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Re-contextualizing Civil Engineering Education: A Systematic Review of the Literature

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Abstract

Emphasizing socio-political context in undergraduate engineering courses is a complex challenge for accredited American engineering programs as they strive to pivot towards a more equitable future. Teaching engineering problem solving by isolating the technical perspective is the dominant culture, and change has been slow and insufficient. Looking at the complex human circumstances in which engineered systems are situated has significant, and sometimes life saving, benefits. On the contrary, the common de-contextualized approach to teaching engineering has been shown to have significant impacts on how students behave as future engineers. Furthermore, eurocentric teaching practices have been documented as a contributor to the lack of gender and ethinic diversity in engineering. Re-contextualizing civil engineering courses has shown to increase students' motivation, sense of social responsibility, and agency.

The ASCE Code of Ethics states that “Engineers … first and foremost, protect the health, safety, and welfare of the public,” a notion that was first added to the code in 1977. In recent years, some civil and environmental engineering (CEE) faculty members and programs have responded to this ethical imperative by re-contextualizing civil engineering education in relation to the communities (“the public”) the civil engineer is ethically obligated to protect and serve. To determine the extent of these efforts to re-introduce socio-technical context in CEE curricula, we are conducting a systematic review of the published literature. The objectives of this research are to document, synthesize, and amplify the work of these scholars and to encourage the community of CEE faculty to re-contextualize the knowledge and skills taught in the CEE curriculum. This paper describes the methodology, including search terms and sources examined, reports the preliminary results of the review, and synthesizes the preliminary findings. Future work will propose strategies and structures that could be adapted and employed by civil engineering faculty throughout the U.S. to 1) engage and retain students from groups that historically have been excluded from CEE and 2) better educate CEE students to engineer a more equitable and just future.

Introduction

Engineering for the civil sector is inherently sociotechnical [1]. Engineers are highly trained professionals who can design solutions to human problems [2]; thus it is important to educate engineers using effective and equitable strategies that foster an understanding of the people and communities affected by engineered systems. Understanding that engineering is inherently a socio-technical process allows an engineer to think not only about creating solutions that work scientifically, but about solutions that promote equity and justice for *people* [3].

Civil engineers have improved the lives of millions of people throughout the world by developing shelter, water, sanitation, and transportation. However, throughout American history, civil engineers also have been complicit with discriminatory government policies, such as redlining and gentrification, that have disenfranchised and harmed people of color (e.g., see [4]–[7]). The inequities that literally were built into our neighborhoods with these policies persist, and the engineering education system still contributes to these injustices by teaching engineering out of context ("de-contextualizing" concepts), effectively separating projects from the community.

This de-contextualization of infrastructure education has documented negative impacts on engineering students and their development as well as on the communities in which they will eventually work. Contrary to many engineering programs' stated goals, and in direct conflict with engineering codes of ethics, Cech documented the *decline* of student concern for public welfare over the course of the students' engineering education (surveyed each spring from first year to 18 months post-graduation) [8]. Further, current ABET Criterion 3 requires that students be able to design and make judgments in context (Student Outcomes 2 and 4) [9].

The concern with infrastructure as inherently a socio-technical system overlaps significantly with the concern with diversity, equity, and inclusion (DEI) in engineering education. Diversity, equity, and inclusion are three interlinked concepts discussed in a variety of manners. We find helpful the National Academy of Engineering's descriptions of embracing diversity, seeking equity, and driving inclusion as [10]:

- Embracing diversity—recognizing that talent is broadly distributed in society and that unique perspectives drive innovation, appreciating the broad dimensions of identity, and confronting historic barriers and contemporary hurdles that shape and distort participation and success in engineering education and the profession;
- Seeking equity—removing barriers, promoting access, and supporting positive working, convening, and social environments; and
- Driving inclusion—celebrating multiple approaches and points of view to develop optimal solutions, building capacity to strengthen the engineering profession, and building and encouraging relationships in … working, convening, and social environments.

