Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #48939

More than Box-ticking: Accreditation and the Integration of Sustainability into Canadian Engineering Education

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Accreditation and the Integration of Sustainability into Canadian Engineering Education

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Abstract

In an interconnected and rapidly changing global economy and climate, engineers need both technical skills and strong systems and critical thinking skills to understand the complex social and environmental context of their work. Many educators, organizations and accreditation boards have recognized the importance of integrating sustainability into engineering education, but for sustainability-focused education to be meaningful, it needs to be integrated thoughtfully into curricula, using evidence-based pedagogies. Accreditation boards play an important role in shaping engineering education, including by requiring integration of sustainability into the curriculum. However, outcomes of sustainability-focused accreditation requirements (both in terms of how universities meet them and ultimately the effect on student learning) have not been thoroughly evaluated.

In this paper, we examine the impact of sustainability-focused accreditation requirements on resulting engineering undergraduate curricula, student experience and learning outcomes, through student surveys and a systematic analysis of online course descriptions and accreditation materials. We focus primarily on the Canadian context as a case study, but also discuss ABET, Engineers Australia, and other international frameworks. As required by all accreditation systems, all surveyed engineering programs included sustainability education as part of the core, required curriculum. However, we find that departmental culture and discipline-specific perceptions may play a larger role than accreditation requirements in shaping and promoting sustainability education. As a result, curricula (and student experience) varies significantly between programs and between universities. We further discuss existing challenges faced by students and instructors in this context, and how these challenges relate to accreditation.

1 Introduction

It is difficult to overstate the effects of unsustainable human activities and development on the Earths environmental systems. Researchers have developed a framework of nine planetary systems that are critical in maintaining a “safe operating space for humanity”, six of which have already been perturbed past safe boundaries, threatening the stability of the Earth’s biosphere[1]. More regionally, the effects of this are becoming increasingly concrete, with more frequent extreme weather events, for example, causing billions of dollars in damage[2].

Sustainable development (developing systems and designing solutions that meet present needs without contributing to critical environmental issues) is a key part of addressing these problems, but to develop solutions that are meaningfully socially, economically and environmentally sustainable, engineers need not only technical skills, but also to understand the complex social and environmental context of their work and to practice engineering in a way that centers these considerations. Sustainability education in engineering aims to teach engineers the skills, knowledge and mindsets required for them to practice sustainable development. While there is growing consensus among professional engineering organizations, accreditation boards, and researchers that more effective sustainability education in engineering is important, different researchers, organizations and individuals have varying perspectives on what exactly meaningful sustainability education entails, with several frameworks proposed to categorize and define sustainability education.

Beyond defining sustainability education and identifying effective pedagogical strategies, practically improving sustainability education requires for these changes to actually be implemented in universities. As Borrego and Henderson describe in their work on changing higher education in STEM[3,4], there are several 'change strategies' that can be used to improve engineering education, from spreading awareness of different pedagogies to more policy-based approaches. Accreditation exemplifies a policy-based approach to shaping education, but as Borrego and Henderson argue, this approach has its limits, and "should not be considered as a cutting-edge change strategy" suited instead to "bringing a large number of programs up to a minimum standard"[4]. In recent years, many accreditation programs have begun to require for engineering programs to cover topics in sustainability. However, the outcomes and limitations of accreditation-based strategies in shaping sustainability education have not been thoroughly evaluated.

We examine the impacts of sustainability-focused accreditation requirements on curricula, student experience and learning outcomes, to better understand where this change strategy has been effective, and where other strategies may be required to further improve the quality of sustainability education in engineering. Research questions are as follows:

- RQ1: How are sustainability-oriented accreditation goals translated into concrete criteria and procedures, and how do these goals, criteria and procedures differ between international counterparts, and relate to UN Sustainable Development Goals and the Engineering for One Planet (EOP) framework?
- RQ2: How are universities meeting these requirements, and to what degree do existing sustainability courses in engineering cover the EOP learning objectives?
- RQ3: What is the student experience of sustainability-focused education in engineering (their opinions of accreditation requirements, their experience in sustainability-focused classes, and their learning outcomes)?

Our work employs mixed methods of data collection and analysis, including student surveys and a systematic analysis of online course descriptions and accreditation materials. We focus primarily on the Canadian context as a case study, but also compare Canadian accreditation with different international frameworks.

2 Background and Prior Work

2.1 Engineering Accreditation

Accreditation of engineering education programs is the process through which educational institutions, or specific programs, fulfill a set of standards set by an accreditation body. It can, on one hand, be seen as a form of consumer protection for students, a process that ensures that the education they receive achieves a minimum level of quality (as defined by the institutions governing accreditation). In many countries, including Canada and the United States, engineering is a regulated profession, and graduation from an accredited engineering program is a requirement for a student to become a licensed engineer. Accreditation of engineering education is therefore closely intertwined with regulation of the engineering profession, and another purpose of accreditation is to verify whether graduates of a given institution and program take on the disciplinary behaviors and content knowledge required by engineering registration boards, or other professional licensing groups. In either case, accreditation plays an important role in shaping educational standards and practices, and in defining or enforcing ideas of disciplinary identity and responsibility.

