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Measuring Misconceptions About Climate Change Between Freshmen and Senior Civil Engineering Students

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Abstract
Anthropogenic climate change is irreversibly affecting the planet and society. Civil engineers hold responsibility to design and construct built-environment spaces that decrease climate changing emissions. The purpose of the research presented in this paper is to assess how undergraduate civil engineering programs contribute to this goal. A cross-sectional comparison between data from a prior national survey of freshmen engineering students interested in civil engineering and pilot data from a national survey to senior undergraduate engineering students was used to assess students' belief in climate change, their understanding of climate science, and desire to address climate change in their careers. The results indicate that senior undergraduate civil engineering students are more likely to believe that climate change is caused by humans (67%) compared to freshmen engineering students (47%). These seniors are also more likely (73%) to agree that action should be taken to address climate change. Yet, only 37 percent hope to personally address climate change in their careers. Senior civil engineering students are more likely than their peers in other engineering disciplines to take classes that include sustainability and climate change as topics (predominately in engineering electives), yet their knowledge of climate science is no better, and in several instances, worse than their engineering peers. For example, civil engineering students are more likely to agree with the statement, "I believe a cause of global climate change is nuclear power generation," and "I believe a cause of global climate change is the ozone hole in the upper atmosphere." Undergraduate education is likely contributing to increased belief and recognition to address climate change but an educational gap still persists in understanding. Future research should explore why misconceptions still exist even when climate change is taught in engineering courses and how particular concepts are explained and how student experiences shape understanding and interest.

Introduction

Civil engineers, who design and construct society's built environment and maintain infrastructure services, have a responsibility to ensure safety and wellbeing for people and the planet [1], [2]. As the global population continues to grow exponentially [3], demand for non-renewable energy is leading to extreme levels of greenhouse gas emissions [4]. The current consumption rate of non-renewable energy and resulting emissions is leading to a reduction of global food production and water supplies, sea level rise, and ocean acidification [5]. Civil engineers are an essential part in solving these challenges. They must not only be aware of the issues but empowered to make change [6].

Unfortuatnely more than half of students interested in civil engineeirng do not believe in climate change [6]. Students interested in civil engineering are similar to other Americans, where about half do not believe in climate change [7]. Further still, only three out of ten working professional engineers agree climate change is causing significant public risk [8]. One reason why these misconceptions persist across the public and among engineering students and professionals is a

lack of education about the impact of climate change [9] and the long term horizon of the effects on society [10], [11].

Climate science is not well-understood by middle and high school students in the U.S. [12]–[14]. Middle school students believe climate change is associated with ozone depletion and causes skin cancer [15]. Similar aged students said pro-environmental behavior like not littering is helping to prevent climate change [16], [17]. In high school, students were shown to hold naive models of the earth's climate system and failed to consider geographic variations. These high school students could describe the effect of climate change on wild animals but were unable to make the connection to livestock and humans [14].

There are many educational interventions to address these significant misconceptions and knowledge gaps, both inside [18] and outside of the classroom [19], [20]. However, just knowing about climate science and recognizing climate change does not guarantee action to address the issue in the future [21]. Students must perceive they can bring about change using their own skills and abilities. Their priorities, shaped by their values and attitude, must align with motivation for action to occur [22].

The formation of engineers during undergraduate engineering programs is an opportunity to correct misconceptions about climate change and help students develop their abilities to mitigate climate change in the future. The research presented in this paper assess how an undergraduate civil engineering program contributes to this goal. A cross-sectional comparison between a prior national survey of freshmen engineering students and pilot data from a national survey to engineering seniors was used to assess students' belief in climate change, understanding of climate science, and desire to address climate change in their careers.