Policies that influence the civil engineering profession have been shifting to encourage consideration of DEI and the importance of context [11]. Accreditation agencies are highlighting the importance of DEI and funding agencies are investing in revolutionary practices. Moving beyond encouraging equal participation, in 2016 ABET added a new criterion for civil engineering curricula to define an engineering team as being "… more than one person working toward a common goal and should include individuals of diverse backgrounds, skills, or

perspectives" [12]. Currently, in spring of 2022, ABET is requesting comments on adding proposed Criterion 5c: "a professional education component that is consistent with the institution's mission and the program educational objectives and promotes diversity, equity, and inclusion awareness for career success" and adding to Criterion 6 the language "The program faculty must demonstrate awareness and abilities appropriate to providing an equitable and inclusive environment for its students, and knowledge of appropriate institutional policies on diversity, equity, and inclusion" [13]. Furthermore, regional accreditation bodies such as the Higher Learning Commission require universities to demonstrate that their "processes and activities demonstrate inclusive and equitable treatment of diverse populations" [14]. The integration of new practices and cultural change in engineering education come at a cost, however. Faculty members must support the changes and institutional resources must be provided for initiatives to be successful for an extended period of time.

Retaining students' interests and supporting their long-term career development is a culturally dependent process. Diverse students have a diverse set of backgrounds, interests, and expectations [15]. In particular, racially-minoritized students face distinct equity challenges [16]. Such challenges and the corresponding inequities exist both in CEE education and in the public infrastructure that is the tangible output of CEE education. Malcom-Piqueux characterizes milestones in the history of US public education in two dimensions: race-neutral vs. race-conscious; and inclusion vs. exclusion [16].

Consideration of CEE education in this framework gives rise to two lessons for future civil engineers. First, although race-conscious exclusion has become less common today in the United States, decisions made decades ago have quite literally cast systemic racism in stone, concrete, steel, and the other building materials of our public infrastructure. Second, race-neutral exclusion continues today in public infrastructure decisions; environmental justice scholars provide recent evidence of its destructive impacts. Currently, non-white communities often experience poorer air and water quality, higher noise levels, and inferior access to transportation when compared with predominantly white neighborhoods [17]. Our students must learn these two lessons, and others.

A large number of publications exist in the area of DEI and engineering education. These publications cover a broad range of sub-topics, including analysis of data trends, calls to action, descriptions of best practices, opinion pieces, case studies, and appropriate and effective pedagogy. In the last 10 years, some CEE faculty members and programs have re-introduced socio-technical context by re-contextualizing CEE education in relation to the communities ("the public"), which we, as engineers, and our students, as future engineers, are ethically obligated to protect and serve. To determine the extent of these efforts, this paper introduces a systematic review of the published literature. For this preliminary literature review, we have focused on

papers that discuss the implementation of interventions – that is, course or curricular changes that were *actually made*.

Methods

Systematic literature reviews have been used to assess the scholarly landscape in a wide variety of fields. More recently, they have begun to be used in engineering education (e.g. [18], [19], [20]), and several scholars have published suggestions for how the methodology can be applied (e.g. [21]; [22]). Borrego et al. noted that "more reviews of existing work across multiple fields, conducted more systematically, will help advance the field of engineering education by lowering barriers for both researchers and practitioners to access relevant findings, by enabling more objective critique of past efforts, by identifying gaps, and by proposing fruitful directions for research" [21]. Torres-Carrión et al. suggest that, in conducting such a review, scholars move from their own personal state of knowledge about the problem to a more "universal state" [22]

We have followed loosely the steps in conducting a systematic literature review as outlined by Borrego et al. [21].

1) *Deciding to do a systematic review*: In preliminary reviews, we did not identify any existing literature review articles focused on DEIJ in infrastructure education. Given the increasing interest in the subject, this seems like an appropriate time to assess the state of things.
2) *Identifying scope and research questions*: The research team developed four initial research questions to guide the literature review:
    - How is DEI incorporated into CE curricula?
    - What is its impact on student learning?
    - What is its impact on student perceptions of identity/belonging?
    - Which efforts are most successful (i.e. seem to have real impacts)?
3) *Defining Inclusion Criteria*: The initial inclusion criteria for our search were that literature must:
    - be published in refereed journal articles, conference proceedings, book chapters, or professional literature;
    - discuss undergraduate or graduate courses, curricula, or institutions; and
    - be relevant to traditional civil and environmental engineering curricula.
4) *Finding and cataloging sources*: We searched databases using OneSearch as well as databases from ASEE and ASCE. Through OneSearch we accessed databases such as ERIC, IEEExplore, and ScienceDirect. The third inclusion criterion was loosely applied considering many ideas from other areas of engineering could be reframed to fit civil engineering quite easily. Each source was reviewed by at least two team members with these filters and thus a list of valid literature was formed. Table 1 lists the search terms used, and the numbers and types of papers resulting are discussed below.