2.1.1 Evaluation of Accreditation Strategies

Over the years, international agreements between regional accreditation organizations has sought to build cooperation and coherence[5,6]. However, accreditation organizations still differ in terms of the specific accreditation criteria, and the concrete policies and procedures they use to evaluate them. These differences have an impact. Accreditation is one means through which evidence-based teaching strategies can be encouraged, as discussed by Borego, Henderson et al[3,4] in their work on strategies for increasing evidence-based pegagogies in undergraduate STEM education. In a multiyear study of the impact of ABET criteria revisions, for example, Prados et al.[7] report significant differences in teaching methods and learning outcomes as a result of a revision to the ABET criteria. Existing work has also discussed similar changes in the Canadian context[8,5], although this work has focused on institutional decision making rather than the student experience or learning outcomes. As Henderson et al.[4] point out however, based on a review of existing literature, “top-down” policy-based interventions mandating single-policy solutions are among the least effective methods for influencing meaningful positive instructional change, and few previous studies evaluate the impacts of these policy interventions on student learning.

2.1.2 Evaluation of Sustainability-related Accreditation Policy

Internationally, professional engineering bodies and accreditation systems have increasingly incorporated sustainability-based criteria into their guidelines and assessments[9,10]. In[10] for example, Byrne outlines sustainability-related imperatives across several accreditation bodies (including ABET, Engineers Ireland, Engineers Australia and EUR-ACE) based on a survey of accreditation documents and literature, showing substantial dedication to sustainability imperatives internationally. Existing work on the impacts of specific sustainability-related accreditation policies and how they translate into curriculum changes and learning outcomes has been limited however. In[11] and[12], Staniškis and Katiliūtė discuss the QUESTE-SI accreditation system, through which several European universities have been evaluated on the quality of sustainability education. However the focus of this work was on presenting the system and its principles rather than on a discussion of the effects of its implementation. In[13], Byrne et al. discuss challenges associated with sustainability-specific accreditation, based workshop discussions between engineering academics. This work discusses themes in educator perspectives on key sustainability competencies and on the role accreditation guidelines play in this context, but as workshop attendees were international it does not discuss specific accreditation strategy, and does not include any quantitative analysis.

2.2 Sustainable Development Competencies

Internationally, many accreditation boards have shifted towards an outcomes-based model, through which programs and student learning are evaluated based on student learning outcomes (an international shift coordinated in part through the International Engineering Alliance's Washington Accord). Using an outcomes-based approach, accreditation bodies shape engineering curricula (and ultimately student attitudes and capabilities) by defining specific objectives relating to sustainability. Specific accreditation criteria and learning objectives are outlined in Section 4.1.1, but similar frameworks categorizing and defining sustainable development competencies have also been proposed in academic work[14,15,16,17,18,19,20] and by other professional organizations and initiatives[21,22]. For example, in the framework put forward by Lozano et al.[14], twelve categories of relevant competences were identified based on a literature review of existing work, including for example, 'personal involvement' and 'tolerance for ambiguity'.

In 2020, the Engineering One Planet framework[22] was co-developed through roundtables and consultations with hundreds of experts from industry, academia, professional associations, nonprofits, and policy spaces, to define critical sustainability focused learning outcomes. In the EOP framework, concrete learning objectives (for example, *"Compare materials properties and performance aligned with end-use application"*). are grouped under nine categories: 'systems thinking', 'critical thinking', 'sustainable business', 'social responsibility', 'communication and teamwork', 'environmental literacy', 'materials selection', 'environmental impact assessment' and 'design'.

As discussed in the EOP framework documents, sustainable development skills are relevant to all UN Sustainable Development Goals[21], but in particular Goal #12: *'Ensure sustainable consumption and production patterns'*. EOP competencies and UN SDGs do not map to each other directly however; EOP competencies are skills, perspectives and understandings that can can be applied in many different contexts or disciplines, whereas UN SDGs relate closely to specific subject areas and content (for example clean water and sanitation) but can be addressed using many different strategies.

EOP competencies align more closely with outcome-based accreditation criteria, in that they all aim to defining key sustainability learning objectives that apply across engineering disciplines, but the scope of the EOP framework and accreditation criteria are slightly different. The EOP framework is significantly more detailed and concrete, and is intended to be used as a tool by educators and researchers during curriculum development and evaluation[23,24,25,26], providing a consistent and thorough categorization of different sustainability-related learning outcomes in the context of engineering. In other words, the EOP framework can be used to support and evaluate various strategies for improving higher-level education (all eight of the change strategies that Henderson et al.[4] define for facilitating change in STEM education, for example), whereas accreditation criteria are designed to define a minimum required level of sustainability education in a policy context (in Henderson et al.'s formulation[4], the 'Enacting' approach).

3 Methods and Context

3.1 Methodology and Research Design

In this study, we take an interpretive approach, since our research questions largely concern individual perspectives and beliefs and how they influence and are influenced by university curricula and the policies of accreditation boards.

