Reimagining faculty, student and community interactions in capstone: A synthesis of liberative pedagogies, citizen engineering and human-centered design

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***Abstract*—In this work-in-progress research-to-practice paper we present a newly integrated set of lenses for creating a senior capstone design course. Our future graduates face several concurrent challenges including both the increasing complexity of technology and rapid pace of innovations, and growing expectations of what engineers design will address in terms of technical and social considerations from users, stakeholders and other communities. Moreover, there are intensifying calls to address equity and inclusiveness across fields of engineering. This work proposes to begin addressing these challenges through a new pedagogical framework that synthesizes three lenses: liberative pedagogies, citizen engineering, and human-centered design and applies this synthesis to capstone design. We specifically focus this pedagogical framework on capstone design given its centrality to preparing students for engineering practice. We review literature on capstone design and summarize each lens. We then discuss our pedagogical design approach for integrating the lenses and present an integrated framework. Our results detail our learning and teaching objectives and assessments we developed from this integrated framework. Finally, we discuss critical reflections on our approach and future challenges we see before concluding.**

***Index Terms*—senior capstone, liberative pedagogies, human-centered design, citizen engineering**

I. Introduction

This work-in-progress paper documents the research to practice design of a new capstone engineering course. Engineering graduates face a future with increasingly complex problems, from rapid climate change, to issues of water scarcity and access, and widespread adoption of smart technologies (e.g., AI and internet of things, see [1]) reshaping industry, manufacturing, and design. There are also growing expectations of engineers to go beyond advancing technology and more fully address the concerns of users, stakeholders and communities they may impact [2]. Calls to address equity and inclusiveness in engineering education are also intensifying [3]. How do we prepare a new generation of engineers for these challenges while simultaneously making engineering more inclusive? One of the most critical steps to becoming an engineer is the capstone design course, where students apply their learning, work with a team and engage deeply with design. To start to address this multifaceted challenge we propose a new pedagogical framework for a two-semester multidisciplinary engineering capstone course. The framework synthesizes three lenses: liberative pedagogies [4], citizen engineering [5], and human-centered design [6].

In our program's first iteration of capstone design, we as professors are challenging ourselves to shift our approach to giving students more agency, in hopes of expanding students' understanding of their role as engineers and to have a greater stake in their learning. Our goal is to engage multiple identities of our students, and for them to stretch beyond engineering expertise in solving complex problems. We believe these results have implications for other engineering course design to promote a more student-centered framing that is inclusive of student identities, enhances student agency and engagement, heightens responsibility to broader communities, fosters deep learning, and supports holistic understanding of human needs. We next discuss background on capstone design and the three frameworks and then present our pedagogical design approach for applying these frameworks to the course. The results present learning objectives, teaching objectives and assessments we developed through this integration and the discussion highlights several key reflections from the instructors.

II. Background

A. Capstone Design

Engineering design capstone courses typically revolve around one major project that is team-based and encapsulates most major design stages from problem scoping to generating design alternatives, to prototyping and communicating results [7]. These courses provide students with: (1) a disciplinary authentic experience that prepares them for engineering work within industry (2) an opportunity integrate knowledge or learning across several fields engineering touches on including

math, science, social and economic considerations; (3) a context for applying and extending core technical skills and knowledge developed in their engineering science courses [8-10]. Moreover, in engineering programs across the United States capstone design courses have become a critical means to (at least partially) address ABET Student Outcome 2, that program graduates are able to apply engineering design to complex problems [11]. There are notable variations across engineering programs such as shorter or longer experiences [10]; those that provide simulated projects [12] or those with real clients in industry [8] or through service-based community partners or nonprofit organizations [13]; and projects that involve multiple disciplines including those outside engineering, across multiple fields of engineering or within a single field of engineering [10, 14-15]. However, the core points highlighted above hold across variations.

B. Human Centered Design

Human-centered design (HCD) encompasses a group of design approaches, e.g., user-centered design, participatory design, empathic design and others [16-18], that share several key features. These approaches place people central to the design process, embrace a more holistic or broader view of users or stakeholders, and seek to involve users throughout the design process [6, 19]. Past research has identified several challenges students face in comprehensively employing HCD approaches. For example, students may: only consider information from users for early-stage design decisions [20], withdraw from or reduce user engagement as problem complexity increases [21], or rely on users and stakeholders without critically assessing the information shared or attempting to synthesize across divergent views [17]. Critical to efforts to support students to develop HCD abilities, [19] employed a phenomenographic approach to uncover how students engaged in HCD, revealing two non-HCD approaches and a continuum of progressively more comprehensive uses of HCD. Others have begun to research additional ways to scaffold student HCD learning, e.g. through reflection activities [16].

