Calling for Engineering Curricula that Address the Climate Emergency: A Brief Case Study of Civil Engineering Programs

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SUMMARY

This work highlights the need for accredited engineering curricula to integrate mandatory climate-related learning and proposes four high-level competencies for consideration. The work surveys ten accredited civil engineering programs in Canada as a case study. The survey result that accredited civil engineering programs provide little to no training toward climate competency underscores the need for greater attention to engineering curricula as a tool by which the engineering profession can begin playing an active role in addressing the climate emergency. Discussions touch on the implicit inclusion of climate competencies in other courses and how this implicit inclusion could become more explicit by looking to medical programs' approach. Discussion also touch on potential challenges arising from inconsistent degree requirements in engineering programs and the engineering culture that centres objectivity.

INTRODUCTION

The climate crisis is the most urgent threat to humanity; the scale of changes in our climate system has not been observed for “many centuries to many thousands of years” [1]. Even under low-emission scenarios, Canada will be 1.8°C warmer than a 1986-2005 baseline by 2040, an increase that has brought and will continue to bring regional changes in precipitation levels and frequencies [2]. R. Daniel Bressler wrote in 2021 that “adding 4,434 metric tons of carbon dioxide in 2020—equivalent to the lifetime emissions of 3.5 average Americans—causes one excess death globally in expectation between 2020-2100” [3]. Air pollution from construction and inefficient burning of fossil fuels lead to further deaths; another 2021 study estimated that nearly one-fifth of deaths worldwide in a given year is due to fossil fuel-related air pollution [4].

As a result, curricula on climate change mitigation and advocacy are an increasingly prevalent topic in professional education discourses. Canadian medical schools face increasing demands for curricula that address the climate emergency and provide climate advocacy training. Emergency physicians Edward Xie, Jennifer Hulme, and Courtney Howard agree with the need for more climate-related components in medical education:

> Given the long lead time to practice change, early exposure to these topics is critical. Sluggish knowledge translation to doctors who have graduated […] underscores the importance of introducing emerging concepts as soon as possible. This is especially urgent when some topics, such as climate change and health, have been supported by a robust evidence base for decades. To gain maximal effect, we must avoid compartmentalizing these issues as “special interest” topics for continuing medical education [5].

The need to be attentive to climate issues is not unique to the medical profession. Corporate lawyer climate change practice group lead Patricia Koval wrote nearly a decade ago that:

> Along with [new climate change] knowledge comes the understanding that if infrastructure is not adapted to these changes and events, property damage and/or personal injury is almost certain to occur. This has potentially serious ramifications for design professionals, including engineers. […] The issue of potential legal liability for failing to adapt infrastructure to climate change related risk has become a key issue over the past year. […] The legal framework in Canada currently permits a court, in the right circumstances, to find infrastructure stakeholders legally liable for personal injury and property damage suffered by third parties, including, in the case of design professionals, on the basis of negligence [6].

Beyond running into the risk of personal injury and property damage, engineers could be designing infrastructure that are ultimately responsible for increased greenhouse gas emissions and poor overall planetary health. David Fork and Ross Koningstein set out an extensive list of changes that engineers could make to address climate change, including scaling up infrastructure around mature technologies like wind and solar power [7]. Fork and Koningstein stress that “we must get serious about carbon sequestration, which is the stashing of CO_2 in forests, soil, geological formations, and other places where it will stay put [...] engineers are seeking and finding numerous opportunities to switch existing systems based on the combustion of fossil fuels to lower-carbon electricity" [7].

The need for climate-competent engineers could also increase as organizations around the world move to decarbonize their operations. Alphabet plans to operate using only carbon-free energy by 2030, Microsoft pledged to be carbon negative by 2030, and Apple committed to carbon-neutral products by 2030 [8]. Similarly, several multinational engineering consulting firms have pledged for net zero carbon at varying dates: SNC-Lavalin by 2030 [9], WSP by 2040 [10], and Stantec by 2030, with an additional goal of carbon neutrality by 2022 [11] [12].