(RQ1) We begin with a survey of available accreditation materials and requirements from three accreditation boards, to better understand these policies and how they compare to each other in terms of intent and implementation.

(RQ2) We survey curriculum and course information across ten North American universities, and quantify the types and amounts of sustainability-related coursework across disciplines, accreditation systems and universities. We discuss the strategies taken by different universities and program to meet accreditation requirements and develop effective sustainability education.

(RQ3) For one university, we evaluate the impact of sustainability curriculum design on student experiences and learning outcomes through a survey of the undergraduate engineering student population.

3.2 Data Collection and Analysis

3.2.1 Accreditation and Curriculum Materials

Accreditation requirements, history, and assessment procedures were sourced from the websites of three national accreditation organizations: Engineers Canada, ABET, Engineers Australia, as well as from the International Engineering Alliance. Documents, website pages and white papers dealing with sustainability education in engineering were analyzed through keyword coding and using thematic analysis to summarize goals and perspectives on sustainability literacy and education.

Program curricula were sourced from online program requirement outlines and course catalogs for ten universities: the five largest Canadian universities and five largest American universities. We include the ten largest Canadian universities and ten largest American universities, allowing us to compare across different accreditation boards. In selecting universities based on program size, our hope was that it would allow for a more direct comparison between similar universities, but we acknowledge that this means that our findings may not generalize to smaller programs. Course descriptions were analyzed for four main disciplines at each university: Electrical Engineering, Computer Engineering, Civil Engineering and Mechanical Engineering, and Environmental Engineering (or 'Bioresource Engineering'). Only undergraduate-level courses were considered, which sometimes included 500-level courses depending on university policies and course naming conventions.

This inventory and analysis of curricula was done by hand through systematic keyword coding to identify the main learning objectives. Based on a close reading of the EOP guidelines, we developed a set of criteria (including lists of key phrases, keywords and topics) to map course outcomes to EOP categories as systematically as possible, but acknowledge that in some cases this strategy for categorizing courses still involved a degree of subjectivity.

3.2.2 Student Survey

To provide a preliminary evaluation of student learning experiences and outcomes, we performed an anonymous survey of undergraduate engineering students from the University of British Columbia. The survey was advertised to all engineering students (approximately 1000 students in total) through social media posts, department emails and physical flyers. Participation was incentivized using a prize draw for two 50$ gift certificate. We received 50 eligible responses. Survey questions were largely quantitative (eg. "To what degree do you agree with the following statements"), but included some short answer questions, which were analyzed using keyword coding.

4 Results

4.1 RQ1: Accreditation Goals and Strategies

Our analysis focuses on three accreditation boards with different purviews:

- **ABET** (originally, the Accreditation Board for Engineering and Technology): ABET provides accreditation of engineering programs internationally, although it was founded and is based in the United States. ABET is not a professional licensing organization, but regional American professional licensing bodies almost universally require for applicants to have graduated from an ABET accredited program.
- **Engineers Canada (EC)**: Engineers Canada coordinates between regional Canadian licencing associations, and facilitates national cooperation on policy impacting the engineering profession (including accreditation of university-level engineering programs).
- **Engineers Australia (EA)**: Engineers Australia directly accredits engineering programs and performs professional licensing of engineers and engineering technologists in Australia.

We also included the International Engineering Alliance (IEA) guidelines. As members of the IEA and original signatories of its Washington Accord, ABET, Engineers Canada and Engineers Australia have agreed to perform accreditation in a way that is consistent with IEA guidelines.

4.1.1 Sustainability-Focused Learning Outcomes or Graduate Attributes

Each of the accreditation organizations studied report a commitment to sustainability, and describe through position statements[27], policy summaries[28], guidelines for professional engineers[29,30] and other public facing outputs[21], their view of how sustainability relates to the engineering profession, and the role of accreditation and in promoting and developing sustainable engineering practices, often citing UN Sustainable Development Goals (UN SDGs)[21].

- **IEA**: The importance of sustainability in engineering is explained in the first paragraph of their 'Graduate Attribute and Professional Competencies' document. These competencies were reviewed and updated explicitly in response to the UN SDGs[27]

  > "While bringing benefits, engineering activity has potential adverse consequences. Engineering therefore must be carried out responsibly and ethically, use available resources efficiently, be economic, safeguard health and safety, be environmentally sound and sustainable and generally manage risks throughout the entire lifecycle of a system. The United Nations Sustainable Development Goals present targets for 2030. Engineers are vital contributors for making progress towards these goals."[31]

- **ABET** Sustainability is also center place in ABET's introductory sentence on their public-facing website:

  > "Our approach, the standards we set and the quality we guarantee, inspires confidence in those who aim to build a better world — one that is safer, more efficient, more comfortable and more sustainable."

  ABET's commitment to sustainability (in response to the UN SDGs) is expanded upon in its 'Sustainable Education' issue brief[?] .

