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Uncovering the Practices, Challenges, and Incentives for Engineering Design Faculty*

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Design, a cornerstone of engineering education, necessarily involves a practical training approach, which often requires educators to navigate non-traditional learning environments. Ambiguity in design is the result of the existence of multiple solutions to a given problem, and the need to find an optimal solution most often based on incomplete information. Research in design education over the years has showcased the importance of providing feedback, coaching over teaching, and including several hands-on activities with clear learning objectives. It is unclear whether this research knowledge has transcended into actual design classrooms, and whether there exists barriers or facilitators in teaching design. In a qualitative interview study with 38 design educators and administrators, we examined the practices and attitudes on teaching design, and any barriers or facilitators they faced, across a sample of schools within the United States. Additionally, we examined the use and faculty attitude on peer review, a potentially scalable approach for providing timely feedback on design. We found that the time faculty spend on teaching is significantly affected by incentives (and requirements) devised by their institutions. The recent growth in classroom sizes has resulted in reduced formative assessments. Faculty expressed concerns about low student engagement, poor communication skills, and their capacity to remain creative while taking risks. Furthermore, instructors supported use of peer learning activities, but they found implementing these activities challenging with respect to the technical needs and student motivation.

Keywords: engineering design; design teaching; teaching strategies; barriers; faculty incentives

1. Introduction

Design is a cornerstone of engineering education and professional practice. Yet, teaching design is a pedagogical challenge owing to the nature of design practice—integrating fact-based domains of knowledge with uncertainty and creativity in problem solving [1, 2]. Educators have experimented with novel pedagogical methodologies for training future designers, and in the process have encountered complex intricacies—uncertainty in design outcomes, variation in learning based on design challenge, team and related issues and more—related to imparting effective design thinking to students [1]. In recent years, design education has shifted towards a problem-based learning model, with real world (or mimicking real world) design projects that provide students with a firsthand design experience. Furthermore, the role of educators has also dramatically changed from a knowledge disseminator to that of a coach [1, 3]. Nonetheless, a key aspect of design education remains the use of situated and frequent feedback that scaffolds and nurtures student learning and performance.

Feedback plays a crucial role in general development of students as independent learners by providing them with information to improve learning (also known as formative assessment). This feedback impacts students beyond the classroom into professional practice [4]. Unfortunately, teacher feedback is time-intensive and does not scale well with class size. Traditional design education relies on a more intimate cooperative learning environment, epitomized by the studio model [5]. Feedback within the studio model is multifaceted, involving both experts and peers. But within the engineering context, design education has traditionally followed a teacher-to-student feedback model unlike its arts and architecture counterparts, where design is often a

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collaborative community learning effort. And although educators across engineering recognize the importance of feedback and the significance of the studio model, implementing such a model requires institutional and administrative support in the areas of course structuring, faculty effort certifications, and human and financial resources. This need for institutional involvement to accomplish such a merger between traditional and non-traditional methods likely impedes widespread adoption.

In recent years, engineering design educators have begun including peer review in some form—feedback on peer presentations or a few assignments, or more formally throughout the course—to increase the frequency and amount of formative feedback students receive [6]. Web-based technologies have made the implementation and management of peer review in large classrooms more manageable. For courses focused on writing (either learning-to-write or writing-to-learn), formal web-based peer reviews have become a common practice, yielding largely beneficial learning and performance outcomes [7–14]. More recently, design educators have offered web-based peer review systems to manage the scale issue [15, 16]. Apart from these stellar examples of peer reviews in the literature, very few studies have looked at the general application of such assessment activities or the perceptions of instructors and administrators of its feasibility.

Effective design education requires a coordinated effort between educators open to new pedagogical techniques and administrators who provide resources and otherwise support their faculty in non-lecture style classes [17]. In this article, we examine the practices of engineering design educators across a sample of higher education institutions within the United States. We specifically focus on unearthing the strategies used by instructors in structuring their design classes, providing feedback to their students, and dealing with barriers faced in accomplishing their tasks. Furthermore, we present instructor perspectives on using peer reviews within classrooms. We interviewed 38 instructors and instructors with administrative responsibilities from 11 higher education institutions in the United States. The interviews revealed faculty faced issues related to classroom structure and organization due to increasing class sizes; poor student communication skills and risk-averse narrow perspective decreasing their design training impact; difficulties in providing detailed and customized feedback to their students in a timely manner; viewed peer reviews positively viewed yet did not use any formal reviews within classroom due to a perception of added instructor work.