5) *Critique and Appraisal*: We are in the process of determining how to assess the suitability of each article given the wide variety of approaches, methods, and goals of the articles.
6) *Synthesis*: We reviewed paper titles and abstracts again to group them into categories, as discussed below. Within the broader inclusion criteria, we focused on a subset of papers "that examine specific curricular actions that highlight DEI in engineering." At least two team members read and coded each article in this subset using rapid, descriptive coding for this preliminary work. Table 2 lists the codes developed. Each code was defined and reviewed by at least two team members. Table 3 shows examples of these codes.

Preliminary Results

Our preliminary search yielded 107 articles from 47 different sources. Table 4 lists the sources for these articles as well as the number of articles from each source. About two-thirds of the sources are journals and just over a quarter are conference proceedings; however, when looking at the number of articles, the gap narrows, with approximately half from journals and almost 45% from conference proceedings. By far the most common source for work in this area is the *IEEE Frontiers in Education Conference (FIE)* with 18, followed by the *ASEE Annual Conference* and the *IEEE Global Engineering Education Conference* with 8 each. The fourth most common source is the American Society of Civil Engineers' *Journal of Professional Issues in Engineering Education and Practice*, which is now the *Journal of Civil Engineering Education*. Table 4 also lists the subset of papers that were used for the analysis. This subset comprises 31 articles from 17 different sources from the years 1996 to 2021. A full list of these articles is available at https://www.zotero.org/groups/4681078/cit-e_public. Almost half of these articles (15) appeared in the proceedings of either *FIE* or the *ASEE Annual Conference*, and as with the full set of articles, about three quarters were published from 2017 to the present.

Figure 1 shows the number of articles by year of publication. The oldest article we found was published in 1996, but the majority of articles (almost 75%) were published from 2017 to the present. The subset we focus on in this paper comprises 31 articles from 17 different sources (Table 4), from the years 1996 to 2021. Almost half of these articles (15) appeared in the proceedings of either *FIE* or the *ASEE Annual Conference*, and as with the full set of articles, about three quarters were published from 2017 to the present.

Our preliminary coding identified 191 instances of the codes listed in Table 2. Of these, 79 were categorized as "specific DEI topics," 66 are grouped as "curricular actions," 23 are related to "reform areas," and 23 fall into "outcomes." The most commonly assigned codes are

- Sociotechnical (21),
- Societal impacts (14),
- Curricular changes for sociotechnical context (13), and
- Students' backgrounds/experiences (13).

Table 1. Search terms

Civil engineering	Environmental engineering	Instruction
Construction	Equity	Justice/ “Social justice”
Courses	Gender/Feminism	Racism/Race
Curriculum/a	Geotechnical	Sociotechnical context
Diversity	Identity	Structural engineering
Education	Inclusion	Transportation
Engineering education	Infrastructure	

Table 2. Initial code set

Curricular Actions	**Reform Areas**	**Specific DEI Topics**	**Outcomes**
Use of technology	Engineering ethics	Community based engineering	DEI literacy
Course modules	Engineering design	Human centered design	Diverse student retention
Collaborative work	Image of engineering	Non-western/culturally diverse examples	Enhanced engineering identity
Comprehensive problems	Civil engineering	Unpacking privilege	
New courses	Geotechnical engineering	Sociotechnical	
Classroom/student feedback	Water resources engineering	Societal impacts	
Curricular changes for diversity or inclusion	Introductory courses	Equitable design	
Curricular changes for sociotechnical context		Engineering history	
Non-technical topics		Varying perspectives	
Community based projects		Technological elitism (engineers know best)	
Project-based learning		Neutrality myth	
Students' backgrounds/experiences		Fighting structural inequality	
Faculty feedback/perspectives			
Student feedback/perspectives			

Table 3. Examples of code definitions

Code	**Definition**
Curricular changes for diversity or inclusion	Changes to a course to emphasize diversity/inclusion of students
Curricular changes for socio-technical context	Changes to technical courses, or creation of new courses, that teach engineers about the social context of their future jobs
Engineering ethics	Teaching about the ethical responsibilities of engineers in practice
Image of engineering	The image of engineering that institutions present to their students (what do students think of when they hear the word engineer)
Socio-technical	Teaching technical engineering topics through a social lens
Equitable design	Focuses on considerations of equity in the design process
DEI literacy	Increasing students' awareness of DEI in the engineering practice (i.e. its importance, how to identify inequities, things to be mindful of when working on projects with various stakeholders)
Diverse student retention	Institutional efforts to better retain students (especially minority students) in engineering programs (e.g. empowering them, increasing their engineering identity, providing mentorship, etc)