- **Engineers Canada**: Engineers Canada position statements and guidelines summarize the consensus of constituent provincial and territorial regulatory bodies, which may differ in their positions and motivations. Nonetheless, Engineers Canada underscores environmental protection in their code of ethics ("Registrants should uphold the values of truth, honesty, and trustworthiness, and they shall safeguard human life and welfare as well as the environment"[32]), and has released guidelines on sustainable development for engineers, explaining that given the importance of sustainable design, "it is incumbent on the engineering profession to provide guidance."[30]

  The importance of sustainability is also reflected in Engineers Canada's position statement on climate change, including a commitment to taking "a leadership role in assuring that codes, standards... promote a low-carbon, clean environment and a sustainable economy"[2].

- **Engineers Australia**: "Promote sustainability" is one of four key points in the Engineers Australia code of ethics. Similar to Engineers Canada, Engineers Australia has released a position statement on climate change[33], a policy statement on sustainability[28] and a more practical set of guideline on sustainable development for its members[29], which it positions, in part as a response to UN SDGs[34].

In addition to high level position statements, commitment to sustainability is also reflected in the accreditation criteria and other accreditation policy documentation through the definition of student learning outcomes (or 'competencies' or 'graduate attributes') that relate to sustainability and to the environment to different degrees. Some outcomes discuss environmental sustainability explicitly (as in IAE's seventh graduate attribute, *'WA7: Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering* *problems in societal and environmental contexts'*[31]), while others relate to sustainability more implicitly, or mention sustainability as a part of a list of possible considerations (as in Engineering Canada's 'Design' attribute: *'Constraints to be considered may include (but are not limited to): health and safety, sustainability, environmental, ethical, security, economic, aesthetics and human factors, feasibility and compliance with regulatory aspects'*[35]).

We map the graduate attributes and competencies used as accreditation criteria[36,35,37] to the EOP learning outcomes[22] (Table 1 and Table 2). These mappings are somewhat subjective, but provide an overview of how explicitly accreditation criteria discuss sustainability, and relate to the EOP objectives.

4.1.2 Accreditation Procedures and Curriculum Requirements

Expected student learning outcomes are not the only way accreditation systems can differ. Program accreditation may also include criteria related to faculty qualifications, institutional student support, facilities and more.

A significant difference in accreditation criteria with respect to sustainability education is in how the Engineers Canada accreditation board evaluates curriculum content and quality through accreditation units[35]. For each course, instruction is described on an hourly basis in terms of content type (eg. 'mathematics' or 'design'), and programs must dedicate a minimum number of instruction hours to 'complementary studies', which includes sustainable development, ethics and social systems. Engineers Australia and ABET do not require such a fine grained inventory of instruction hours, and do not require for a minimum amount of instruction time to be explicitly dedicated to sustainability[36,37].

The three accreditation systems use similar procedures to evaluate student learning according to their respective learning outcomes or graduate attributes: programs must define detailed learning indicators and objectives, describe and demonstrate the strategy used to evaluate student learning, including assessment instruments, outcomes and examples of student work. Programs are also required to demonstrate how the curriculum aligns with these learning objectives, through course descriptions and using course materials and syllabi.

4.2 RQ2: Sustainability Curricula

Sustainability-related coursework was analyzed for a subset of engineering disciplines (Electrical Engineering, Computer Engineering, Civil Engineering, Mechanical Engineering and Environmental Engineering) across ten Canadian and American universities:

- **Canadian universities**: University of Toronto, University of British Columbia, University of Waterloo, McGill University, University of Alberta, University of Calgary
- **American universities**: Arizona State University, Texas A&M University, University of Central Florida, Ohio State University, Florida International University

Courses were sorted into the following categories based on systematic course description keyword coding:

a) relating primarily and explicitly to environmental sustainability

Table 1: Mapping Accreditation Criteria to EOP Competencies: Skills, Experiences and Behaviors

Accreditation Body	Engineers Canada Graduate Attributes	ABET Student Outcomes	Engineers Australia	IEA Graduate Attributes
Materials Selection	**9 (impact of engineering on society and the environment)** and **4 (design)**	**2 (design with consideration for social and environmental factors)**	**1.6 (understanding ... sustainable engineering practice)** and 1.5 (knowledge of engineering design and contextual factors)	**7 (environment and sustainability)** and **3 (design)**
Design	**7 (environment and sustainability)** and **3 (design)**	**2 (ability to apply engineering design)**	**1.6 (understanding ... sustainable engineering practice)**, 1.5 (knowledge of engineering design and contextual factors) and 2.3 (application of systematic design processes)	**7 (environment and sustainability)** and **3 (design)**
Critical Thinking	**9 (impact of engineering on society and the environment)** and 10 (ethics and empathy) and 3 (investigation)	1 (identify, formulate, and solve complex engineering problems) and 6 (develop and conduct appropriate experimentation, analyze and interpret data)	**1.6 (understanding ... sustainable engineering practice)** and 1.4 (discernment of knowledge development ... within engineering) and 3.1 (ethical conduct and professional accountability)	**7 (environment and sustainability)**, 6 (ethics) and 2 (problem analysis)
Communication and Teamwork	**9 (impact of engineering on society and the environment)** and 7 (communication skills) and 6 (individual and team work)	3 (ability to communicate effectively) and 5 (ability to function effectively on a team)	**1.6 (understanding ... sustainable engineering practice)** and 3.2 (effective oral and written communication), 3.6 (effective team membership and team leadership)	**7 (environment and sustainability)**, 10 (communication) and 9 (individual and teamwork)
Environmental Impact Assessment	**9 (impact of engineering on society and the environment)**	**2 (design with consideration for social and environmental factors)**	**1.6 (understanding ... sustainable engineering practice)** and 1.5 (knowledge of engineering design and contextual factors)	**7 (environment and sustainability)**

Outcomes relating explicitly to sustainability are shown in green.