The prior national survey, called Sustainability and Gender in Engineering (SaGE), included a representative sample (n=191) of freshmen engineering students intending to major in civil engineering. The national survey to senior engineering students was modeled after SaGE, and other national surveys about climate change [7]. The preliminary results from the national survey using pilot data (n=224) at one large, public Southeastern research institution are being reported. Student demographics from the preliminary study are representative of the student population at the institution within civil engineering and demographically are similarly to the freshmen engineering student sample population.

Background

This study is the first of its kind to measure how undergraduate engineering curriculum influence beliefs about climate change, students' understanding of climate science, and students' willingness to address this issue in their careers. The SaGE survey was originally developed and distributed in 2011 to a stratified random sample of institutions across the country with the intent to measure gender differences among students interested in sustainability [23]. Gender was found to be a predictor of students most interested in sustainability. Females represented 63 percent of these students [24]. Students most interested in sustainability were also found to be more racially diverse.

Similar to how gender was related to student interest in sustainability, gender was also found to be a predictor for belief in climate change [9]. Although, race, identifying as Caucasian, and academic performance, using final grades of nine science courses and one math and English course were not strong predictors for belief in climate change. This prior work provides a foundation for the research presented in this paper. The interest here is understanding not just first-year engineering students' beliefs about climate change but how these beliefs differ from senior engineering students, their understanding of climate science, and their willingness to address this issue in their career.

So, a national survey for senior engineering students was modeled on the SaGE survey, the Yale Project on Climate Change Communication [7], [26], and the climate literacy survey from Clarkson University [27]. Additional questions were developed about engineering course content and standards [28], [29], sustainability [30]–[32], critical engineering agency [33], and career choice [34]–[36]. The survey includes 40 anchored, numerical, multiple choice, and categorical questions divided into six sections: (1) career goals, (2) college experiences, (3) about you, (4) climate science, (5) people and the planet, and (6) demographic information.

The survey measures the relationships between understanding of climate change, how this develops critical engineering agency to address these topics, and how this translates to career plans. By understanding the particular identities of engineering students and the ways in which they desire to address climate change, researchers can begin to identify areas where students mistakenly perceive climate change as unrelated to engineering and particular experiences that make empowerment to address climate change more likely. Presented in this paper are the preliminary results of this national survey to senior engineering students. The national survey is currently being distributed to over 50 institutions across the country, to over 4,000 senior undergraduate engineering students.

Five research questions are asked, in effort, to begin to explore the how curriculum and college experiences influence belief about climate change, understanding of climate science, and willingness to address climate change in their careers. The next section outlines these questions and the methods sections provides details about the sample population and survey distribution. The results and discussion offer some insight about what might be expected in the full data across 4,000 senior undergraduate engineering seniors.

Research Questions

The following five research questions begin to explore the differences between freshmen and senior civil engineering students:

1. How do beliefs about climate change differ among freshmen and senior civil engineering students?
2. How frequently was climate change a topic covered in courses taken by freshmen engineering students in high school? And how frequently was climate change a topic covered in courses taken by senior civil engineering students in college?
3. What extent do freshmen and senior civil engineering students want to address climate change in their careers?

4. Do senior civil engineering students recognize the causes of climate change and methods to reduce or slow climate change?
5. How do senior civil engineering students compare to other engineering seniors in their ability to recognize the causes of climate change and methods to reduce or slow climate change?

Methods

Participants

Responses from the Sustainability and Gender in Engineering (SaGE) survey were used to help answer the five research questions. The SaGE survey included 47 anchored, numerical, multiple choice, and categorical questions. The survey distribution targeted 4-year engineering institutions and was distributed in 2011. A comprehensive list was compiled from the American Society of Engineering Education's online profiles. Institutions without undergraduate engineering programs and programs not in the U.S. were removed from the list. A randomized sample of 47 schools were contacted through email and 10 agreed to participate. Representatives at the participating institutions distributed the paper-based survey to students in their introductory/ general engineering course.