Engineering ethics, non-technical topics, DEI literacy, and enhanced engineering identity were the next most common. The first three of these (sociotechnical, societal impacts, and curricular changes for sociotechnical context) are distributed among 18 of the articles. Within these articles, the most frequent codes are students' backgrounds/experiences and engineering ethics. Examining the set of sources for the articles, both the initial set and smaller subset, suggests that work to re-contextualize knowledge and skills in civil engineering education has been shared in both journal publications and conference proceedings. As noted above, the most common sources for articles of this type are the proceedings of the *Frontiers in Education Conference* and the *American Society for Engineering Education Conference.* These venues provide opportunities for dissemination as well as discussion, building community around these issues.

Discussion

There is momentum for integrating sociotechnical context into the civil engineering curriculum. The majority of articles in both the complete and subsets were published recently – between 2017 and 2021. We might have expected an uptick in such work in the aftermath of the death of George Floyd in 2020 and the resulting consciousness raising in the general public, and we see such a result in 2021. But looking at the years immediately prior, the trend had already begun.

Table 4. Sources and number of articles included in the preliminary analysis

Source	**Number**	**Subset**
IEEE Frontiers in Education Conference	18	7
ASEE Annual Conference	8	6
IEEE Global Engineering Education Conference	8	
Journal of Professional Issues in Engineering Education and Practice / Journal of Civil Engineering Education [*/]	8	3
Book	5	1
European Journal of Engineering Education	5	3
International Journal of Engineering Education	4	
World Engineering Education Forum	4	1
Environmental Engineering Science	3	
Journal of Engineering Education	3	
Journal of Management in Engineering	3	
Canadian Journal of Science Mathematics and Technology Education	2	1
International Journal of Engineering, Social Justice, and Peace	2	1
Journal of Diversity in Higher Education	2	
One paper each from: *Baltic Region Seminar on Engineering Education, Seminar Proceedings; Advances in Engineering Education; Bulletin of the Ecological Society of America; Chemical Engineering Education; CoNECD - The Collaborative Network for Engineering and Computing Diversity; Construction Research Congress;* *Digital Creativity; Education, Citizenship and Social Justice; IEEE International Conference on Professional Communication; IEEE International Geoscience and Remote Sensing Symposium; IEEE International Systems Conference* *IFAC World Congress; International Conference on Interactive Collaborative Learning; International Conference on Software and Information Engineering; International Journal of Education in Mathematics, Science and Technology; International Journal of Engineering Pedagogy; Journal of Civil Engineering Education*[*]*; Journal of College Student Retention: Research, Theory & Practice; Journal of Computing in Science and Engineering; Journal of Women and Minorities in Science and Engineering; Leadership and Management in Engineering; MPDI Social Sciences Journal; Procedia Manufacturing; Proceedings of the Institution of Civil Engineers; Proceedings of the National Academy of Sciences; Public Library of Science; Research in Higher Education Science and Engineering Ethics; Sustainability; Technological Forecasting and Social Change; TR News Magazine; U. Maryland Research Report; Urban Education*		9
Total	107	31

[*] The *Journal of Professional Issues in Engineering Education and Practice* became the *Journal of Civil Engineering Education* in 2020. If we combine these, there are 8 total articles.