Table 2: Mapping Accreditation Criteria to EOP Competencies: Knowledge, Understanding and Systems Thinking

Accreditation Body	Engineers Canada Graduate Attributes	ABET Student Outcomes	Engineers Australia	IEA Graduate Attributes
Environmental Literacy	**9 (impact of engineering on society and the environment)**	Not explicitly addressed	**1.6 (understanding ... sustainable engineering practice)**, 1.1 (comprehensive, theory based understanding) and 1.5 (knowledge of engineering design and contextual factors)	**7 (environment and sustainability)**
Responsible Business and Economy	**9 (impact of engineering on society and the environment)** and 11 (economics and management)	**4 (ability to recognize ethical and professional responsibilities)**	**1.6 (understanding ... sustainable engineering practice)** and 2.4 (application of systematic approaches to the conduct and management of engineering projects)	**7 (environment and sustainability)** and 11 (project management and finance)
Social Responsibility	**9 (impact of engineering on society and the environment)**, 8 (professionalism) and 10 (ethics and equity)	**4 (ability to recognize ethical and professional responsibilities)**	3.1 (ethical conduct and professional accountability)	6 (ethics) and 5 (the engineer and society)
Systems Thinking	**9 (impact of engineering on society and the environment)** and 2 (problem analysis)	1 (identify, formulate, and solve complex engineering problems)	**1.6 (understanding ... sustainable engineering practice)**	2 (problem analysis), **7 (environment and sustainability)** and 6 (the engineer and society)

Outcomes relating explicitly to sustainability are shown in green.

For example, McGill's CIVE324: 'Sustainable Project Management: Lifecycle approach to project and construction management. ***Sustainable practices*** *are introduced at all project stages. [...]*

b) relating primarily and explicitly to social systems and social responsibility

For example, UBC's APSC367: 'Humanitarian Engineering: Politics and Practice: 'An interdisciplinary study of best practice, politics, and ***ethics*** *associated with technical solutions to humanitarian assistance within Canada and abroad. [...]'*

c) relating implicitly, or in part, to environmental sustainability

For example, Waterloo's CIVE241: 'Transportation Principles and Applications: Application of scientific principles to the planning, design, maintenance and management of transportation systems. [...] Transportation economics, ***environmental impacts****, and demand estimation.'*

d) relating implicitly, or in part, to social systems and social responsibility

For example, UofT's APS360H1: 'Applied Fundamentals of Deep Learning: A basic introduction to the history, technology, programming and applications of the fast evolving field of deep learning [...] Special attention will be paid to ***fairness and ethics issues*** *surrounding machine learning.'*

e) not relating to sustainability, or having minimal relation

For example, UofT's AER307: 'Aerodynamics: Review of fundamentals of fluid dynamics, potential-flow, Euler, and Navier-Stokes equations [...]'

The proportion of electives and core curriculum courses in categories (a) and (c) for each department are shown in Figure 1. This analysis was done for all courses (both core courses and electives) in each department, to illustrate the degree to which sustainability is integrated across the department's courses rather than the degree to which specific programs cover sustainability, which is a slightly different question. For example, it is possible that a computer engineering program could require computer engineering students to take multiple extra-departmental courses relating to sustainability without offering any from within the department. Similarly, at one university, a basic calculus course might be offered by the environmental engineering department, while at another, students would take a similar course through the math department, which helps explain some of the variation between universities. Analyzing sustainability content by program (instead of by department) is complicated by the fact that some programs have multiple streams and options with slightly different core courses or curriculum options. Nonetheless, our analysis shows some clear trends, with electrical and computer engineering departments teaching the least sustainability content and civil and environmental engineering departments teaching the most sustainability content, across all universities from both Canada and the United States.