In total, 937 surveys were returned. Of the 937 responses, 688 students indicated an interest in engineering. The survey asked respondents to: "Please rate the current likelihood of your choosing a career in the following: bio-engineering, chemical engineering, materials engineering, civil engineering, industrial/systems engineering, mechanical engineering, environmental engineering, and electrical/computer engineering." Each response was organized on a 5-point anchor scale ranging from "0-Not at all likely" to "4-Extremely likely". Students who selected "4-Extremely Likely" for civil engineering are identified as likely civil engineering students in this paper. Out of the 688, 206 (29%) indicated an interest specifically in civil engineering by selecting "4-Extremely likely". Of the 206 students, 191 answered the question about whether they believed climate change was caused by humans. These 191 students were used to report findings presented in this paper. Of the 191 responses, 56 indicated they were female and 135 indicated they were male.

The survey for senior civil engineering students also asked whether students believed in climate change. Of the 228 students who received the survey, 83 were from civil engineering. The remaining were mechanical and environmental engineering students. Male civil engineering students composed 66% (55) of respondents and female civil engineering students composed 30% (25). Three students did not respond. Gender is a statically significant predictor of climate change belief. The ratio of male to female civil engineering students between the freshmen sample population and senior civil engineering sample population was not significantly different ($\chi^2 = 0.1172$, $p = 0.732$).

Survey Questions

1. Research question one asks, how do beliefs about climate change differ among freshmen and senior civil engineering students? To answer this question, students were asked, "To what

extent do you disagree or agree with the following:" "Climate change is caused by humans". Students selected categorical responses including Strongly Agree (4), 3, 2, 1 or Strongly Disagree (0). Percent differences were compared between freshmen and senior civil engineering students.

2. The first part of research question two asks, how frequently was climate change a topic covered in courses taken by freshmen engineering students in high school? To answer this question, students were asked, "Please indicate whether the following topics were covered in your last high school courses. (Mark all that apply)". One of the topics was "climate change". Students option were binary, marking either yes or leaving blank for "Biology, Physics, Chemistry, or Other Course(s)". The second part of research question two asks, how frequently was climate change a topic covered in courses taken by senior civil engineering students in college? To answer this question, students were asked, similar to the freshmen engineering students, "Please indicate whether the following topics were covered in your last college courses (Mark all that apply)." One of the options was "climate change," and the option was binary, mean students either marked yes or left the response blank for "Discipline Specific Engineering, Engineering Elective, Non-engineering elective, or Other Course(s)". In addition, senior engineering students were asked, "Compared to your peers, how likely are you to take sustainability related courses in your area of academic interest," on a scale from 1 to 5 with 1 being "Not at all likely" and 5 being "Extremely likely." And "Compared to your peers, how likely are you to gain understanding of global climate change from college courses," on a scale from 1 to 5 with 1 being "Not at all likely" and 5 being "Extremely likely."

3. Research question three asks, what extent do freshmen and senior civil engineering students want to address climate change in their careers? To answer this question, both freshmen and senior engineering students were asked, "Which of these topics, if any, do you hope to directly address in your career? (Mark all that apply)" One of the topics was "climate change". The option was binary, students either marked they hope to address climate change or not in their career.

4. Research question four asks, do senior civil engineering students recognize the causes of climate change and methods to reduce or slow climate change? To answer this question, senior engineering students were asked two questions. The first question asks, "I believe that a cause of global climate change is..." followed by ten statements to complete the sentence. The statements include: "burning fossil fuel," "nuclear power generation," "the ozone hole in the upper atmosphere," "livestock production," "dumping trash into our oceans," "waste rotting in our landfills," "agricultural use of chemical fertilizers," "deforestation," "volcanic eruptions," and "acid rain". The second question asks, "I believe a way to help reduce or slow down climate change is…" followed by ten statements to complete the sentence. The statements include: "building more nuclear power stations instead of coal power stations," "making more of our electricity from renewable energy resources," "recycling more," "not wasting electricity," "fertilizing the oceans to make algae grow," reducing air pollution from toxic chemicals," "changing lifestyles to reduce consumption," limiting the use of aerosol spray cans," increasing public transportation," and "eating less meat."