The importance of introducing emerging concepts during formal training, the need to move away from labelling climate change competency as a "specialty," the potential for the lack of climate change adaptation in engineering design to lead to legal liability, the availability of information on engineers' ability to address the climate crisis, and the large-scale organizational shift to decarbonize all point to the need for the Canadian engineering curricula to better equip graduates to address the climate emergency.

METHODS

Understanding the *status quo* on engineering curricula's inclusion of climate change concepts is the first step to better equipping graduates to address the climate emergency. To this end, the paper outlines four basic climate competencies and surveys ten accredited civil engineering programs for the presence of these climate competencies along with climate-adjacent courses.

Overview of climate competencies for engineers

This work contends that basic levels of four climate competencies are crucial: (1) state of planetary health, (2) climate change mitigation, (3) climate adaptation, and (4) carbon capture and storage. These competencies are adaptable to many engineering disciplines, including civil, building, environmental, geological, mining, and architectural engineering.

Climate competency #1: State of planetary health

Engineering graduates should have an understanding of the relevant international bodies including the Intergovernmental Panel on Climate Change (IPCC) [13], Planetary Health [14], the United Nations Framework Convention on Climate Change (UNFCCC) [15], and the UNFCCC Conferences of the Parties (COPs) [16]. Understanding the interactions between the atmosphere and oceans, the carbon cycle, global warming trends and their impacts on other indicators, such as precipitation, permafrost thaw, and wildfire, is also important [1].

Climate competency #2: Climate change mitigation

Engineering graduates should be aware of global decarbonization goals, the required pace of emissions reduction to keep the average global temperature increase below 1.5°C [1], pollution-related health risks, and carbon sinks and sources [17]. Engineering graduates should have an understanding of systemic approaches to decarbonization, including renewable forms of energy such as solar, wind, geothermal, and tidal, energy efficiency, the definition and interpretation of net-zero carbon, net-zero energy, and notions of transition, scaling, acceleration, and innovation [17].

Climate competency #3: Climate adaptation

Engineers must build for climatic patterns of the future. Engineers must become adept at sourcing and incorporating region-specific projections and designing structures that are resilient to the anticipated impacts of a range of climate scenarios. A basic understanding of climate adaptation strategies in Canada [2] and around the world [17] is necessary for engineers to design for inevitable climate impacts. The use of thermosyphons for the management of infrastructure and foundations built on permafrost, clean air shelters for air quality and wildfire preparedness, water retention infrastructure, flexible stormwater management systems, and increased precipitation management plans are examples of adaptation strategies that students could learn about. Overview of standards under the *Northern Infrastructure Standardization Initiative* [18] including CSAS500:21 Thermosyphon Foundations for Buildings in Permafrost Regions and CSA S501:21 Moderating the Effects of Permafrost Degradation on Existing Building Foundations [19].

Climate competency #4: Introduction to carbon capture and storage

IPCC literature indicates that significant innovation in carbon capture and storage technologies will be necessary to keep the average global temperature increase below 1.5°C [1]. Engineering graduates should have a basic understanding of concepts relating to carbon capture and storage such that they may contribute to the innovation [20]. These concepts could include conventional, pyrogenic, and natural (such as reforestation and afforestation) carbon capture and storage, direct air capture, and biochar.

Survey of civil engineering programs

As a case study, the authors reviewed the course calendars of accredited civil engineering programs at ten institutions in Canada as of Winter 2022 to discern the level of inclusion of the above competencies. The authors labelled each competency as not offered, offered-required or offered-complementary (optional) for each program.

RESULTS

Table 1 presents the level of inclusion of climate competencies and climate-adjacent courses in ten civil engineering programs. Table 2 presents verbatim descriptions for identified climate-adjacent courses for reviewed civil engineering undergraduate programs. Most programs offer environmental courses such as hydrology, water resources, water treatment, pollution control, greenhouse gas emissions, and air quality that are "climate-adjacent." However, courses directly pointing to the above climate competencies are not part of the curriculum at any of the reviewed institutions.

