Civil Engineering Students' Beliefs about Global Warming and Misconceptions about Climate Science

Tripp Shealy[1], Andrew Katz[2], Allison Godwin[3], Michael Bell[4]

[1]Assistant Professor, Dept. of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA 24061. (corresponding author) E-mail: tshealy@vt.edu

[2]Assistant Professor, Dept. of Engineering Education, Virginia Tech, Blacksburg, VA 24061. E-mail: akatz4@vt.edu

[3]Associate Professor, Dept. of Engineering Education, Purdue Univ., West Lafayette, IN 47907. E-mail: godwina@purdue.edu

[4]Graduate Research Assistant, Dept. of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA 24061. E-mail: msbell1@vt.edu

Abstract

Civil engineers will face increasing challenges in their career due to climate change. The infrastructure they design and construct will directly contribute or mitigate it. Action to reduce the greenhouse gas emissions that cause climate change requires both a belief in human caused global warming and a basic understanding of climate science. To understand where current engineering education efforts are successful or may need more consideration, a national sample of civil engineering students, and students from other engineering disciplines, were asked about their belief in global warming, understanding of greenhouse gases, the causes of global climate change, and ways to help reduce or slow it down. The overwhelming majority of civil engineering students (83%), and students from other engineering disciplines (81%), acknowledged that global warming is happening. Nearly three out of every four civil engineering students (73.5%), and other engineering students (71.3%), believed that global warming is caused by humans. Although, only about half of civil engineering students (55.6%), and other

engineering students (52.3%), felt that global warming is personally important. The majority of civil engineering students and other engineering students did not understand the causes and actions to reduce global warming. More than half of civil engineering students (60%) believed nuclear power generation is a cause of global warming, which is significantly more than students from other engineering disciplines (52.6%). More than eight in ten civil engineering students (83%) incorrectly believed or were unsure that the ozone hole in the upper atmosphere is a cause of global warming. A possible explanation for these misconceptions is civil engineering students recognized general problems, like nuclear waste and the ozone hole, but they did not link particular causes with particular consequences. Possible interventions are discussed for making climate change information personally relevant to engage students to think about cause and effect related to the climate.

Introduction

The effects of climate change are already reducing global food production and water supplies, increasing sea level rise, and ocean acidification (Karl 2009). The majority of greenhouse gas emissions contributing to climate change are from the built environment (US EPA 2014; World Bank 2017). Residential and commercial buildings account for nearly 40 percent of total U.S. greenhouse gas emissions (EIA 2019). The transportation sector contributes about 30 percent of total U.S. greenhouse gas emissions (US EPA 2015b). Civil engineers contribute directly to the design and construction of these physical systems and need to play a central role in reducing greenhouse gas emissions and mitigate the effects of climate change now and in the future (ASCE 2018).

Civil engineers will need to design stronger asphalt and concrete roadways to combat buckling from increased temperatures, washouts from precipitation, and settling from thawing

48 permafrost (*Potential Impacts of Climate Change on U.S. Transportation* 2008). Civil engineers
49 are also needed to contribute to smarter infrastructure – infrastructure that can detect poor air
50 quality and alert officials (Tambo et al. 2016; Younger et al. 2008) and infrastructure that can
51 communicate with cars and prevent accidents. Civil engineers will need to address examples like
52 residents in Louisiana and Maryland who are beginning to leave their homes and retreat inland to
53 escape rising floodwaters (Johnson 2018; Waldman 2017). Civil engineering education needs to
54 develop engineers that understand climate science and are able to address these dynamic
55 challenges for society and the environment (*The Climate Change Educational Partnership*
56 2014).