5. Research question five asks, how do senior civil engineering students compare to other engineering seniors in their ability to recognize the causes of climate change and methods to reduce or slow climate change? Other senior engineering students were compared to senior civil engineering students to the statements in research question four.

Responses were compared using a chi-squared test. The chi-squared test is used to determine whether there is a significant difference between the frequencies of responses chosen between freshmen and senior engineering students. Statistical significance was set to 0.05.

Results & Discussion

How do beliefs about climate change differ among freshmen and senior civil engineering students?

Senior civil engineering students are statistically ($\chi^2 = 9.145$, $p = 0.0025$) more likely to agree that climate change is caused by humans. Table 1 provides the descriptive statistics. The difference in percent agreement between freshmen and seniors is 20 percent. More freshmen engineering students interested in civil engineering are more likely to disagree that climate change is caused by humans than agree. More alarming, is that more than a third of senior civil engineering students disagree that climate change is caused by humans. These students will be responsible for designing infrastructures, which will need to withstand more extreme natural disaster events (e.g. flooding, heat waves, droughts) over the next half century. Failure by a third of the respondents to recognize humans effect on the climate is troubling because addressing the issue will require not only recognizing why the problem persists but also coordination among various engineering and stakeholder groups.

Table 1: Senior civil engineering students are more likely to agree "climate change is caused by humans".

	Disagree	**Agree**	**N**	***p***	χ^2
Freshmen	53% (100)	47% (91)	191	0.0025	9.145
Seniors	33% (27)	67% (56)	83		

When asked whether, “we should be taking stronger actions to address climate change,” senior civil engineering students were statistically ($\chi^2 = 3.922$, $p = 0.0476$) more likely to agree compared to freshmen engineering students. The difference in agreement from freshmen to senior was 15 percent. While this increase is encouraging, still nearly one in three senior civil engineering students do not agree that action should be taken. This is particularly worrisome because of the role civil engineers will play in the coming decades to mitigate the effects of climate change.

Table 2: Senior civil engineering students are more likely to agree "We should be taking stronger actions to address climate change".

	Disagree with Taking Action	Agree with Taking Action	N	*p*	χ^2
Freshmen	40% (76)	60% (113)	189	0.0476	3.922
Senior	28% (22)	75% (58)	80		

How frequently was climate change a topic covered in courses taken by freshmen engineering students in high school?

Of the 191 responses, 158 (87%) indicated climate change was covered in at least one high school course. The most likely course, to include climate change was Biology (47%), followed by Other (29%), Chemistry (20%), and Physics (11%). Figure 1 provides a histogram of the number of students who selected each course. Nearly nine out of ten of these students received formal education about climate change in high school but still less than half believe climate change is caused by humans.