2. Related work

There are several leading research topics currently being pursued by the design education research community including, cognitive models of learning, design pedagogy, processes, and activities, to name a few [1, 18]. Research on all these fronts reveal the intricacies involved in achieving effective design training. Engineering design involves complex cognitive and social processes [1], high ambiguity [19], and iteration and negotiation [20]. It is also shaped by the designer's own ongoing construction and application of knowledge [1, 21]. Furthermore, unlike traditional experiences in science and mathematics, where problems typically have a small number of solutions that can be fact checked, design problems require a more divergent approach that explores multiple co-existing solutions. Adding to this, professional designers often allude to the "fail fast and iterate often" mantra—counter to the expectations of most students, who are typically used to being rewarded only for correct solutions. Consequently, student designers may not necessarily possess the experience, technical breadth, and/or aptitude in navigating a multi-solution problem, therefore requiring the role of design educators as coaches.

Effectively developing students' design thinking abilities requires creative classroom practices such as utilizing experiential practices such as problem-based learning, providing appropriate and timely feedback, and encouraging reflexive skills [5, 22]. Elements of these practices make design education a resource intensive activity with unclear long-term sustainability given increasing student enrollment [23].

In recent years, design educators, researchers, and practitioners, have come together to address challenges faced in design education and to share their thoughts on how to better educate future designers and engineers. For example, the Mudd Design Workshops series (e.g., MDW IX, 2015) has generated several important discussion topics and commitments from its participating members to prioritize and improve design pedagogy. From the start, it seemed clear that design education requires a complete overhaul—including refocusing on *coaching* over *teaching* as a methodology and addressing *grading* and *learning* in ways needed for design education [3]. Several of the concepts that surfaced in such conferences have been implemented in classrooms along with guidelines on what constitutes good design education [1].

Today, it is widely accepted that design education requires some use of project-based approaches, with hands-on experiences that enable students to use and sharpen their design thinking skills [1]. Such an approach is critically—and necessarily—served by formative feedback that helps student designers identify gaps in their learning and performance and make amends to maximize them. Enabling students to reflect on their learning and experiences can boost the permanency of information and skills acquired, situate the feedback, and keep the big picture in view [24, 25]. Yet, training students to critically reflect on their work or learning is in itself a pedagogical challenge. One potential way to increase student reflection is to use peer critiques, where students provide each other feedback, typically using a rubric. Conducting peer reviews inevitably induces self-assessment within reviewers [26], in addition to enhancing student learning [8]. Unfortunately, a majority of assessment and pedagogical methods currently employed involve instructor-to-student knowledge transfer, with formal peer-peer learning playing a distant second place.

The use of formal peer review or critiques are more common in design education in arts and architecture, where the culture and expectations of the field have been molded around the studio practice [27–29]. In fact, attendees from early workshops at MDW advocated the use of studio-style pedagogy in engineering design [30], recognizing its impact on multiple dimensions of student experience and learning [28]. Yet, studio-based pedagogy in engineering design remains as distant as before. A primary issue with studio-based classes is scalability—requiring increasing human, financial, and time resources. Furthermore, design educators from fields other than arts and architecture seldom have the same cultural and social experiences of relying on peers for feedback and as a source of learning. This scalability issue is a known limitation in the field, with researchers and educators exploring ways to bridge the practices across design fields [3, 16, 31–33].

Literature in the field is scattered with case studies of good design education practices [33–35]. However, they seldom seem to scale well to other institutions, or even remain sustainable within the host institutions over a long term. With design being increasingly recognized as an important activity—one that should be pervasive across several courses including traditional math and sciences—it is pertinent that the research community examine the current practices in the field and adapt and prioritize their work to benefit the larger needs of design community and pedagogy. In this line, the current article examines a sample of design educators and their practices across engineering design within the United States. This article examines the following:

- What are the issues design educators face in fulfilling their teaching goals?
- What are typical feedback provisioning strategies used by engineering design educators?
- What were the participant perceptions with regards to using peer-peer learning methods such as peer review of student work?

3. Methods

3.1 Researcher role and study setting

This study emerged from data collected as part of National Science Foundation's I-Corps for learning program. A subset data collected was used to generate a report on the questions described above (sample size of N = 38). This selection was based on whether participants interviewed were instructors of design education or instructors with administrative responsibility impacting design educators in a higher education field other than arts and architecture. The interviews spanned several institutions across United States (largely on the East Coast) covering numerous institution types: teaching- vs. research-focused, private vs. public, and large vs. small.