Courses were also categorized depending on which EOP topics they related to most closely, based on keyword coding and analysis of implicit themes. For example, the following course (Waterloo's ENVE391) was categorized as relating most closely to **Environmental Impact Assessment** (green keywords) and **Social Responsibility** (purple keywords):

> ***Law and Ethics*** *for Environmental and Geological Engineers: Philosophy of environmental controls; introduction to national and international regulatory structures relevant to industrial planning, emissions control,* ***environmental impact assessment****, occupational health; stance of government, industry and community*

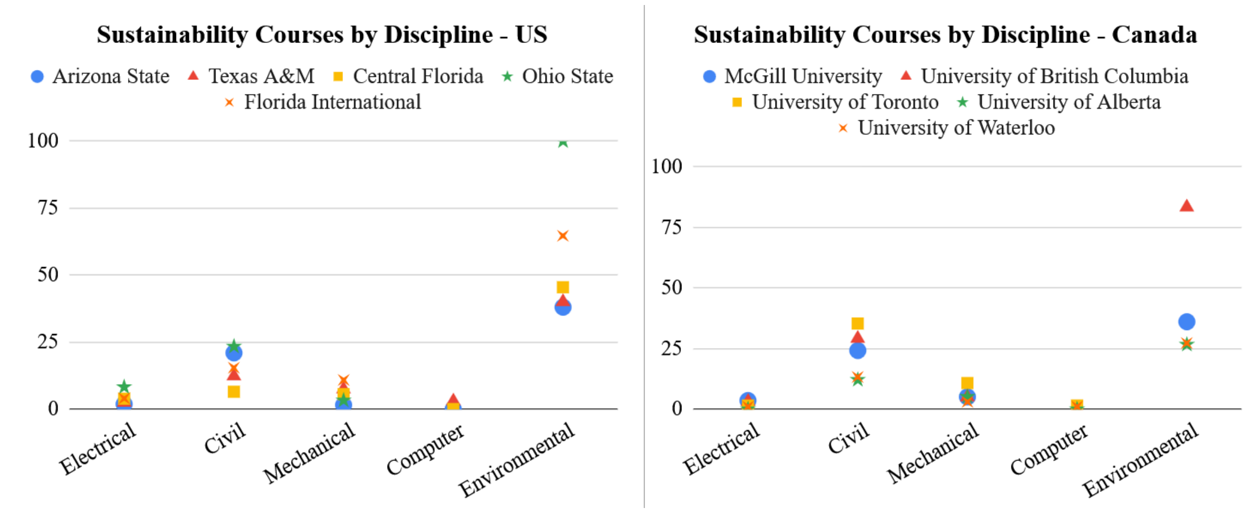

Figure 1: Sustainability-related courses (courses relating either primarily or indirectly to sustainability) as a percentage of all coursework

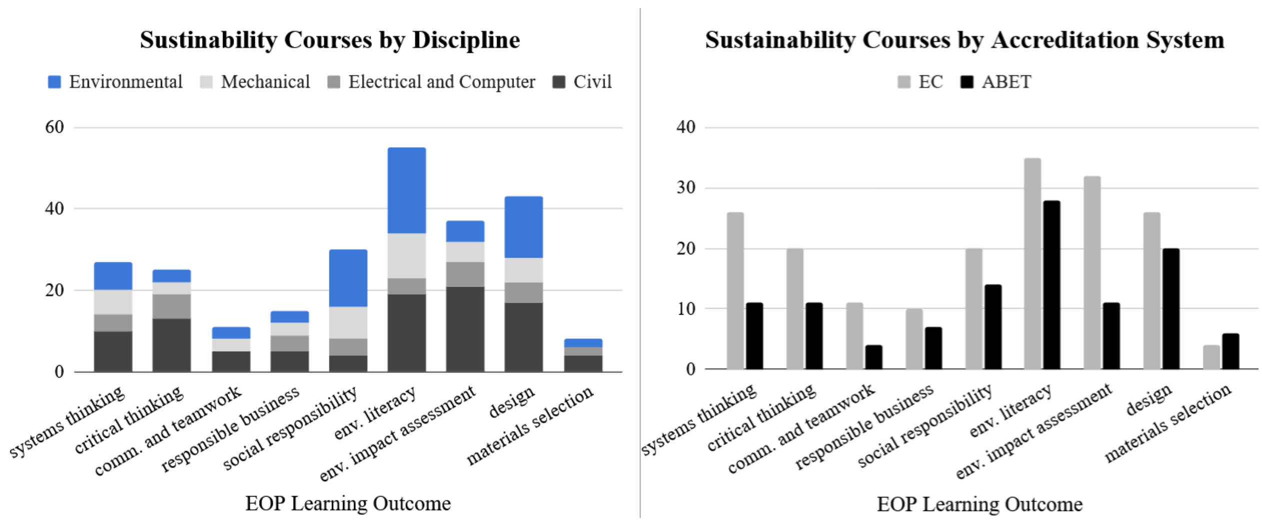

Figure 2: Sustainability Coursework addressing EOP Learning Outcomes

> *pressure groups. Contract law.* ***Professional ethics****, including the* ***social responsibility*** *of engineers, conflicts of interest.*

Results are summarized grouped by country and by discipline above (Figure 2). Note that while many courses teach general design skills, teamwork skills etc., this analysis only includes courses that also relate to sustainability specifically. As discussed (Section 3.2.1), this analysis involves a degree of subjectivity, but coding criteria and keywords and a discussion of the handling of ambiguous cases is included in Appendix **??**.