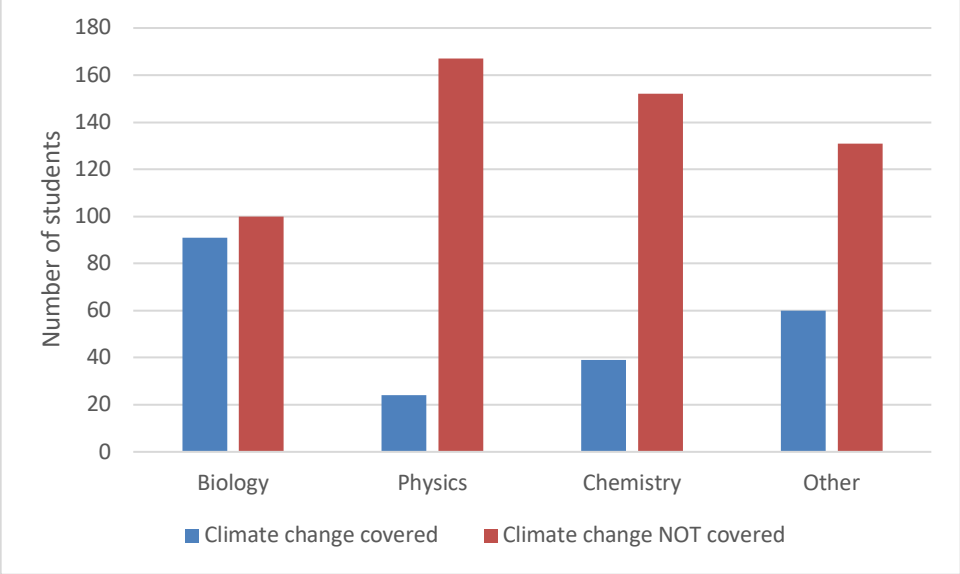

Figure 1: 87% of freshmen engineering students interested in civil engineering indicated climate change was a subject covered in at least high school Biology, Physics, Chemistry, or Other course.

How frequently was climate change a topic covered in courses taken by senior civil engineering students in college?

Of the 83 senior civil engineering students, all indicated climate change was a topic covered in at least one of their courses. Compared to non-engineering electives and other courses, discipline specific courses and engineering electives were more likely to include climate change as a topic. The course most likely to include climate change as a topic was engineering electives (31% of respondents selected this option). Figure 2 provides an illustration of these descriptive statistics.

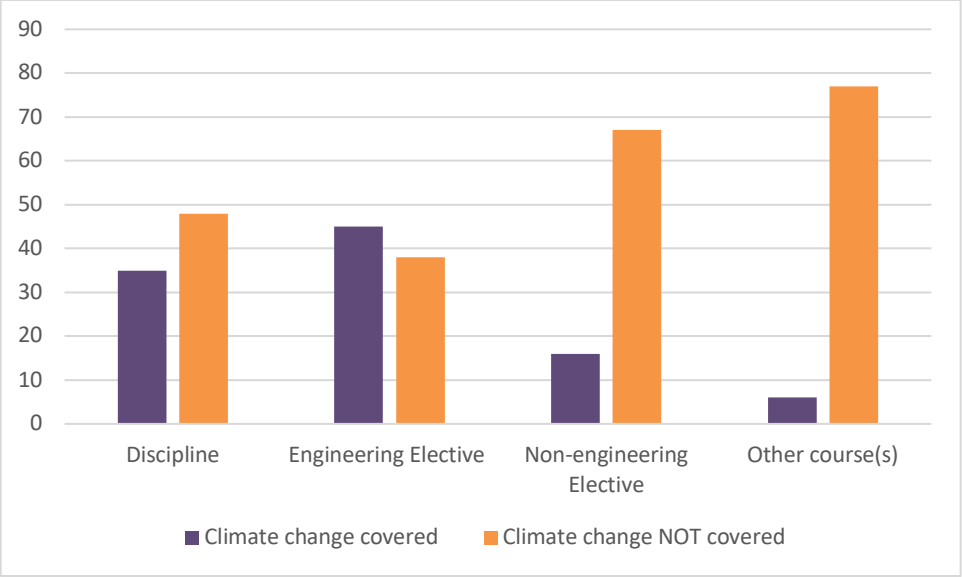

Figure 2: All civil engineering students indicated climate change was a topic covered in at least one of their courses; the largest group (31%) of students was engineering elective.

Compared to other senior engineering students who participated in the survey, civil engineering seniors were statistically ($t = -3.85$, $p < 0.001$) more likely to take sustainability related courses and gain understanding of climate change from college courses ($t = -5.27$, $p < 0.001$). Table 3 compares civil engineering students to both environmental and mechanical engineering students who participated in the survey.

Table 3: Senior civil engineering students are more likely to take sustainability related course and gain an understanding of climate change from college courses.