Table 1: Climate competencies and climate-adjacent courses in ten civil engineering programs.

Climate & Engineering Competencies	1: State of Planetary health	2: Climate Mitigation	3: Climate Adaptation	4: Carbon Capture & Storage	Climate-adjacent courses
UofT [21]	-	-	-	-	CIV 380 (req)
McGill [22]	-	-	-	-	CIVE 519 (comp) CIVE 561 (comp)
Concordia [23]	-	-	-	-	ENGR 202 (req)
UBC [24]	-	-	-	-	-
Polytechnique Montréal [25]	-	-	-	-	CIV 3220 (req) ING 8971 (comp)
UofA [26]	-	-	-	-	-
McMaster [27]	-	-	-	-	ENGPHYS 3ES3 (req)
Waterloo [28]	-	-	-	-	CIVE 230 (req) ENVE 279 (comp)
Western [29]	-	-	-	-	CEE 4485A/B (req)
Queen's [30]	-	-	-	-	-

"-" = not offered; comp = offered, complementary; req = offered, required

Table 2: Descriptions for identified climate-adjacent courses for reviewed civil engineering undergraduate programs in Canada

University	Climate-adjacent Courses	Course Description (*verbatim*)
UofT	CIV 380 Sustainable Energy Systems	This course will provide students with knowledge of energy demand and supply from local to national scales. Topics include energy demands throughout the economy, major energy technologies, how these technologies work, how they are evaluated quantitatively, their economics and their

		impacts on the environment. In addition, the ever changing context in which these technologies (and emerging technologies) are being implemented will be outlined. Systems approaches including life cycle assessment, will be refined and applied to evaluate energy systems. A particular focus will be placed on analysis of energy alternatives within a carbon constrained economy. [31]
McGill	CIVE 519 Sustainable Development Plans	Geared for solving real-world environmental problems related to water at the local, regional and international scale in Barbados. Projects to be designed by instructors in consultation with university, government and NGO partners and to be conducted by teams of two to four students in collaboration with them. [32]
	CIVE 561 Greenhouse Gas Emissions	Greenhouse gas inventories at various scales from national to institutional. Emission estimation methods including field measurements and engineering calculations for anthropogenic sources including fossil fuel combustion from transportation and energy production, cement production, hydroelectric reservoirs, oil and gas systems, landfills, wastewater treatment and sewer systems, and agriculture. Technical and policy options for reducing greenhouse gas emissions. Group project. [33]
Concordia	ENGR 202 Sustainable Development and Environmental Stewardship	Introduction to the concept of sustainable development and the approaches for achieving it. Relationships with economic, social, and technological development. Methods for evaluating sustainability of engineering projects, including utilization of relevant databases and software. Impact of engineering design and industrial development on the environment. Case studies. [34]
Polytechnique Montréal	CIV 3220 Impacts sur l'environnement et dével. durable	Historique, principes et concepts du développement durable. Rôle des ingénieurs et outils à leur disposition dans un contexte de développement durable. Processus provincial et fédéral d'études d'impacts sur l'environnement et de demande de certificats d'autorisation au Québec. Aspects socio-économiques, légaux et biophysiques des projets de la planification jusqu'au démantèlement. Techniques d'identification et d'évaluation des impacts environnementaux. Processus de participation publique. Risques technologiques et évaluations environnementales. Études de cas. [35]
	ING 8971 Projet intégrateur en développement durable	Projet intégrateur de quatrième année d'une durée d'un trimestre divisé en deux volets : travail en équipe et travail individuel. Volet équipe : résolution d'une problématique d'ingénierie et conception technique dans une perspective de développement durable. Travail en équipe mixte, ouvert à tous les génies, encadré par une équipe technique multidisciplinaire. Prise en compte dans la conception des impacts des solutions proposées sur l'environnement, la société et l'économie. Volet individuel : développement d'une expertise individuelle en matière de développement durable.