57 Amid this background of challenges, civil engineering education about climate change is
58 especially needed because only half of first year college students interested in studying civil
59 engineering believe global warming is caused by humans (Shealy et al. 2017b). This frequency
60 of belief among civil engineering students is less than the general public (Marlon et al. 2016).
61 Despite this clear need, the effects of civil engineering education on students' belief about global
62 warming, their understanding of climate science, and how they perceive the effects of global
63 warming on themselves and others are not well understood. In addition, how civil engineering
64 students' beliefs, knowledge, and perceptions about climate change compare to other engineering
65 disciplines is also unknown. Civil engineering students studying how to design and construct
66 vital infrastructure systems will face questions in their career, such as, what resources are
67 available; how severe will the consequences of the climate impact be in my community; how
68 soon will the effects occur; and how likely is the potential climate impact. If civil engineering
69 students are not well educated about climate science, they will be less prepared to answer these
70 questions knowledgeably.

The purpose of the research presented in this paper is to measure what civil engineering students in their final semester of college believe about global warming, their understanding of climate science, how civil engineering students perceive the effects of climate change, and how these attitudes and knowledge compare to other engineering disciplines. The background provides a summary of recent literature about student beliefs about global warming, education related to climate science and perceptions about climate change being a technical and social issue. The research questions follow, and the methods explain the data collection process. The results offer insight into particular attitudes and misconceptions commonly held by civil engineers and other engineers. The discussion and conclusion offer perspectives on what the results mean for the future and highlight potential educational opportunities to correct misperceptions and understanding among civil engineering students nationally.

Background

Beliefs about human-caused global warming

The number of Americans who believe the planet is warming is happening is at an all-time high (Leiserowitz et al. 2020). Roughly seven out of every ten Americans think global warming is happening and about six out of ten understand global warming is human caused (Leiserowitz et al. 2020). In contrast, only about three out of every ten Americans believe civil infrastructure systems, like sewer systems, roads, and bridges should be a high priory to protect from the effects of global warming (Leiserowitz et al. 2020). Civil engineers who believe and understand the effects of climate change on these systems are needed to make the case about why prioritizing these physical systems are necessary for the public's health and safety.

Unfortunately, few professional engineers (only three out of every ten) believe climate change will cause significant public risk (Lefsrud and Meyer 2012). The belief among first-year

civil engineering students is not much higher. In the United States, only half of first-year college students in civil engineering believe in human caused climate change (Shealy et al. 2017b). Civil engineering students are more likely to take sustainability courses and learn about climate change in the classroom compared to other engineering students, but they do not excel above other engineer students in their knowledge of climate science (Coleman et al. 2018). Civil engineering students do not recognize global warming will have a serious impact on themselves, their family, and people in their community now or in the next 25 years (Coleman et al. 2018). This prior research is consistent with the general public who agree that climate change will not affect them in their lifetime (Hamilton 2011).

Beliefs about climate change are strongly tied to social, religious, and political factors (Weber and Stern 2011). For instance, frequency of discussion with friends and family are strong predictors for acceptance of human caused climate change (Stevenson et al. 2016). Two in five students learn about climate change from family or friends (Leiserowitz et al. 2011). Cooperative learning environments also have a significant and positive effect upon beliefs about global warming and its effects on climate change (Devine-Wright et al. 2004). For example, a peer-to-peer learning model is most effective for training programs about climate change (Eiseman et al. 2020). Similarly, understanding a student's sociocultural activities in which they already participate is the strongest predictor for climate change understanding and should be the foundation for developing educational experiences that personally resonate with students (Hestness et al. 2019).

Religious affiliation is also a significant predictor of global climate change perception. Students that self-identify as Christian, and especially fundamentalists, are less likely to believe in the existence of global climate change (Fusco et al. 2012). Climate change is also

politically polarizing (Leiserowitz et al. 2020), but the politicized discourse around climate change among students does not necessarily follow the traditional political party boundaries (Zummo et al. 2020). In other words, how a student would vote (Republican or Democrat) does not directly predict how they will talk about climate change (Zummo et al. 2020) Together, this prior work indicates that there are various background factors and educational experiences that may influence civil engineering students' beliefs and knowledge about climate change.