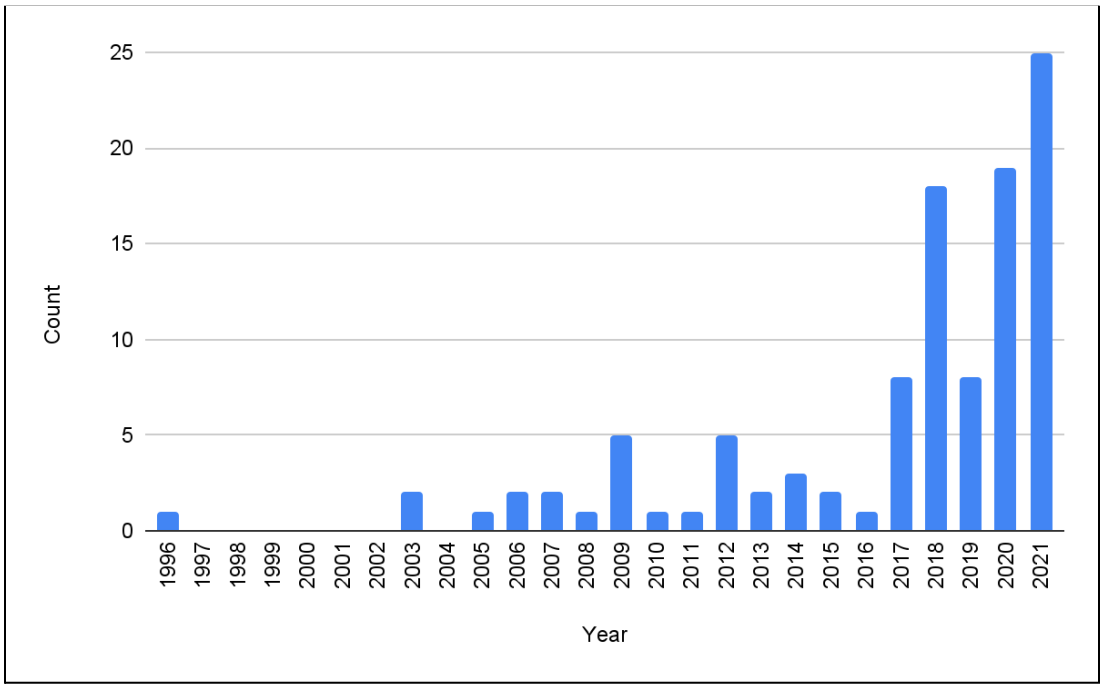

Figure 1. Articles published by year

Paradoxically, the academic literature reviewed in this paper can lag years [23] behind the accomplishments of the scholars who are doing great work at institutions across the nation. At the same time, this literature foreshadows translatable blueprints for a more equitable culture in engineering education that engages with a more diverse set of cultural contexts [15], [24]. Student populations dynamically change with time, and the instructors of courses have a responsibility to keep up. The pragmatic authors of papers in the DEI field will be clear about their published work providing only a few of the many strategies which should be further developed to solve our contextualization and equity issues in civil engineering education [25]. Furthermore, even beyond the publication delay, it can take a substantial amount of time for a research paper to be found and utilized by a reader with the agency to change a course or university policy. In approximately four years, an engineering student can shift from being a college freshman to being a critical middle actor in infrastructure systems who has the agency to create change in sociotechnical systems [26]. This literature review is a step towards analyzing the current available strategies, and we will develop it further with a specific focus to better understand social justice and anti-racism work given the current socio-political context in America.

Engineering educators have undertaken efforts to address issues at both the curriculum and course levels. For example, several papers describe work to (re)design courses and curricula at Rowan University (e.g. [25]) and the University of San Diego (e.g. [24], [27]–[32]). At Rowan University, the Civil and Environmental Engineering Department undertook a multi-year effort

to increase diversity in the department [25]. They employed a variety of approaches, including curricular change designed to incorporate sociotechnical context. The University of San Diego's efforts at "Developing Changemaking Engineers" cross engineering disciplinary boundaries and have inspired curricular change that "requires an enhanced curriculum with a focus on student teamwork, a greater consideration of social context, improved communication with diverse constituents, and reflection on an ethical understanding of their decisions and solutions" [28]. Some of the efforts at both of these institutions have been supported by large National Science Foundation grants, which can remove barriers such as financial resourcing and incentives for faculty promotion and tenure that can hinder the implementation of this type of work.

In addition to these large-scale institutional efforts, faculty members at these and other institutions have designed and implemented changes to contextualize material in individual courses. Olson and Acero, for example, describe the mixed success of their efforts to integrate "changemaking" into an operations research course [31]. Farrell et al. integrated DEI focused case studies into an environmental engineering course [25]. Judge describes implementing case studies highlighting sociotechnical issues in environmental, geotechnical, and transportation courses [33], and Hoople et al. detail an interdisciplinary course focused on energy [32]. Larsen and Gärdebo ask students to apply a social justice lens to infrastructure planning [34]. Several authors describe interventions in Statics courses (e.g. [24], [35]). Chen and Przestrzelski apply a different lens in introducing social justice into a statics course through looking at gerrymandering and centroids; while this isn't a typical civil engineering context, it does reinforce the sociotechnical nature of problems [27]. Finally, Riley re-imagined and implemented liberative pedagogies in a thermodynamics course as described in her seminal 2003 article, with ideas that formed the basis for and inspired much subsequent work in transforming technical courses into *socio*technical courses [36].