	Other Engineering Majors			Civil Engineering Majors			Comparison		
	N_1	X_1	S_1	N_2	X_1	S_2	t-test	DF	p
… take sustainability related courses.	111	3.1	1.4	79	3.8	1.2	-3.85	182	<0.001
… gain understanding of global climate change from college courses.	106	3.1	1.4	73	4.1	1.2	-5.27	167	<0.001

*N=sample size, X=sample mean, S=sample standard deviation, DF= degrees of freedom

What extent do freshmen and senior civil engineering students want to address climate change in their careers?

Senior civil engineering students are more likely ($\chi^2 = 4.21$, $p = 0.042$) to want to address climate change in their careers compared to freshmen engineering students. However, the low percent in both groups is somewhat surprising. Nearly 3 out of 4 civil engineering students believe action needs to be taken to address climate change (Table 2) but less than half want to address it

personally (Table 4). This is troubling because senior civil engineering students are more likely to learn about climate change through college courses and in courses directly related to their discipline, yet this education is not transferring to willingness to address the issue in their career.

Table 4: Seniors are more likely to want to address climate change in their careers (but both percentages among freshmen and seniors are low).

	Do not want to address climate change	Want to address climate change	N	*p*	χ^2
Freshmen	75% (143)	25% (48)	191	0.0402	4.21
Seniors	63% (52)	37% (31)	83		

Do senior civil engineering students recognize the causes of climate change and methods to reduce or slow climate change?

A total of 20 true-false questions were asked to senior civil engineering students about the causes of climate change and methods to reduce the effects of climate change. Ten of these questions (50%) were answered incorrectly by the majority of civil engineering students. The majority of civil engineers incorrectly answered that they believe the cause of global climate change is… "the ozone hole in the upper atmosphere," "nuclear power generation," "dumping trash into our oceans," "agricultural use of chemical fertilizers," "volcanic eruptions," and "acid rain." Figure 3 illustrates both the percent correct and incorrect about the causes of climate change.

The number of incorrect responses is concerning because, again, these students indicated taking more classes about sustainability and learning about climate change in their courses compared to their peers in mechanical and environmental engineering. While the hole in the ozone and trash in our oceans are bad for the planet these are not directly related to climate changing emissions. Failing to differentiate between the causes of climate changing emissions is a necessary understanding in order to begin correcting the issue in their career.