3.2 Interviews

This study involves qualitative semi-structured interviews. Semi-structured interviews allowed us to extend our exploration of emerging view points and gain further insights into the participants' workflow and perceptions. Furthermore, probing questions were used to better understand participant responses. Interviews were conducted within the participants' own work setting either in-person or through video conference and lasted anywhere from 30 to 60 minutes. Participants were advised on the purpose of the interview, including the use of data to generate a report on strategies used within the classrooms. We collected data by taking handwritten notes, and when appropriate interviews were audio recorded with participant consent (N = 27).

3.3 Participants

Participants were recruited using a snowball technique, and represented a range of design instructors (tenured, tenure-track, non-tenure track, adjunct, and teaching assistants), some instructors with administrative responsibilities (dean, chair, faculty facilitator etc.).

3.4 Data analysis

Audio files were reviewed using windows media player and transcribed into text manually. All text data were then coded using MAXQDA (VERBI Software, Berlin, Germany), a qualitative analysis software. The data were coded by the first author using thematic content analysis—similarities and difference in the themes were iteratively identified and revised [36].

4. Findings

This article examines the pressing issues in facilitating design classes along with the practices and strategies employed to resolve the issues. To situate the findings, the participants had taught many different design classes across majors and year in school, spanning the breadth of major project-based design classes taught within the fields of engineering, computer science, and human-computer interaction. Several instructors reported teaching multiple design classes over preceding few academic years. Table 1 describes the demographics of the participants who were included in the study.

In the interviews, five major themes were uncovered (see Fig. 1).

Table 1. Participant rank at institution. Affiliation indicates whether participants were employed by research or teaching focused institutions

Rank	N (affiliation)
Tenured	21 (14 research, 7 teaching)
Tenure-track	7 (research)
Visiting	1 (research)
Adjunct	6 (5 research, 1 teaching)
Teaching Assistant or Lecturer	3 (research)
Total	38 (27 faculty, 11 faculty with administrative responsibilities)

Below we describe each of these major themes (see Table 2) and their significance in detail.

4.1 Course structure and organization

As often noted in higher education research [37, 38], classroom size plays an important role in student learning. Faculty from research-focused institutions noted increasing classroom sizes and remained concerned with handling additional students in their classes. An instructor at a research-focused public institution concerned with increasing enrollment advised, ". . . *there needs to be a cap on it [enrollment], otherwise there may be an issue managing the teams, and physical space for the class*". His class size increased from 15 students to current high of 77 over the past few years. Another instructor at research-focused public institution had similar concerns with growing class room enrollment, stating, ". . . *now that the classes are growing it is more challenging to make a personal interaction with the students.*" Currently, single-section classes contained anywhere from 12–75 students, with a few exceptions where students in some classes exceeded 200.

As explored in other higher education contexts [39], where possible, very large design classes were split into small sections, but multi-section courses require additional instructors per section. Having multiple sections also introduces variations in student experiences, grades, and instructor engagement across the sections. One approach for controlling some of the variation was to use a core teaching team (typically one to three instructors) for

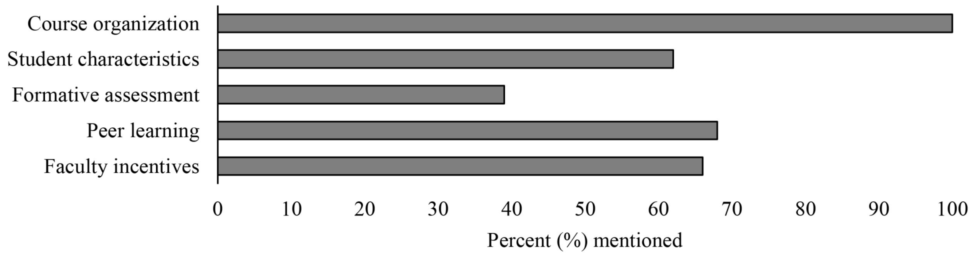

Fig. 1. The relative theme frequency in interviews (N_{total} = 38).