C. Liberative Pedagogies

Liberative pedagogies (LP) are an approach to teaching derived from the work of Freire [22] and hooks [23] that focused on well-being, liberation, and caring for the whole student [4]. These pedagogies ask the instructors to consider "the roles privilege and power play in the classroom along line of gender, race class, ability, age, sexuality, and professional status (p.142)" in the hopes of moving engineering toward to a more diverse profession. Following the lead of Donna Riley [4] in her transformation of a thermodynamics classroom, we adopt the following pedagogies: connecting experiences to life; students as authorities in the classroom; creating a community of scholars; taking responsibility for one's own learning; ethics, policy, and integrity; race and class in the engineering classroom; and decentering western civilization. We see this as a very intentional shift in our classroom culture.

D. Citizen Engineering

Citizen Engineering (CE) is a mindset that recasts how an engineering student or professional views their role as an engineer within local communities and broader social groups [5.24]. Citizen engineers are not only employees of a corporation or within some industry, but are also members of several other communities and embody their engineering role within these communities. They have a shared commitment with these communities and a clear sense of responsibility in terms of how their work and role as an engineer impact these groups. There are several frames through which citizen engineering community connections may be viewed, with an emphasis on: environment, public policy, ethics and law, business and corporate social responsibility, and collaboration [5].

E. Related Research

While we recognize there is extensive literature on capstone design, with limited space we can only highlight this work briefly. Here we focus on work that studies frameworks similar to those in the present study. Several authors have applied or studied HCD or similar approaches in capstone courses [24-28]. Although limited work appears to have applied CE to design, CE shares many similarities with service learning, including an emphasis on local impact, engaging community members and considering criteria beyond technical dimensions. Service learning has also received considerable attention [29-33]. Some work has also sought to combine HCD and service learning, e.g., [34], however little work has studied liberative pedagogies in capstone design.

III. Research Direction

In integrating these three frameworks to create a new two-semester senior design course we ask: How do we prepare a new generation of engineers for these exigent challenges while simultaneously making engineering more inclusive?

IV. Pedagogical Design Approach

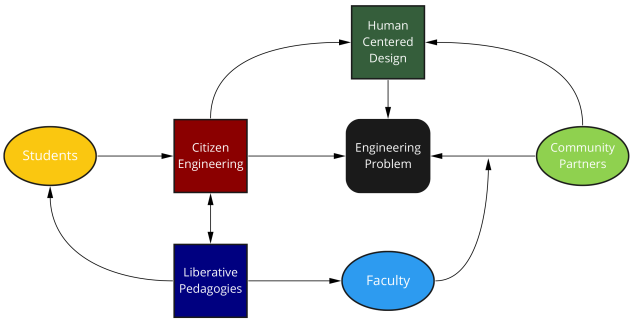

Fig. 1. Integration of the Lenses and Participants

This work does not have a traditional methods section as it is focused on course design. Our course design began by reading and discussing literature on the three lenses to address the research question in section III. For each lens

we discussed how the authors enacted or suggested enacting different components of the lenses in teaching and how these components overlapped with our course objectives. There were some components, such as considering ethical and environmental implications that overlapped with ABET and others, such as considering intellectual property (CE) that did not seem to apply to our project and were thus eliminated from our course design. These notes and discussions resulted in an integrated diagram that connects the three lenses and all class participants including students, ourselves as faculty, design project clients, and stakeholders, see Fig 1. Following this, we combined our notes to create a representation of the lens components, key design skills we had added to our list, and ABET 1-7, and mapped how these all related to each other. The second author took this mapping and created an initial draft of the learning objectives. The authors reviewed and revised the list together resulting in Table I.