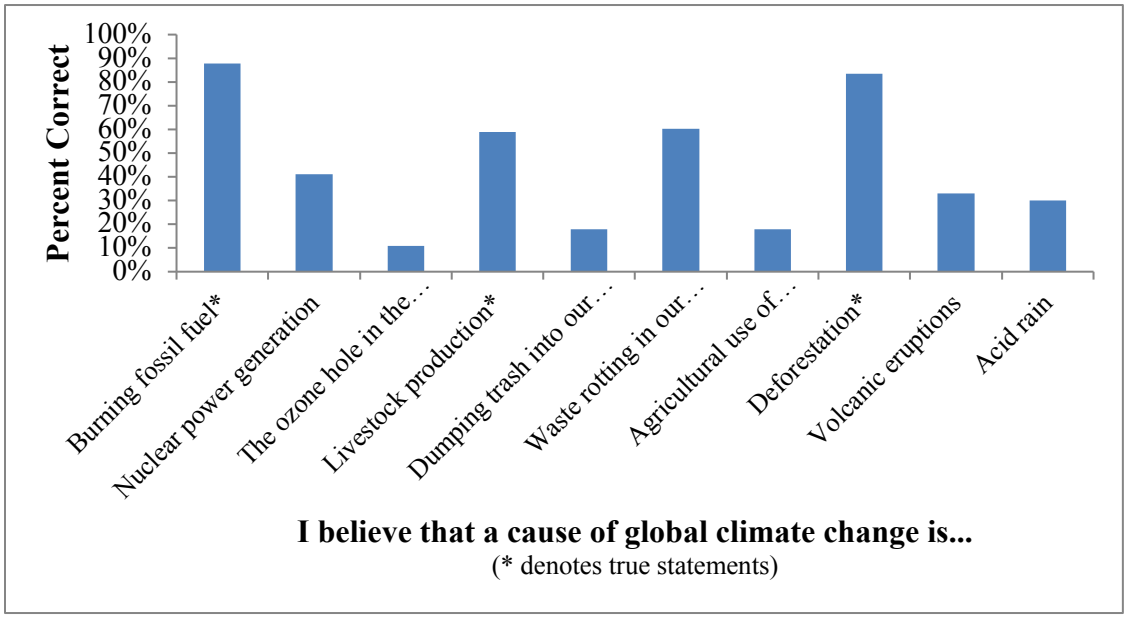

Figure 3: Civil engineers incorrectly selected half of these causes as related to climate change

When asked "I believe a way to help reduce or slow down climate change is…" followed by ten statements, the majority of civil engineering students incorrectly answered five (50%). Figure 4 provides the five incorrectly answered responses. The five correctly answered were: "building more nuclear power stations instead of coal power stations," "making more of our electricity from renewable energy resources," "not wasting electricity," "changing lifestyles to reduce consumption," and "increasing public transportation."

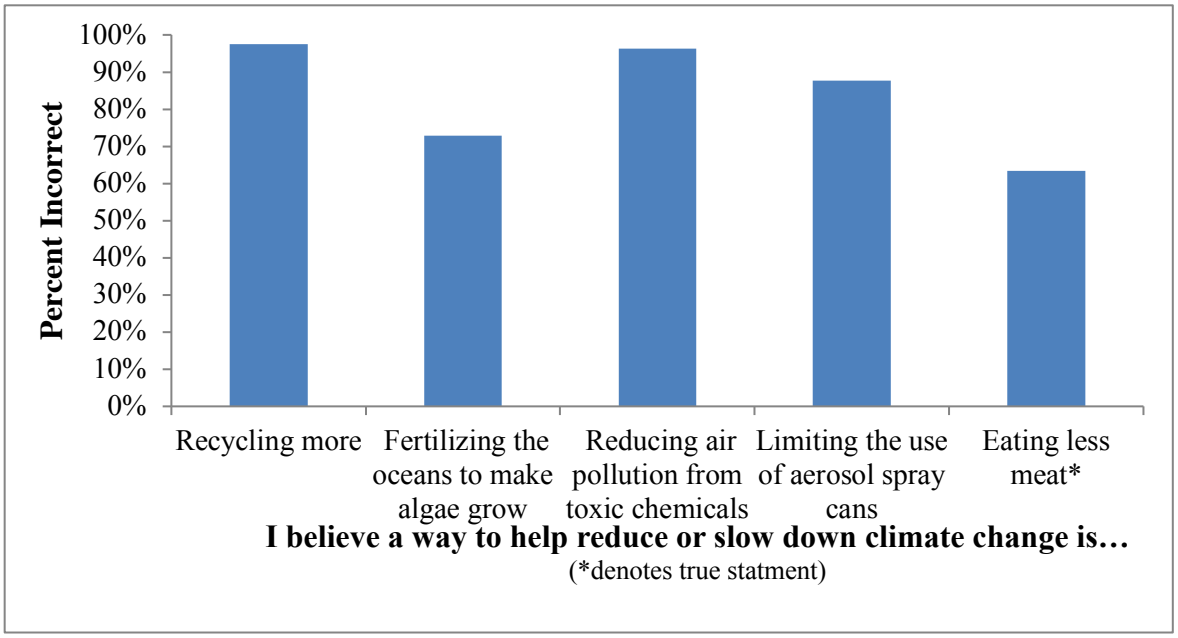

Figure 4: Civil engineering students incorrectly answered 50% of the responses about how to reduce or slow down climate change

How do senior engineering students compare to other engineering seniors in their ability to recognize the causes of climate change and methods to reduce or slow climate change?