Table 2. Themes uncovered in the interviews along with prototypical quotes

Themes	Description	Prototypical Quotes
Course Organization	Issues related to structure and organization of the course due to increasing enrollment or lack of resources	". . . class split into sections . . . not every section received similar instructor engagement"
Student characteristics	Poor communication skills, risk-aversion, and narrow perspectives of incoming students	". . . biggest frustration is communication . . . they need more structure and constraints"
Formative Assessment	Difficulties in providing formative feedback valued by design students	". . . I am not providing enough detailed feedback . . . timely feedback"
Peer learning	Peer learning valued by instructors, but not formally implemented	". . . encourage diverse feedback . . . difficult to make it work"
Faculty incentives	Current incentive structure and lack of alignment with design faculty needs	". . . course is intensive . . . [incentives] limit my time and effort"

all the sections, with teaching assistants (TA) or other faculty instructors leading individual sections as mentors or coaches (also known as section-in-charge). The core teaching team handled lectures and overall course facilitation. Grading of final presentations or other similar major milestone assignments were completed either exclusively by the core teaching team or in collaboration with the section-in-charge. In-class experiments, individual assignment grades, and mentoring teams through projects remained in the domain of section-in-charge.

Other features of classroom instruction and program structure largely depended on whether the class spans one or more semesters, level of students catered to (e.g., freshman vs. senior), and resources available to the instructor (e.g., availability of mentors, clients, etc.).

4.2 Incoming students with poor communication skills and a risk-averse and narrow perspective

A majority of the instructors interviewed described three major issues with incoming students: poor communication skills, narrow or fixed perspective, and avoiding risk in their design process. Several instructors shared their frustration with students miscommunicating or not understanding faculty instruction, goals, deadlines etc., as has been noted in the literature from the perspective of the student [40]. Even within teams, faculty find that students poorly share information—often delegating work to each other and working as independent units within the team, oblivious to potential learning moments their team members encounter. An instructor, pointing out the low written communication skills of her students, described her predicament in assessing their design work, ". . . *their writing is so bad that I cannot gauge if they were learning correctly or just do not know how to communicate. My strategy is to have very little writing assignments (twice per semester) and more creative design or sketching assignments*." Strategies such as the one mentioned here seemed to be the trend, with many instructors focusing more on oral presentations and structured assignments in lieu of traditional written design reports.

Instructors note their struggles with design fixation in students [41] and especially conservative approaches that students often follow, as one instructor cited, ". . . *projects in early terms overly constraints and creates a design fixation. Students do not think out of the box*." Adding to this, instructors also face difficulties in structuring classes to encourage exploring design solution space. For example, an instructor concludes, ". . . *I have struggled to create a class where students take risks . . . they need more structure, more instruction. If I give them white space and ask them to create a design, none do or succeed.*"

Instructors were also concerned with decreasing student participation in classes [42, 43], many declaring "*students are not as engaged as they used to be*." Instructors often stated this reduced engagement was due to increasing use of personal digital devices in class, inability of the students to view the big picture, and difficulty creating and participating in a social community within the course.

4.3 The difficulties in formative assessment within design education

Participants were acutely aware of the importance of frequent and detailed feedback in supplementing and improving student performance and learning, as with any kind of instruction that involves students producing complex artifacts [44, 45]. Yet, this task was considered a major pain-point in their weekly workflow, largely due to the structure of incentives designed to engage and justify faculty effort in teaching (described in greater detail in section 4.5). Students often did not receive the type of feedback they seek, as one instructor notes: "*with so many teams, it takes a lot of time to give feedback, yet students want more detail, especially if it is criticism. There is not enough time to bolster my feedback and get it done within a week* [one week was considered timely]." Another instructor remarking on the current design education set up at their institution (large research focused private school) states: "*in the current set up, sadly, not every student receives the feedback they should be receiving . . . lot of them get sufficiently detailed feedback at the final capstone presentation—and find out why was everyone mean to them* [sic]". In view of the constraints, instructors chose to simplify assignments for grading or completely eliminated them. In other cases, instructors used team presentations to provide directive public feedback, hoping to passively impact other teams present in the class. Overall, the instructors recruited in this report remained largely concerned with feedback provision and perceived to be providing less or infrequent feedback to their students.

