifth an energy integration. One problem was chosen from the carbon recycling process and one from renewable fuel production. Both topics were highly interesting for the students. Mentors received the course instructor's approval after they designed their problems. The course instructor made sure that problems' difficulty level was appropriate for students, challenging and understandable. Initially, we planned to introduce the problems in a written format as a homework question; however, we decided to change the format to video. The problem presented as a video adds another dimension, to where students can see and listen to practicing engineers; further allowing themselves to relate to the engineers. This was thought to produce a greater impact on the students' engineering identity development. Upon approval, industry mentors recorded a video introducing the problem and its relevance to their job. Videos start with introducing the mentor and their company, continuing by introducing the process, the problem, and its relevance to their work. Problems were introduced to students as HW assignments: first, they needed to watch the video and understand the process. Then each stage of the problem was distributed to HW sets. Both the video and written form of the problems were delivered to students. Overall time commitment from mentors was around 10 hours (3 hours of problem design, 2 hours of meeting with the project team, 3 hours of recording, and 2 hours of interviews). During Summer 2021, the project team worked with two other mentors to design two additional problems for the course. Those problems were from the plastic recycling process and pharmaceutical applications, which are exciting topics for students. As an example, pharmaceutical applications mentor problem can be accessed via this link: https://www.youtube.com/watch?v=g_q3CS1XcKU

Introduction of Up-to-Date Industry Problems into Targeted Course

To distinguish the impacts of the course curriculum changes from those of the interaction with industry mentors, multiple implementation conditions were planned to be evaluated. In Spring 2021, only the up-to-date problems/projects designed by industry mentors were introduced to the course. However, students did not interact with industry mentors; mentors did not give guest lectures and were not present during end-semester presentations. This baseline condition serves to measure the impact of curriculum changes on attitudes and identity development. Traditionally, CHE 210 course has been taught in-person each Fall and Spring semester at the University of Illinois at Chicago (UIC). Due to the COVID-19 pandemic, the course had to be moved online for the Spring 2021 semester. The course instructor decided to deliver the course asynchronously. Every week, he recorded his videos, posted them online, and assigned HW/Quiz/Exam via Learning Management System, Blackboard. With this set-up, he had minimal contact with students, only if they attended his office hours. Industry-relevant problems were introduced to the course in this online set-up with minimal interaction between the course instructor and students. In the Fall 2021 semester, the UIC Chemical Engineering department returned to in-person instruction, and the CHE 210 course was delivered in the classroom as the traditional format. We planned the Fall 2021 semester as the first full implementation that included: introducing three problems, inviting mentors to the class to interact with students, and students presenting to mentors at the end of the semester. All three problems were assigned to students. Each mentor visited the course (two of them in person and one remotely) where they presented themselves, experiences, and problems. Mentors attended the students' end-of-semester presentations and gave direct feedback to the students. As an example, Part 1 of one of the mentor's problems is shown below:

Mentor Problem: Biotherapeutics Process Comparison
As a newly hired process engineer at a prominent biopharmaceutical company, your director informs you that patient demand for an immunoglobulin (Ig) drug within your company's product profile has increased significantly. They have requested that you determine what is the appropriate process for filling the demand increase of 1000 kg per day of this Ig therapeutic. One process currently performed at your facility is plasma fractionation. In this process, human plasma (P) is fractionated by changing ethanol content and pH using alcohol (EtOH), acetic acid (HAc), and sodium hydroxide (NaOH). Because of the diversity of proteins in human plasma, the products of this process include the target immunoglobulin (IG), albumin (ALB), and other therapeutics (OT). This well-established process has an approximate mass-based reaction as follows:

$$1\,P + \ 0.3\,HAc + 0.5\,EtOH + 0.25\,NaOH \rightarrow 0.1\,IG + 0.3\,ALB + 0.2\,OT$$

Another option is to use recombinant DNA (r-DNA) microbes which have been modified to produce the target protein in a fermenter. After further processing, the product can be isolated. Although this process is not established at your facility, a licensing company is willing to license the process as long as you only purchase the microbes from them at a steep cost. Since the recombinant microbes (RM) consume a growth media (GM) and purified oxygen (O2) to produce a single protein (IG), the process is significantly simpler and does not result in byproducts. A mass-based reaction for this process is as follows:

$$0.33\,MB + \ 10\,GS + 2\,O2 \rightarrow 1\,IG$$

Prices for each of the raw materials and products are listed below. Based on your understanding of these processes and the prices for the materials involved, determine the process economy, and choose which of the processes you would recommend pursuing to fulfill the patent needs.

Table 1: Raw Materials Pricing

Process	Raw Material	$/kg
Plasma Fractionation	Human Plasma (P)	75
	Acetic Acid (HAc)	10
	Alcohol (EtOH)	5
	Sodium Hydroxide (NaOH)	15
Recombinant Processing	Microbe strain (M)	50
	Growth Stock (GS)	1
	Oxygen (O2)	5

Table 2: Products Pricing

Process	Product	$/kg

Plasma Fractionation	Immunoglobulin (IG)	500
	Albumin (ALB)	100
	Other Therapeutics (OT)	200
Recombinant Processing	Immunoglobulin (IG)	500

Instrument Development and Employment

Two survey instruments to measure self-efficacy and engineering identity were chosen based on the literature. Both instruments were piloted in two different courses at the end of the Fall 2020 semester. Upon analyzing the results of the surveys, self-efficacy survey instruments were slightly modified, including changing the Likert scale. On the other hand, the engineering identity survey instrument was found to be outdated, and another up-to-date engineering identity instrument was chosen based on the literature. Both surveys were implemented at the beginning and end of the Spring 2021 and Fall 2021 semesters.