As the learning objectives could not communicate our desired liberative pedagogical approach, we created Teaching Objectives to document our goals in our day to day approach to the course (Table II). These will serve as our north star as we continue to develop aspects of the course and allow us to review and reflect on these goals throughout the two semesters of teaching. We decided to take the process one step further and determine how each learning objective will be assessed through students' work. The discussion about how to forefront values of citizen engineering and liberative pedagogies created a need for additional conversations and work by the students.

TABLE I
LEARNING OBJECTIVES MAPPED TO LENSES AND ABET STUDENT OUTCOMES

Learning Objectives	**Lenses + ABET**
1.1 Design Skills - Problem Definition	
1.1a Listen, observe, and understand the problem from multiple perspectives	ABET 1,2 Empathy (HCD)
1.1b Understand the environmental, ethical, and societal conditions of the problem	ABET 2,3,4 Ethics, envr, policy (CE) Ethics, policy, integrity (LP)
1.1c Discern the political conditions and societal conditions of the problem	ABET 2,3,4 Policy (CE)
1.2 Design Skills - Ideation Strategies	
1.2a Explore divergent concepts across the design space	ABET 1, 2 Ideation (HCD)
1.2b Consider the environmental and ethical implications of proposed solutions	ABET 1,2 Ethics, envr (CE) Ethics, policy, integrity (LP)
1.3 Design Skills - Prototyping	
1.3a Use technical and scientific information to design solutions	ABET 1,2 Modeling (HCD) Technology (CE)
1.3b Consider environmental and ethical implications of design solution, especially the materials, energy, waste, and life cycle of the product	ABET 2,3 Envr, Ethics (CE)
1.3c Utilize skills and tech, e.g. CAD, rapid prototyping, machine shop	ABET 1 Technology (CE)
1.4 Design Skills - Testing	
1.4a Design tests, collect data and determine reasonableness and implications of results	ABET 6
1.4b Design user tests to evaluate concepts	ABET 2,6 User validation (HCD)
2.1 Professional Skills - Communication	
2.1a Effectively communicate design ideas with other engineers	ABET 3 Collaboration (CE) Community of Scholars (LP)
2.1b Effectively communicate design details and environmental, ethical and societal implications of designs with community partners	ABET 3 Collaboration (CE)
2.2 Professional Skills - Teamwork	
2.2a Effectively work with other engineers to build and share knowledge and design solutions to problems	ABET 5 Collaboration (CE) Community of Scholars (LP)
2.2b Effectively work with community partners	ABET 5 Collaboration (CE)

V. RESULTS: PEDAGOGICAL DESIGN

Our resulting pedagogical design produced tables of student learning objectives, teaching objectives, and a list of assessments for both semesters of the course. The learning objectives incorporate citizen engineering [5], human centered design [16, 19], ABET 1-7 [11], and other capstone design objectives. Liberative pedagogies was difficult to integrate in the learning objectives, as its focus is pedagogical choices. Thus we created teaching objectives and wove HCD, ABET, and CE into the teaching objectives as additional practices we wish to model. We present our current in-progress draft of these below.

A. Learning Objectives

Table I lists each of the learning objectives of the course and the corresponding frameworks that inspired the learning objective. Our learning objectives are split into two larger categories of design process skills and professional skills. Integrating Citizen Engineering [5] and Liberative Pedagogies [4] into the course added a significant examination of environmental, ethical, and public policy to many steps of the design process and additional learning objectives. The inclusion of these covered environmental, ethical, and public policy concerns listed in ABET Student Outcomes 2 and 4.

B. Teaching Objectives

The teaching objectives bore out of a need to integrate the liberative pedagogies into the course design, as well as a few other objectives from the other lenses and ABET that did not fit in the learning objectives. We plan to utilize this table as we plan the day-to-day activities of the course and as a discussion tool in meetings about the course to ensure we are focusing on our goals. We see this table as a starting point as we continue to read, design, and reflect on the course.