Teaching with a sociotechnical context inherently incorporates ethics and engages engineers to think empathetically [37]. Several articles in our subset focus on engineering ethics education. Since ethics courses fundamentally focus on context, this is not necessarily "re-contextualization." However, engineering ethics educators are exploring how their work can have greater impacts, often through case studies and engaging students in macro-ethics that go beyond individual dilemmas, and these methods can be employed to shift courses from "purely technical" to "sociotechnical." For example, Rottman and Reeve introduced and assessed the efficacy of equity-focused case studies in an ethics course [38]. Campbell et al. introduce engineering students to care ethics [39], while Douglas and Holbrook focus on ethics as social justice [40]. In these ethics courses as well as in many of the other courses described in this literature review (e.g. [28], [41]), reflection forms an important component of student learning.

The authors cited above include some common elements in incorporating a sociotechnical approach in their courses. Summarizing from the articles cited in the preceding paragraphs, case

studies frequently were integrated to embed technical learning outcomes within a social context. Project-centered learning, often with an element of community engagement, also contributed to centering technical knowledge within the larger socio-technical problem the students were trying to solve. These types of learning activities naturally lead to discussions of ethical implications and considerations of equity and justice. Reflection activities also helped students to process experiences that sometimes go beyond what they might have anticipated in an engineering class. Authors also noted that scaffolding for students is important – understanding the experience students have had engaging with issues of equity and justice and structuring courses so the level of complexity increases during each course and, for larger efforts, throughout the curriculum.

Integrating these elements can be difficult, though, for faculty members who largely have been trained in traditional technically-focused programs [28]. In addition, students can be resistant to the complexities of a sociotechnical approach when they are expecting to apply math and science concepts in straightforward contexts. The scaffolding described above, coupled with guided reflection, can engage students in "buying in" to these approaches. Further, several of the efforts we reviewed articulated learning theories that framed their efforts, providing a theoretical basis and structure as well as guidance for assessment of these efforts.

As noted above, many of the efforts we reviewed were supported by funding agencies, with significant investment by the National Science Foundation. This funding brings legitimacy to what might be seen as efforts to "soften" engineering education, and it brings real resources in terms of funding for faculty time and student support. It also supports the very real difficulties in coordinating efforts across courses and throughout a curriculum. Several of the authors have anticipated the challenge of sustaining enthusiasm and resources once these large grants end (e.g, [24]) Also, because these efforts have such substantial resources behind them, the approaches are not necessarily transferable to other institutions without such external funding. However, if these institutions are successful in creating lasting change in their own institutions and sharing frameworks that can be applied in other institutional contexts, the culture will eventually change and these efforts will become normalized within the resources available.

Conclusion

Following a systematic review process, we identified 107 papers that address DEI in CEE education. Upon further review, we examined more closely 31 of these articles that examine specific curricular actions that highlight DEI in engineering. Although the earliest of these articles was published in 1996, there have been consistently one or two articles per year in the 2000s. More importantly, there has been a marked increase in the publication rate since 2017. The most common venues for this work are the *Frontiers in Education Conference* and the *American Society for Engineering Education Conference*. Based on our coding, the most common concepts addressed in these articles are variations of sociotechnical context.

These results show that there is a robust conversation happening about these issues in at least two professional venues – the *FIE* and *ASEE* conferences. Further, readers can see other venues – specific conferences, journals, and other outlets – that may, perhaps, be unexpected places to look for relevant literature. Common elements in many of the articles we reviewed include the use of case studies as a tool for contextualization and implementation of reflective practices. Engineering educators can find in these articles examples of approaches that have been implemented and assessed. Many of these efforts are supported by grant funding, suggesting that external recognition and resources provide an important catalyst for change.

As noted earlier, the results presented in this paper are preliminary. As the team continues its review of articles, our coding structure will expand and become more robust, allowing us to draw deeper conclusions and ultimately both amplify existing efforts and identify gaps that can be filled in the coming years.

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