		Cette compétence est transférable au projet d'équipe et liée aux intérêts et à la formation de l'étudiant. [36]
McMaster	ENGPHYS 3ES3 Introduction to Energy Systems	A survey course on energy systems with emphasis on the analytic tools needed to evaluate them in terms of performance, resources and environmental sustainability, costs, and other relevant factors over their life cycles. [37]
Waterloo	CIVE 230 Engineering and Sustainable Development	This course introduces the concept of sustainability and how it applies to decision-making in civil engineering. The course begins by defining sustainability, both practically and technically, and describing the concepts of systems, and systems interactions. Quantitative methods and measures of effectiveness are derived and applied to components of sustainability; air quality, water quality, energy, transportation and solid waste. Economic concepts and their applicability to sustainability are described for both developed and developing countries. [38]
	ENVE 279 Energy and the Environment	Conservation of energy, energy balances on closed systems. Steady-state and transient heat transfer via convection, radiation, and conduction. Mechanical and electrical work. Internal energy, enthalpy, and specific heats of solids, liquids and gases. Phase change in natural environmental systems; The basics of heat engines, refrigerators, and heat pumps. Function, evaluation, and design of energy resource technology: wind and hydroelectric turbines, photovoltaics, geothermal energy, biomass and biofuel, natural gas and petroleum extraction, and tidal energy. Renewable energy policy and implications. [39]
Western	CEE 4485A/B Cities: Resilience and Sustainability	A first course in Urban Physics focused on urban resilience and urban sustainability. The relation/opposition of these two notions are discussed. [40]

DISCUSSION

Implicit inclusion of climate competencies in other courses

A review of subject descriptions in course calendars indicate that a number of required and complementary courses cover some climate-related topics, but these climate-related topics are usually not central to the course and do not align with the climate competencies above. In other words, existing courses may not be teaching and encouraging engineering graduates to think sufficiently critically about climate change issues.

McGill University engineering professor Dr. Mary Kang teaches *CIVE 520 Groundwater Hydrology*, a required course in the civil engineering program at McGill. The course touches on geological carbon capture and storage in the context of groundwater resources. Dr. Kang discusses the potentially implicit inclusion of course topics that result in climate competencies:

> Some would argue that parts of this are integrated into courses, although not explicitly. For example, in my Hydrology and Water Resources course, we talk a lot about the challenges of using historical data on making design decisions and study flood prevention, which is needed more and more in a changing climate. In my Groundwater Hydrology course, I talk a lot about how climate change may be impacting groundwater resources as well [41].

The efforts of individual professors to actively incorporate climate-related topics are encouraging but should not replace the need to provide students with climate competencies in the form of mandatory and standalone foundation courses. Again, as Xie, Hulme, and Howard write: "To gain maximal effect, we must avoid compartmentalizing these issues as 'special interest' topics" [5].

Looking to the Canadian Federation of Medical Students

Engineers could look to other professionals with stakes in the climate crisis, such as physicians and medical learners. The healthcare community recognizes a need to advocate for solutions to climate change as a way to reduce the health risks that a changing climate confers [42].

A committee of medical learners, through the Canadian Federation of Medical Students, undertook an environmental scan of Canadian medical school curricula and found climate advocacy skills training in medical education inconsistent or entirely missing [43]. These medical learners developed and have been advocating for the formal inclusion of a virtual, interactive, and skills-based longitudinal climate advocacy training series to address the climate competency gap in Canadian medical school curricula [43].

The training series includes the delivery of workshops throughout an academic year by experts and community leaders that address topics ranging from healthcare reform to the impacts of climate change on health and the importance of climate action. In its inaugural year, the series offered 25 workshops to 1,140 participants from 17 Canadian medical schools [43]. Following the completion of this workshop series, medical students' self-perception on preparedness to advocate for climate change issues that affect the health of the population and patients increased [44].