Misconceptions about climate change

Students' belief in global warming and its effects on climate change does not match the scientific consensus. This reality could be attributed to the inherent difficultly in understanding climate science (Carnesale and Chameides 2011). Middle and high school aged students are observed to wrongly report climate change being associated with ozone depletion and the cause of skin cancer (Andersson and Wallin 2000; Baker et al. 2013; Karpudewan et al. 2015). College students also confuse the weather and climate (Lombardi and Sinatra 2012). For example, recent weather events are used as evidence among students (Gowda et al. 1997) and science teachers (Papadimitriou 2004) for climate change.

A deeper examination of the root of misconceptions reveals students often hold incomplete and incorrect knowledge elements built within structurally sound mental models (Chang and Pascua 2016). The erroneous information built within mental models makes misconceptions about climate change a challenge to correct (Chang and Pascua 2016). For instance, students can accurately describe the anticipated effect of climate change on wild animals and plants but often cannot recognize the impact higher up in the food chain, for example, on livestock (Shepardson et al. 2010). Students that are able to recognize the role that the forest and animals play in modulating climate change are more likely to have increased belief

and attitude about mitigating climate change (Higuchi et al. 2018). Correcting misconceptions about climate change requires instructors to understand how students' construct mental models about climate science.

Students' misunderstanding of climate change can also stem from an error in their ontological assumptions (Chen 2011). The connection between weather and climate utilizes a pattern matching heuristic (Chen 2011). Climate change belongs to a different kind of ontological model. Treating climate change as an object rather than a process can also lead to climate change misconceptions (Chen 2011). Engaging in deliberate discussion about climate change and tackling the misconceptions of these mental models head-on can help change beliefs (McNeal et al. 2014) and even students' willingness to take action on mitigation (McNeill & Vaughn, 2010).

How students learn about climate change can shape their understanding about the topic. Educational programs that focus on personally relevant information and activities (e.g., how climate change will impact them) are more effective than merely presenting facts (Monroe et al. 2019). For instance, students interacting with scientists to explore local climate conditions and collect data (Hallar et al. 2011) or engaging in film making projects exploring the potential effects on their communities (Littrell et al. 2020) were particularly effective learning experiences. Educational experiences that develop a student's personal understanding of climate change is also likely to lead to student engagement toward climate change action (McNeill & Vaughn, 2010).

Student misconceptions can stem from a variety of sources in their educational pathways. The prior literature indicates that students often understand aspects of climate change but are unable to link incomplete knowledge with the large systems of climate change as a process.

Education can have a positive effect on mitigating these misconceptions once they are identified through personally and culturally relevant pedagogies (Monroe et al. 2019).

Climate change as a technical or social issue

One approach to engage students on climate change action is through framing it about the issues they care about. For example, birdwatchers are less motivated to take action to address climate change when framing climate change dangers about humans (Dickinson et al. 2013); describing the implications of climate change about birds is highly effective in changing their future actions (Dickinson et al. 2013). Focusing on the positive effects on society rather than on the negative risks to the environment can increase willingness to adopt mitigation measures among the public (Bain et al. 2012; Spence and Pidgeon 2010). Framing climate change about human rights (Howell 2013), social justice (Howell and Allen 2019), health (Adlong and Dietsch 2015), or economic development (Bain et al. 2016) are likely to lead to action to address climate change.

Social factors such as the process and culture of education can shift willingness to adopt mitigation measures for climate change (Shealy et al. 2017a). However, focusing on the social implications of climate change is only helpful if students see themselves and their community as likely to be affected. Lack of personal risk perception about climate change is a barrier to taking action (Weber 2011). People who hold higher levels of personal responsibility also hold temporal and spatial perceptions about climate change that are consistent with science (Kellstedt et al. 2008).

Having an understanding about the social and technical effects from climate change is especially critical for students studying civil engineering. Through their engineering decisions, these students will determine energy use and environmental degradation for decades. Civil engineering students will make decisions that not only account for current costs but also more

accurately weigh future consequences of their choices on community well-being and quality of life. They will be faced with both the social implications of climate change (e.g., large population shifts due to climate migration) and technical implications (e.g., increased erosion and salt water intrusion to water systems due to sea level rise). Just as framing climate change about birds motivates birdwatchers to take action, framing climate change issues as relevant to the discipline may also motivate civil engineering students.