The graduate research assistant interviewed six randomly selected students, stratified by gender, at the beginning and end of the Spring 2021 semester to determine reactions to the instructional design and instructional events and materials. We also interviewed two mentors at the end of the Spring 2021 semester and with the course instructor at the beginning and end of the Spring 2021 semester. Moreover, the graduate research assistant interviewed ten randomly selected students, stratified by gender, at the beginning and end of Fall 2021.

Data Analysis

We had a low response rate to survey questions in the Spring 2021 semester, possibly because of minimal in-person contact with students due to the asynchronous delivery of the course. However, by including incentives such as extra credit, we administered the same surveys at the beginning and end of the Fall 2021 semester and had more than a 75% response rate.

During Summer 2021, the graduate assistant transcribed Spring 2021 interviews via software tools. We coded and analyzed the interviews using analysis software MAXQDA. This content analysis helped us to identify challenges, difficulties, and gains of adopting this approach to the engineering program and provide an appraisal of student outcomes, including cognitive and affective responses. Based on this baseline condition (Spring 2021), the interview process was piloted, coding was refined, and responses were analyzed.

Results

We first analyzed mentor interviews and tried to identify their gains and challenges. Those results were published in the 2021 ASEE meeting [37]. Since the consented student response rate for the end of the semester surveys for Spring 2021 was low (18 responses in the beginning and only 5 responses at the end of the semester out of 52 students enrolled in the course), we did not have meaningful results for analysis. On the other hand, Spring 2021 student interviews provided insightful information as summarized below.

- Students’ perspectives about chemical engineering had broadened.
- All the participating students did not know any chemical engineer before starting the program.
- Their recognition by others is based on family members who do not know what chemical engineering is.
- Industry problems implemented in the course shortcut the students’ recognition and gave them a base to compare their performance.
- In the beginning, students' understanding of “what chemical engineering is” was very limited. Mentor problems helped them to define the field more in-depth.
- Students related themselves to mentors in the videos which helped them to increase their engineering identity.
- Even mentor problems did not change the way students recognize themselves as an engineer or not, problems gave them a metric to measure their level with industry mentors seen on the videos.
- Almost all the students reported that they realized how important the course content is and how relevant the course content is to industry applications.

Below, narratives from various students are listed:

“It feels more like real than just bookwork, like it felt like I could actually be like doing this someday. And it just didn’t feel like reading it out of the book and putting it all together because this is a real person. she explained this is something that I did at the beginning of her career. And I'm just like, oh my God, like I'm doing it too!”

“I think it gives us like a really good perspective, on like what you should be expecting out of this. Like graduate... Like a beginner position. Like you would be expected in a way to do. So, I think it was very beneficial and eye-opening. I'm like, oh, this is real. Like what you're learning. it's not like those buffer classes. It's like when are you going to do an art writing class? Like when are you going to use it? Like never. But like this is, oh, you will be using this when you graduate. These matters. I think it is important.”

“I'd say I think a basically just showing that these are the kind of problems that chemical engineers face on a day-to-day basis, but maybe like whatever is given to us is just a minor version of it, just like diluted so that we don't think too much about it. That's, I think, the most interesting part. Then on a day-to-day basis, we do such cool activities.”

“Earlier, I thought a chemical engineer was all about just sitting in a lab and doing your work. Just research over there and do whatever you are studying in your masters about the fluid mechanics and some of the equations and stuff that I remember. I thought that was it. But then I see those videos and I see, OK, wow, there's a lot of industry work that I didn't know about. So, it definitely changed my whole vision on chemical engineering.”

“Given the problems on the homework assignments that we're like from industry pretty much directly related to the course material that we were learning. So it makes me feel a little bit more confident that this is actually what chemical engineers do and some aspects of their jobs, which is interesting for sure.”

“It made me realize that the things that we're learning, because sometimes it's hard to kind of bridge the gap between the education aspect and the industry aspect, so it made me realize that the things that we're learning are actually being applied in the actual industry. I guess by having industry problems and videos from the people to kind of show yes this is -like these energy balances and working processes and chemicals -is relevant to our future jobs and industry. So that definitely influenced a little bit, which was interesting.”

“It gives us a taste of what people do in the industry because a lot of people are confused or just don't exactly know how this stuff applies to when we graduate. So, I like that they added this aspect into 210 because I don't think I've seen this in another class before and it's just kind of... I don't know if it makes it more interesting, it just adds another value. It's like this is actually like what you're going to be doing in the future if you're studying chemical engineering. It's like these are examples of what chemical engineers actually do and this applies to your coursework.”

Future Work

The first full implementation was during the Fall 2021 semester. Students had in-person interactions with mentors. Mentors visited the class and introduced their problems to students. Additionally, mentors attended the students’ end-of-semester presentations where they related a course concept, of their choosing, to everyday life. Surveys and interview data were collected at the beginning and end of the Fall 2021 semester. This data is currently being analyzed. Based on the immediate feedback from the Fall 2021 semester, the Spring 2022 implementation was redesigned and is currently being enacted. At the beginning of the semester, student surveys and interviews were completed, and mentor problems were introduced.

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