Related to the 20 true/false response questions about the causes of climate change and methods to reduce or slow down climate change, civil engineering students answered more incorrectly than their engineering peers. Specifically, civil engineering students respond correctly at a less frequent rate than other engineering seniors to "I believe a cause of global climate change is nuclear power generation," (F, t= -2.431, p=0.016) "I believe a cause of global climate change is the ozone hole in the upper atmosphere" (F, t=-2.045, p= 0.042), and "I believe a way to help reduce or slow down climate change is building more nuclear power stations instead of coal power stations" (T, t=2.379, p=0.019).

Civil engineers appear not to excel above other engineering students in their knowledge of climate science even though they are more likely to take sustainability courses and learn about climate change in their courses. This educational gap must be closed to ensure civil engineers are properly equipped with knowledge to succeed in their careers and ensure safety and security for society in the design and construction of built environment spaces and infrastructure systems.

To summarize the results, senior civil engineering students are more equipped than freshmen engineering students to recognize that humans are causing climate change and they are more

likely to agree that action needs to be taken. Yet, only one out of three of these students want to personally address the issue in their career. Civil engineering seniors are more likely than their peers in other engineering disciplines to take classes that include sustainability and climate change as topics, yet their knowledge of climate science is no better, and in several instances, worse than their engineering peers. This is especially concerning because these students are months from working as engineers designing and constructing our built environment and appear to lack knowledge of basic climate science. Gaps in civil engineering education must be identified to combat this issue.

There are several limitations to these findings that need to be addressed in future research. First, the data are cross-sectional rather than longitudinal. Two surveys were used with the same questions. SaGE was distributed in 2011 and the pilot survey for senior engineering students was distributed in 2017. In addition, there were limited choices of topics for students to pick. For example, the ten methods for reducing climate change are not the only possible approaches. Students may have been more aware or able to identify other techniques not listed. Future work can expand these options and gain a better understanding through more qualitative methods, such as observations and interviews with students. In addition, looking at particular student experiences in and out of the classroom to understand how these beliefs, understanding and willingness to address climate change develop. Misconceptions seem to exist even when climate change is taught in engineering courses. Future research should also examine how particular expertise and topics are taught and how these experiences shape understanding of, and interest in, addressing climate change in their future careers.

Conclusion

Sending civil engineers into the workforce with misconceptions about the basics of climate science and methods for reducing climate changing emissions is a disservice to society. Consequences of climate change include strain on infrastructure systems, greater disruptions during natural hazard events, and further depletion of environmental resources. Students studying how to design and construct vital infrastructure systems must consider questions such as: what resources are available, how severe the consequences of climate change will be, how soon should they expect deviations from normal weather conditions, and what will be the impact on the community in terms of long term hazards and short-term vulnerabilities. Civil engineering students who are not well educated about climate science will not be able to answer these questions and design appropriate engineering solutions.

The results reported in this paper convey both progress and a gap in understanding. Senior engineering students are more likely to agree that humans are causing climate change and are more likely to agree that action needs to be taken to address the issue. However, only one out of three want to personally address the issue in their career. Their understanding of what is causing climate change and how to mitigate it is less than other engineering peers, yet they are more likely to take classes that include sustainability and climate change as topics. The long-term vision is that this research becomes a catalyst for research and teaching about topics related to climate change. More research appears needed in how to effectively delivery content and cases that deal with climate change and its implications for sustainability. Teaching should support students' critical engineering agency (e.g., empowerment and identity in engineering contexts)

and beliefs about sustainability. Students' agency and beliefs may influence their career choice and expected career outcomes. As a result, the more civil engineering students will hopefully pursue careers to solve societal challenges that mitigate and prepare for climate change.

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