Comparing how students from various disciplines of engineers think about climate change is imperative to understand how the current engineering education ecosystem trains students to understand and want to address climate change. There is promising evidence that civil engineering students may be better equipped for climate change; they are more likely to take courses about sustainability than other engineering students but this does not increase the likelihood they believe in human caused climate change (Coleman et al. 2018). Civil engineering involves interaction with the public and designing systems that directly service the public. In light of these differences in training, we investigated whether civil engineering students were more likely to recognize the social issues associated with climate change than students from other engineering disciplines.

Research Questions

The purpose of the research presented in this paper is to understand how civil engineering students compare to other engineering disciplines in their beliefs about global warming, misunderstanding of climate science, and whether they view global warming as a technical or social issue. The research questions are:

1. What do civil engineering students believe about human-caused global warming?

a. How do civil engineering students' beliefs about human-caused global warming compare to engineering students from other disciplines?

2. What aspects of climate science are misunderstood among civil engineering students?
    a. How do civil engineering students' understanding about climate science compare to engineering students from other disciplines?
3. How do civil engineering students perceive global warming, either as a technical or social issue?
    a. How do civil engineering students' views about global warming being a technical and social issue compare to engineering students from other disciplines?

Methods

A national sample of senior engineering students completed a survey in Spring and Fall of 2018. The sampling frame included four-year institutions chosen from the National Center for Education Statistics institutional database. A stratified random list was created by categorizing institutions by undergraduate engineering enrollment, including small (< 5,400), medium (5,400-14,800), and large institutions (> 14,800). This approach was used to avoid oversampling from a few large institutions or the numerous small institutions in the United States.

Capstone instructors were contacted and asked to distribute the survey. A total of 90 capstone instructors returned surveys from students in their class. No incentives were given to the capstone instructors or students for completing the survey. Capstone instructors received paper surveys by mail, along with instructions to distribute the surveys to their class. Instructors returned completed surveys from their students for a total sample of 4,364 senior engineering undergraduate students.

Students were removed if they did not respond to specific survey questions that were used for analysis. Students from four disciplines were also removed from the analysis because of small sample size (below 30 respondents per discipline). The disciplines removed from analysis included mining, nuclear, agriculture/biological/biosystems, and engineering physics. Students that did not list a discipline were also dropped from the analysis. The total number of students included for analysis after removing students that did not respond to the specific questions listed below and from under represented disciplines was 2,658.

Of those who disclosed their gender in the survey, 73.4% were men (1950), and 25.1% were women (668), 1.5% indicated non-binary or a gender not listed (40). This percent of male and female students is consistent with the national gender demographics of undergraduate engineering students (Yoder, 2018). The representation by geographic locale was also representative of the current U.S. population. Figure 1 illustrates all of the participants' home zip codes by state. The larger the dot the more students are represented from that zip code. The map was created using ggplot2 (Wickham 2009), a package within R statistical software (R Core Team 2019).

Out of the 2,658 students in the sample, 15.4% were civil engineering students (408). Of the civil engineering students who disclosed their gender in the survey, 74% were men (302), 25.3% were women (103), and the remaining 0.7% indicated non-binary or a gender not listed (3). Table 1 provides the number of students represented in each discipline for all of the 2,658 student sample.

Beliefs about human-caused global warming

To answer research question one about what do civil engineering students believe about global warming, we examined the frequency of responses indicating students strongly agree or agree

with the statements "How much do you agree or disagree with the following statements…" with the following statements, "I am sure that global warming is happening," "Global warming is caused by humans," and "Global warming is an important issue to me personally."