Inconsistent degree requirements in engineering undergraduate programs

The inconsistent degree requirements and course offerings between engineering undergraduate programs may be among the challenges in moving toward engineering curricula that lead to climate competencies. For example, engineers in the civil, building, environmental, geological, mining, and architectural fields share responsibilities in designing, planning, constructing, and managing the built and natural environment. These fields are interdisciplinary and overlapping in nature with the synthesis of practical and theoretical knowledge from each field leading to unique subdisciplines: civil and architectural engineering intersect in structural engineering; environmental and geological engineering intersect in hydrogeology; civil and environmental engineering intersect in building science and water resources; and civil and geological engineering intersect in geotechnical engineering, among others.

These disciplines are critical to the successful engineering of the built and natural environment but lack consistency in the availability of climate-related courses across civil-adjacent undergraduate programs. For example, at the University of Waterloo, the environmental engineering program includes the mandatory climate-adjacent courses *ERS 215 Environmental and Sustainability Assessment* and *ENVE 279 Energy and the Environment* [45], while the geological engineering program has no required or complementary courses that could lead to the identified climate competencies [46].

This suggests that geological and environmental engineering alumni from this institution who pursue the field of hydrogeology may have very different understandings of their subdiscipline's ability to address climate change. Comparably, a brief scan of curricula for geological, mineral, and mining engineering programs at Ontario universities presents a similar lack of mandatory climate-related course offerings with the sparse exceptions of complementary course offerings in environmental impact assessments [46] [47] [48] [49].

Medicine is among the professional programs that are threading planetary health and climate competencies into their curricula [43]. Engineering disciplines traditionally steeped in natural resource extraction (such as oil and gas, minerals, hydroelectricity, surface water, and groundwater) should be catching up to medicine in better equipping its graduates with the tools necessary to address climate change.

Climate change and the engineering culture

The lack of consideration for the needs of and the impact of climate change on diversely identified and situated communities may be a result of the focus on objectivity that persists in engineering [50]. As a profession whose primary responsibility is to the public [51], engineering could and should contribute to increasing awareness of climate change and other critical issues in the Anthropocene.

Engineers' skepticism around the possibility of including non-numerical considerations while maintaining the expected level of objectivity in the application of scientific principles poses challenges in recognizing and addressing the climate crisis [52]. Just as the work of engineers could play an important role in increasing the awareness of and conversations about a broad range of policy issues, this work intends to launch a conversation around the ways in which engineers can serve as champions in climate change mitigation and climate adaptation.

CONCLUSION

The importance of introducing emerging concepts during formal training, the need to move away from labelling climate change competency as a "specialty," the potential for the lack of climate change adaptation in engineering design to lead to legal liability, and the availability of information on engineers' ability to address the climate crisis all point to the need for the Canadian engineering curricula to adopt climate change components.

This work included surveying ten Canadian civil engineering undergraduate programs as a case study to discern the level of inclusion of the four climate competencies. Results indicated that courses directly pointing to the four climate competencies are not part of the engineering curriculum at any of the reviewed institutions.

This work discussed the implicit inclusion of climate competencies in other courses and how this implicit inclusion could become more explicit by looking to medical programs' approach. The work also presented brief discussions on potential challenges arising from inconsistent degree requirements in engineering undergraduate programs and the engineering culture around objectivity.

This work intends to serve as a springboard for the Canadian Engineering Accreditation Board to begin or continue considering updates to the engineering curriculum that would more directly lead to climate competencies. This work also encourages engineering programs to begin or continue expanding their course offerings specific to climate with a view to helping students develop critical perspectives on climate issues.

Finally, this work calls on engineering programs and educators to integrate climate change considerations into student design project requirements, including those of fourth-year (capstone) design projects. For example, capstone instructors can include a project requirement to incorporate mitigation and adaptation measures using region-specific temperature and precipitation projections for the anticipated lifetime of the design in question.

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