At one large research-focused public institution, there was little-to-no instructor feedback provided in freshman-level design classes (with enrollment of 300–350). Overwhelmed by the sheer number of teams, instructors at this institution resolved to focus on building teams and social skills at the freshman level, while still scaffolding design work in senior and capstone design classes. At another similar institution, resources and faculty focus were shifted to freshman design classes, where close to 8 instructors (1 faculty, 7 TAs) interacted weekly with students in person. An instructor at the institution concludes, "*I was able to wrangle the department to give me so many TAs* [at freshman level] . . . *at junior and senior level design classes there are not many* [TAs] *left and there is relatively little time where we meet specifically with the teams*". Utilizing TAs seems to be an obvious choice in reducing faculty burden. However, instructors who receive such support are often hesitant to involve TAs in deeply engaging roles. Faculty instead requested TAs to accomplish grading technical assignments, or rubric-based grading of low stakes deliverables. In only a few instances were TAs expected to provide "*lightweight design*" feedback—keeping teams on track and setting realistic expectations. As novice instructors, feedback provision at the level of detail and volume that students' desire, can be quite challenging. A student instructor tasked with providing presentation feedback at a large private research-focused university describes her experience: "*It is challenging to grade these presentations all day . . . I have mental blocks and do not provide enough feedback to my students*".

4.4 Peer reviews were positively viewed yet not formally implemented

Several instructors (18/38; 47%) seemed to be moving towards using some form of communal feedback methodology such as peer reviews—where peers play an active role in feedback provision—primarily as a countermeasure to decreasing use of formative feedback. Similar patterns exist in other coursework involving complex student artifacts [29, 46]. At the same time, it was evident from our interviews that instructors value the learning opportunities that such peer engagement present while also simultaneously improving student critiquing skills—skillsets which many believed students do not possess enough of today. The most preferred situation for use of peer reviews reported was in project presentations, where instructors often solicited feedback from students in class. Peers either provided written paper-based or oral feedback. Faculty cited the inconsistent participation, lack of student engagement (as one instructor points out, "*students did not care to provide feedback to all teams . . . they were simply preparing for their turn to present*"), and increased effort require to facilitate peer feedback as impediments in formalizing its use throughout the course. As an alternative, instructors used discussion boards within their classroom learning management systems, wikis, Facebook posts, or blogs, to generate peer discussion, supplementing the feedback as needed. This methodology allowed for easier facilitation compared to presentation feedback, while also making it easier to archive the feedback. However, as noted in presentation feedback, some teams did not receive enough feedback, and discussions often went off track, requiring some level of moderation from the instructors.

In support of increasing the use of peer reviews in classrooms, instructors noted several beneficial aspects. A few commonly-cited aspects include: improvement in quality of student work as a result of displaying their work to their peers, providing prudent and meaningful critique, handling ambiguous or critical feedback maturely, and the multi-perspective feedback that peer reviews generate. We found several instructors stating "*we know peer learning is beneficial*", "*it* [peer review] *is one thing we don't do enough of and I think it is important*", and "*I am not doing it* [peer review] *currently, but I wish I was.*" Peer reviews were often not formally implemented, i.e., as an integral pedagogical activity, primarily because of the concern instructors had with the effort needed to facilitate the process and with student participation. One of the two instructors who used a formal peer review process noted, "*It [peer review facilitation] took a lot of faculty time to set up and was a pain to use [software tool used]. Additionally, students think that grading is not their job but that of teachers.*" Another instructor who attempted to use peer reviews opined, "*It* [peer review] *is just a pain . . . no easy way to do this. The logistics are difficult whether we use LMS or a specific tool.*" Instructors also questioned the capacity of students to provide feedback that was helpful in the context of design-based learning, as one faculty member concludes, "*. . . I hesitate whether they* [students] *have capability to give feedback. It requires more expertise than they really have. So ability is a concern to me.*" Similar apprehensions were raised when other instructors alluded to the variability of peer projects and associated domain knowledge that is needed to provide valuable feedback.

4.5 The state of faculty incentives in design education

The practices and incentive structure differed most notably between research-focused and teaching-focused institutions, as has been generally noted in the literature [17, 47, 48]. Tenured and tenure-track faculty in research-focused institutions were only nominally expected to split their time equally between research, service, and teaching. In reality, most faculty mentioned spending most of their time on research, followed by service and teaching. A second-year tenure-track instructor in a large private research-focused institution justifies their focus on research over teaching, "*What is my incentive to be a good teacher? They are pretty minimal . . . some of my worst teachers have gone on to get a tenure . . . even the actual class instruction and feedback provision is affected because I want more grant proposals in, get more research money and prove myself.*"