Another question asked about the perceived action society should be taking to address climate change. The question specifically asked, "To what extent do you disagree or agree with the following…," followed by "we should be taking stronger actions to address climate change." A chi-square test was used to compare civil engineering student responses to engineering students from other disciplines on these statements. A chi-square test is appropriate because it tests to see whether distributions of categorical variables differ between groups.

Misunderstanding of climate science

Multiple survey items were used to answer research question two about students' misunderstanding of climate science. The *first survey item* asked students about their understanding of causes of climate change. The question asked, "I believe that a cause of global climate change is…" with ten items and an anchored numerical scale from "(0) Strongly disagree to (4) Strongly Agree". The items that contribute to global warming are italicized: "*Burning fossil fuels*," "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." Student responses were scored for students who indicated strong or moderate agreement (or disagreement) with each statement. The response items with small impact on global warming include: "nuclear power generation," "the ozone hole in the upper atmosphere," "dumping trash into our oceans," "agricultural use of chemical fertilizers," "volcanic eruptions," and "acid rain." The byproducts of nuclear power generation are bad for the environment and animals but the production of

276 nuclear energy does not directly contribute to global warming. In addition, the ozone hole in the
277 upper atmosphere does not directly contribute to global warming. This is a common
278 misconception among students (Andersson and Wallin 2000). Dumping trash into our oceans
279 creates ocean pollution. This is also bad for the environment and animals (US EPA 2015a) but
280 not a direct contribution to global warming. Similarly, agricultural use of chemical fertilizers and
281 acid rain are detrimental to the environment and animals but the direct contribution to global
282 warming is low. Volcanic eruptions can impact the climate (USGS 2018). For instance, during
283 major explosive volcanic eruptions gasses are injected into the stratosphere, but most of it is
284 removed within several days to weeks and has little impact on long-term global warming (USGS
285 2018). The number of student responses that agree with these items were summed for a total
286 score ranging from a minimum of zero to a maximum of ten.
287 A t-test was used to compare scores between civil engineering and students from other
288 engineering disciplines for the overall knowledge about sources of climate change. In addition,
289 the rates of correct response on individual items were compared between civil engineering
290 students and students from other engineering discipline using a chi-square test to understand
291 individual concepts. Bonferroni correction was used to adjust for the multiple comparisons
292 (Sedgwick 2012). Results that meet the adjusted confidence interval are italicized in Table 3.
293 The second survey item asked about students understanding of ways to reduce or slow
294 down climate change. The question asked, "I believe a way to help reduce or slow down climate
295 change is …" with ten items and an anchored numerical scale from "(0) Strongly disagree to (4)
296 Strongly Agree". The items that help reduce or slow down global warming are italicized:
297 "*Building more nuclear power stations instead of coal power stations*," "*planting more trees in*
298 *the world*," "*making more of our electricity from renewable energy resources*," "recycling

more," "*not wasting electricity*," "fertilizing the oceans to make algae grow," "*changing lifestyles to reduce consumption*," "limiting the use of aerosol spray cans," "*increasing public transportation*," and "*eating less meat*." Using the same procedure described above, correct student response for these items were totaled. A t-test was used to compare correct scores between civil engineering and students from other engineering disciplines for the overall score, and a chi-square test was used to compare correct responses on individual items. Bonferroni correction was applied when multiple items were being compared (Sedgwick 2012). Results that meet the adjusted confidence interval using Bonferroni correction are italicized in Table 4.

The third survey item asked students, "Which of the following… (Mark one per row)" with the following statements, "is the most abundant greenhouse gas?" (correct response: Water vapor H_2O) "amplifies the greenhouse gas effect the most?" (correct response: Methane CH_4) "should we be most concerned about when thinking about global warming?" (correct response: Carbon Dioxide CO_2), with the following response options: "Carbon Dioxide CO_2", "Water vapor H_2O", "Methane CH_4", "Oxygen O_2", and Ozone O_3". A chi-square test was used to compare the percentage of correct responses among civil engineering students to other engineering students.