C. Assessments

As we wrote each learning objective, we began having conversations about how we wanted students to engage in these skills through class activities. We developed three major types of assessments, reflective memos, a research project, and a

TABLE II
TEACHING OBJECTIVES MAPPED TO LENSES AND ABET

Teaching Objectives	Lenses + ABET
Equip students with design skills and tools needed to become a successful engineer and designer	ABET 1,2 Technology (CE)
Encourage student agency and authority in lessons and project management	ABET 7 Community of scholars (LP)
Frequently discuss equitable, ethical, environmental and societal implications of research and design decisions	ABET 2,4 Envr, ethics, policy (CE)
Model empathy for clients, awareness of gender, race, and class issues, forefront conversations about justice, privilege, and equity	Race and class (LP) Empathy (HCD)
Create a community of respectful scholars within the classroom and conditions for productive critique	Community of scholars (LP)
Decenter western civilization in examples and readings	Decenter western civilization (LP)
Model communication, teamwork, and respect between each other, toward the students and with clients	ABET 3,5 Collaboration (CE)

final design report. These will be supplemented with in-class activities that will focus on discussion and presentation.

The goals of how to best create a community of scholars, where students teach each other and us, and have meaningful discussions about the environment, ethics, and society meant we must have different types of activities than we experienced in our own training as an engineer. This led us to forefronting the first semester with a research project focused around post-industrial sites located in the rust-belt city in which our university is located. We modeled this off an assignment described in the paper by [4]. We hope this assignment will first, focus students on the community in which the university is situated, second, begin conversations about environment, ethics, and policy, and third, allow students to serve as experts on a topic. The research project will be used to assess learning objectives 1.1b, 1.1c, 1.2b, 1.3b, and 2.1a.

We also wanted to normalize the practice of reflective writing to help students think about the activities and design processes that they learned, or analyze their own design activities. This is to encourage meta-cognition and have a mechanism for us to monitor their progress. This reflective writing would utilize a skill, memo writing, taught to them in a required communications course. We are also exploring options such as videos or audio reflections for students whose strength lies in other forms of communication. Memos will assess progress throughout the two semesters (like extended minute papers). Memos will be used to assess learning objectives 1.1a, 1.2a, 1.2b, 1.3a, 1.4a, 1.4b, 2.1a, and 2.1b.

Lastly, like many capstone design courses, the final course product will be a report. This will be presented to the client at the project's end and must be comprehensible by non-engineers. This report will consist of earlier memos revised and compiled for the final report. While drafts of the report will be assessed through the memos during both semesters, the final report will assess all learning objectives except 1.3c. We also plan to assess learning objectives through client reviews, observations of students discussions, and others.

VI. DISCUSSION

Our progress has surfaced several reflections. These cover three themes: critically reflecting on our role as instructors, intentionally scaffolding skills and mindsets, and embracing tensions between lenses. We briefly address each. First, reflecting on our role as instructors, both authors acknowledge their position in society as a white woman and man who were born in the United States. Many of our students will have different backgrounds, experiences, and ways of navigating the world that we will need to be mindful of and responsive to when pushback emerges. Under the same theme, the inclusion of teaching objectives was motivated by the LP [4] lens. In applying this lens, we realized it was important to make our own instructional practice more transparent to students through these teaching objectives, so that students have more opportunities to provide feedback to us. Relying on learning objectives alone, we risk masking our role as instructors.

Second, scaffolding skills and mindsets emerged from our realization that many of our students would have limited experience with skills and mindsets inherent to the class. Instead of employing a "just in time" model where students learn and immediately apply a skill, we created a semester one research project as scaffolding [25] where students can practice design skills, citizen engineering mindsets, etc. In this way students can begin to develop these skills before they are fully immersed in design problems. Third, for embracing tensions, we discovered some tensions while integrating the lenses. For instance, citizen engineering often focuses on involvement in local communities but liberative pedagogies pushes us to decenter western civilization and consider students' backgrounds, so a local project around the university may not address both of these. Instead of avoiding these tensions, we hope to make them points of conservation within our class.

VII. CONCLUSION AND NEXT STEPS

In this work-in-progress we shared our ongoing effort to integrate three lenses, liberative pedagogies, citizen engineering and human centered design, and apply this new framework to the creation of a senior capstone design course. Our progress has led to the development of learning and teaching objectives and an initial set of course assessments. Working on this course has forced both of us as instructors to critically reflect on several issues, including our role as instructors, particularly in embodying a liberative pedagogies approach, where and in what modes to provide scaffolding for students to develop needed skills for their projects and the reality of several tensions between the lenses. Going forward we are actively recruiting from local nonprofit and community organizations to act as clients for our students and will continue to develop our assessments, activities, and pedagogy following the integrated framework.

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