4.3 RQ3: Educator and Student Experiences and Learning Outcomes

4.3.1 Student Survey Results

We received and analyzed 50 eligible responses to our student survey on experiences with sustainability education in engineering at the University of British Columbia. While these findings might not generalize across all institutions, the University of British Columbia was generally representative of other North American universities during our curriculum analysis. Survey questions were grouped into four categories:

- Sustainability Course Experiences: The most common problems and challenges that students report with respect to sustainability coursework as follows (from the most common):
    1. Lack of relevance or applicability (eg. "The sustainability course I took was ... very disconnected from the rest of my studies.")
    2. Lack of student engagement (eg. "generally it was not very engaging and easily forgettable")
    3. Superficiality (eg. "I guess we never go super in-depth about it, we only learn that in theory [sustainability] is very important")
    4. Instructional strategies and 'Preaching' (eg. "Often, an answer is fed to students. We're engineers and hate that. Let us figure out *why* something is so, without spoonfeeding it.")
    5. Sustainability Education as an 'afterthought' (eg. "It usually seems like more of an afterthought and not a main focus")
- Core Competency Self Evaluation: Students were asked to self evaluate their competencies according to the Engineering One Planet framework, given examples of specific learning outcomes (Figure 3). Students rate their abilities least highly in categories like 'materials selection' and 'environmental impact assessment', which require both sustainability and discipline specific technical skills and knowledge.
- Student Opinions: Students were asked to report agreement or disagreement with a series of statements relating to sustainability education (Table 3). The majority of students were in agreement in terms of the importance of sustainability education and the importance of sustainability to them personally. Opinions on questions around how sustainability education should be implemented were more varied.

5 Discussion

5.1 Sustainability Curricula: Sustainability Education in Existing Coursework

During our collection of course data, we found every engineering program required for students to take a core curriculum course that related to either environmental sustainability (ecological systems, the environment, climate change, energy literacy, etc.) or social responsibility (ethics, social systems, fairness, etc). Often, programs had many such courses, including at least one

Table 3: Student Opinions on Sustainability Curricula and Accreditation

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
'Sustainability and the environment are very important to me, personally.'	30%	40%	23%	5%	3%
"It is important for all engineers in my discipline to learn about sustainable design and the environment.'	25%	45%	13%	15%	3%
'Engineering programs should be required (by accreditation bodies) to cover sustainable design and the environment.'	18%	33%	23%	13%	10%
'I would like access to a greater variety of courses and opportunities to learn about sustainable design.'	20%	30%	25%	23%	3%
'I would prefer sustainability to be integrated throughout my technical courses, rather than concentrated in sustainability-centered courses.'	23%	20%	23%	23%	13%

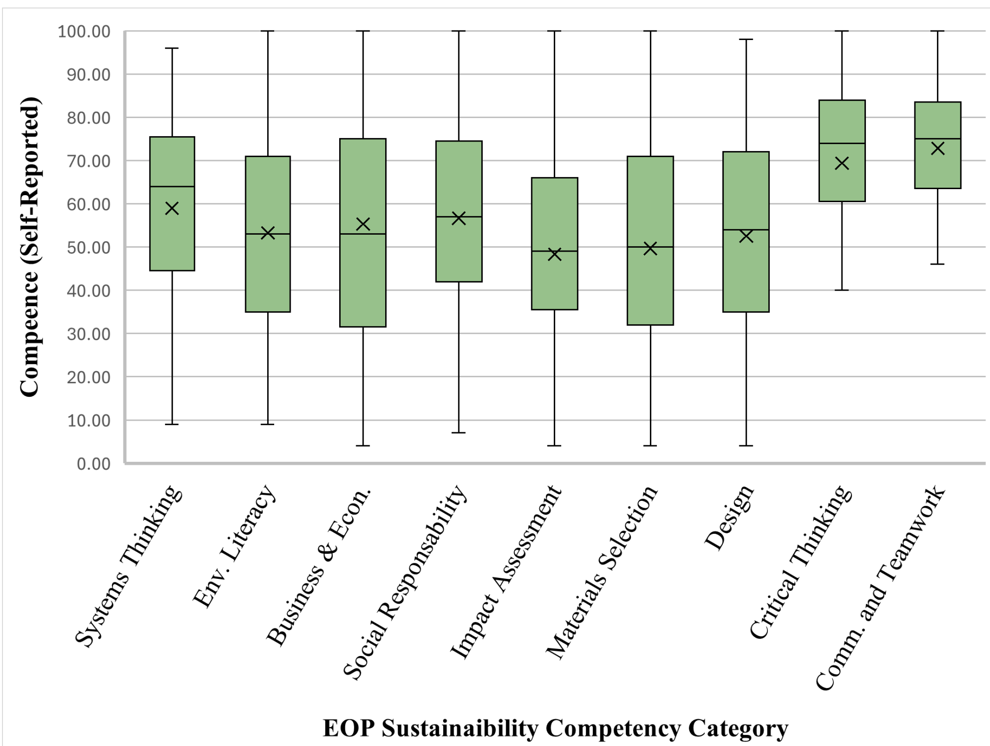

Figure 3: Student Self-Evaluation of EOP Core Competencies

Box and whisker plot indicating minimum and maximum values, high and low quartiles, the median (horizontal lines) and the average (x).

dedicated primarily and explicitly to environmental sustainability. In several cases however, electrical, computer or mechanical engineering departments did not offer any courses related to sustainability. Students from these programs were required to take an extra-departmental course on society, the environment or the engineering profession, fulfilling accreditation requirements without meaningfully integrating sustainability throughout the technical curriculum.