Furthermore, in some institutions, instructors often received fewer teaching credits when classes were not typical lecture-type, making it difficult to justify spending more time and effort. The problems multiply in multi-section classes or classes with multiple co-instructors. In many institutions, faculty members were often unpaid (or received fewer teaching credits) for their time assisting or mentoring teams, making it difficult to ensure consistent feedback and mentoring across sections. Adjunct faculty—who were hired specifically to teach—were under different pressures when facilitating design-based classes. Most often, it was their availability on campus that stymied their efforts in consulting with students outside class and in feedback provision. Overall, low or non-existent faculty incentives in research-focused institutions have impacted the effort and time faculty spend on teaching—especially affecting resource-intensive courses such as design-focused project-based classes. A faculty member at a large research-focused private school concluded, "*. . . it is lack of time on* [sic] *faculty to keep up with what's out there* [new pedagogies, tools etc.] *. . . also very little incentive to make changes to the course*."

Not surprisingly, teaching-focused institutions had fewer issues with faculty incentives to teach. Most instructors at such institutions were expected to spend close to 60% of their time in teaching, with the rest spread out over research and service. Importantly, tenure requirements were directly tied to teacher ratings and student recommendations. Class sizes in the teaching-focused institutions were often in the range that was considered manageable by most faculty members—typically 8 teams of 3–4 students per team. Instructors in teaching institutions were interested in peer learning to enhance their current pedagogy. And like their peers in research-focused universities, were unaware of the new tools and practices that would help them implement peer learning activities in class.

5. Discussion

The experiences instructors shared were predominantly affected by their institution type: research focused vs. teaching focused. Research-focused institutions typically had larger enrollment compared to their teaching-focused counterparts and had faculty incentives that encouraged research over teaching. This combination of factors creates a challenging atmosphere for instructors teaching resource-intensive classes such as engineering design. Students in engineering design classes often work on ill-defined problems with a set of acceptable solutions—requiring more frequent and detailed feedback, and structured coaching.

As anticipated, class size directly impacted the quality of instruction and interactions instructors had with their students. A strategy we noted split the classroom into manageable sections. Dividing classes into multiple sections did seem to help manage larger enrollment and physical space limitations. It also allowed a more intimate setting for the instructors and their assigned students to gain a level of mutual empathy and understanding. However, splitting the class into multiple sections introduces variation in student experience—to an extent controlled by using standardized lecture material and/or splitting instructors into teaching team and mentoring team—and increases the resources required to run such classes, which is not available at many institutions.

Faculty incentives and their impact on the overall practice was a prominent and overarching theme that came from our interviews. It had a clear influence on every aspect of instructor and classroom practice, right down to the use of tools such as peer reviews. Nearly a decade ago, Todd and Magleby [17] described the state of faculty incentives for those involved in design-related teaching, expressing their concern with current evaluation of design faculty. In our work, we found no improvement in the incentive structure for faculty in research focused institutions—although we note several additional courses introduced in schools that utilize design-based learning. Teaching-focused institutions seemed to provide appropriate faculty incentives, which, combined with small classroom sizes, provided the necessary support for faculty to fully invest their time and effort in a design-based learning curriculum.

Increasing class sizes and reducing resources perceptibly impacts feedback provision. We noted several institutions where feedback, specifically directed to the unique needs of project teams, was rarely provided. Even without the helpful incentives, the effort-centric nature of grading and providing timely feedback to a large number of unique design problems and/or solutions that students develop further pushes faculty members to their practical limits. Providing timely feedback, when it matters most to the students, is often at odds with generating detailed and constructive feedback. Traditional design classrooms in arts and architecture augment instructor feedback with peer feedback [28]—in our sample of instructors, feedback from peers was largely limited to presentations. Decreasing feedback provision is an important issue, being widely discussed in the higher education community [49, 50] and requires a strategic evaluation of the resources needed and course structure design to enhance the feedback students receive.

Another issue noted by faculty was skills and the mindset of incoming students. Instructors found students do not possess the skills to handle failure, an integral part of design, in good spirits, and therefore avoided taking risks. Effective designers allude to the "fail fast and iterate often" philosophy—which seems difficult to implement in classrooms. Students are attuned to viewing failure as an expression of their performance and not as an integral part of design. In the end, failure by itself, only creates learning opportunities which need to be seized upon and utilized by the instructors to engage students in the design discourse, and to seek and iterate on diverse ideas. In addition to creating such learning moments, faculty often face difficulty in creating opportunities for iterative design and weaving-in diverse perspectives—often requiring a complete course redesign and increased scaffolding with open-ended feedback support.

5.1 Strategies to mitigate the challenges uncovered

As novice designers, it is expected that students do not fully possess the necessary design skills to explore the design space, frame the problem, and work towards an acceptable compromise—the burden of engaging students falls squarely on instruction and course design. Effective design education is complex and requires commitment from faculty, administrators, and institutions. Instructors in our report were intimately aware of this, but faced additional challenges associated with lack of incentives and resource constraints.

The challenges uncovered in this report provide an insight into the environment in which engineering design education currently resides. The importance of design education in engineering continues to motivate educators to pursue design-based curricula, but these educators then inevitably face daunting challenges in fulfilling their mission to often result in less than satisfactory outcomes. Below we highlight a few strategies that could mitigate some of the uncovered challenges.

Design education is expensive, requiring material and infrastructure support for product research and prototyping. This cost is further amplified by the iterative nature of the design process and the need to experiment with multiple ideas. While material and infrastructure support are essential, the lack of guidance and supervision from stretched-out mentors or instructors can negatively affect the usefulness of such investments. It is imperative that administration also invest in faculty support and development, creating an incentive structure that supports rather than hinders the design faculty in delving deeper into traditional and non-traditional learning environments that design education demands. Teaching credits based on lecture-style classrooms do not easily translate to design education, where instructors spend time on not only the creative and technical training of their students, but also on developing several personal attributes that enable students to manage working in and across teams in high-intensity creative environments. A comprehensive evaluation of faculty incentives and teaching credits needs to be undertaken to ensure the focus on design-based learning does not overlook the primary stakeholder of its success—instructors.

Increased faculty support can greatly improve instructor involvement and reduce several barriers that design-based learning classes face. However, individual faculty mentors can still only support a limited number of students if they are to develop meaningful working relationships with the teams and gain an understanding of the projects. We found that a class size of 30–40 was considered manageable by the instructors. With increasing enrollment in engineering classes, there exists a greater pressure for the administration to increase classroom sizes. This presents an interesting design challenge—how can you engage and provide support to more students who each require customized, detailed feedback and instructor support at every step of the design process? A simpler solution would be to increase the number of design faculty and maintain an acceptable student-to-teacher ratio. However, the training needed to be effective in design instruction and the current incentive structure make it difficult to attain this goal. An alternative opportunity exists in the use of outside mentors and industry partners, who can provide a unique perspective that engages students further and alleviates some of the instructor centric effort. However, outside mentors may not be cognizant of student schedules, and may require additional coordination effort from faculty members.

As described earlier, technology can play a major role in supporting education at scale. We found instructors were unaware of available software and were unsure on how to facilitate their use in class. This presents an opportunity for researchers and designers alike to develop tools and processes that enable effective design education within large classes with limited resources. We described one such strategy: use of digital peer review tools to utilize the diverse experiences of students in class in providing valuable feedback [15, 51]. There are several avenues for design instructors and researchers to evaluate such digital methods, and design curriculum and processes that fully utilize all available resources in class, helping manage the course scaling issues.

Strategies described above require a collaboration between the University administration and faculty members and will require increased advocacy for the need and benefit of supporting design-based engineering curriculum and its impact on student outcomes. It is important that the engineering design community undertake this challenge of *designing* a better future of engineering design education.

5.2 Study limitations and future work

The sampling choice utilized in the study limits generalizability to higher education, engineering design in the United States. Furthermore, the relatively small sample size, especially within institutional categories, may limit generalizability. Yet, interviews are primarily meant to raise awareness of issues and provide a strong basis for future exploration of this subject. Future work could involve surveys that could be applied more broadly to systematically explore and dig deeper into the themes uncovered here.

6. Conclusion

In this report, we examined the issues faculty faced in engineering design education, their strategies in feedback provision, and their opinion on peer-peer learning. As illustrated in the article, faculty incentives and practical resource limits play a major role in determining the level of engagement faculty have with their classes—most notably impacting feedback provision. Schools that prioritize research over teaching were associated with low faculty incentives to engage in effort-centric courses such as design-based classes. While we found that faculty members valued peer-peer learning, many faculty were concerned with low student design abilities and critiquing skills.

This study provides insights into the current statues of engineering design education, raising awareness of the need for the design community to rally together in improving the conditions surrounding design education and the impact that design-based learning can have in an engineering student's academic and professional career.

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