We observe significant variation between programs in terms of the proportion of the curriculum dedicated to sustainability. Discipline was much more predictive of the quantity and type sustainability content than accreditation system. Programs centered specifically around Environmental Engineering unsurprisingly have a higher proportion of sustainability education in their curricula. The number of courses that either mention sustainability or primarily concern sustainability is also much higher in Civil Engineering than Electrical, Computer and Mechanical Engineering. This underscores the importance of factors other than accreditation, such as perceptions of disciplinary roles and identities, and discipline-specific norms in shaping sustainability education, and suggests that minor accreditation differences play a smaller role.

Different programs also varied significantly from university to university within the same accreditation system and discipline. This suggests that factors like faculty interest, student communities, university culture and departmental culture also have an important effect. As discussed (Section 4.2), this may be more reflective of differences in how departments and programs are structured however, rather than actual differences in the amount of sustainability content students receive.

The degree to which sustainability was integrated throughout the curriculum also had an effect on which EOP sustainability competencies were covered, with less integration of sustainability content across technical electives leading to less coverage of more concrete sustainable development skills like materials selection or environmental impact assessment. For example, typically (in 8/10 of the programs we analyzed) Electrical Engineering programs required for students to take a course that introduced at a high level, the impact of technology on the environment (EOP: Environmental Literacy), a course introducing design (EOP: Design) and a course relating to professional ethics (EOP: Social Responsibility), but few electrical engineering electives covered the other sustainability competencies. On the other hand, Civil Engineering programs generally had more integration of sustainability throughout departmental electives, and more coverage of the more skills-based EOP competencies like environmental impact assessment. In keeping with this observation, a common opinion among survey respondents from Electrical and Computer Engineering was that in their experience, the available sustainability coursework was difficult to relate to their other work, and that they would have preferred to discuss more concrete applications and problem solving. These results illustrate how the way sustainability is included in curricula (whether it is integrated throughout electives or concentrated in core required courses) is related to student learning objectives and outcomes.

5.2 Student Experiences and Challenges

Student responses expose some interesting contradictions and help show the challenges associated with teaching sustainable development skills to engineers.

The most common student concern with existing coursework is that the content is too general, qualitative and superficial. For the majority of students surveyed, all or most sustainability-related coursework they had completed was from general engineering courses (rather than discipline-specific electives) on the impact of technology on society and the environment. In future work, we hope to interview educators and administrators to better understand why some programs have practical and discipline specific sustainability education integrated throughout the curriculum, while in others students are required to take more general extra-departmental courses. One reason for this could be cultural differences across disciplines and differences in how individual faculty members perceive disciplinary identity and sustainability education. Consistent with this, several students reported that in their departments, sustainability education is treated as an 'afterthought' or 'box-ticking exercise', and as secondary to technical coursework.

Integrating more sustainability-education throughout the curriculum could address these student concerns by helping relate sustainability content more directly to concrete applications and other technical course content. Survey respondents had mixed opinions on this however, with only 43% in favor of integrating sustainability throughout technical courses.

Encouragingly, despite mixed experiences in existing sustainability coursework, the majority of students still report a high degree of personal investment in sustainability, that they want more sustainability coursework, and that they think it is important for students in their discipline to learn about how their work relates to sustainability.

Slightly over half of students agreed that accreditation should require coverage of sustainable design in engineering programs, with less than a quarter of students in disagreement. This is notable, given that these requirements could translate into more restrictive program requirements and limit student flexibility in choosing courses (ie. they are required to take a course on sustainability, rather than choosing to take a sustainability elective). Student approval of sustainability-related accreditation requirements could stem from a general commitment to sustainability and belief in policy-based strategies for addressing sustainability concerns. Alternatively, it could reflect their personal interest in taking sustainability coursework, and a perception that these accreditation requirements remove barriers that might otherwise prevent them from taking sustainability electives (eg. pressure to take other technical coursework). We continue to interview students to better understand their position and opinions on these topics.

6 Conclusions

Sustainability education in engineering is critical, but for it to be meaningful, it needs to be thoughtfully implemented. We evaluated the impact of sustainability-focused accreditation requirements on university curricula, student experience and learning outcomes and discuss challenges and opportunities for developing more effective sustainability education in engineering programs. Our findings show that while existing accreditation requirements ensure that students receive a minimum level of coursework related to sustainable development, several challenges remain. Specifically, curriculum analysis shows a lot of variation between programs in terms of how sustainability is integrated with technical content, and students report concerns around the applicability and relevance of existing coursework.

In future work, we hope to gather data from a wider range of programs, universities and accreditation systems, to strengthen our findings. We are also interviewing students and faculty to better understand their experiences, and to understand reasons behind curriculum design decisions and their impact on student learning.

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