Another survey item asked, "What percentage of climate scientists think that human-caused global warming is happening?" with response options, "0 – 10," "11 –50," "51-89," and "90-100%." The correct response is "90-100%." A chi square test was used to compare the percentage of correct responses among civil engineering students compared to other disciplines of engineering students.

The final survey item about misconceptions asked, "How much do you agree or disagree with the following statements about Earth's climate?" providing an anchored numerical scale

from "(0) Strongly disagree" to "(4) Strongly Agree" (true statements are italicized): "The Earth's climate has remained pretty much the same for millions of years," "The greenhouse effect and global climate change are likely unrelated," "Global warming is happening because too many of the sun's rays get to the earth," "*Global climate change is accelerated by the melting of snow and ice-covered surfaces*," "If human civilization had never developed, there would be no greenhouse effect," "*An increase in the greenhouse effect is causing global climate change*," "Climate and weather are basically the same thing," and "There is no definitive proof that either the greenhouse effect or global climate change exist." A chi-square test was used to compare the percentage of correct responses for each item among civil engineering students to other engineering students. Bonferroni correction was used to adjust for the multiple comparisons. Results that meet the adjusted confidence interval are italicized in Table 5.

Perceptions of global warming as a technical or social issue

To answer research question three about perceptions of global warming being a technical or social issue, the survey question asked students, "I believe that global warming is a(n)…" with eleven items and an anchored numerical scale from "(0) Strongly disagree to (4) Strongly Agree". The eleven items included: "Environmental issue," "religious issue," "social justice (fairness issue)," "political issue," "scientific issue," "engineering issue," "health issue," "economic issue," "national security issue," "agricultural (farming, food) issue," or "poverty issue."

An exploratory factor analysis was used to understand which items grouped together in students' response patterns. From this analysis, two factors emerged: technical and social issues (see Table 2). The technical issue items include environmental, scientific, engineering, health, economic, and agricultural. The social issue items include religious, social justice, political,

national security, and poverty. The factor loadings are were acceptable (> 0.40 with no cross-loading items). The Root Mean Squared Error of Approximation for the model is 0.085, and the Tucker-Lewis Index is 0.935, which suggests a moderate to a good fit of the model (Xia and Yang 2019).

A "technical" and "social" score for each student was derived by taking mean anchored scores for each factor. Civil engineering student mean scores for each factor were compared to students from other engineering disciplines using a one-way ANOVA test.

Results

The overwhelming majority of civil engineering students and students from other engineering disciplines believed in human-caused global warming and its effects on climate change

We examined beliefs of civil engineering and other engineering students on these topics and found no statistically significant difference. Eighty three percent of civil engineering students (n = 339) acknowledged that global warming is happening. Eighty one percent of other engineering students also acknowledge that global warming is happening ($\chi^2(1) = 0.974$, $p = 0.328$). About three out of four civil engineering students (73.5%, n = 300) and other engineering students (71.3%, n = 1580) believed that global warming is caused by humans ($\chi^2(1) = 0.737$, $p = 0.39$). Similarly, about three out of four (74%, n = 305) civil students and other engineering students (72%, n = 1588) believed that we should take stronger action to address climate change ($\chi^2(1) = 1.49$, $p = 0.22$). Half of civil engineering students (55.6%, n = 227) and other engineering students (52.3%, n = 1158) felt that global warming is personally important to them ($\chi^2(1) = 1.44$, $p = 0.22$).

Students struggled to identify the factors and driving forces behind global warming

On items measuring understanding the causes of climate change, civil engineering students answered fewer than half of the questions correctly, 42% on average. This percentage is significantly less than students from other engineering disciplines ($t = 2.35$, $p = 0.019$) who correctly answered 45%. More than half of civil engineering students (60%) believed nuclear power generation is a cause of global warming. This response is significantly more than students from other engineering disciplines (52.6%; $\chi^2(1) = 21.768$, $p < 0.001$). About eight in ten civil engineering students (83%), and students from other engineering disciplines (79%), incorrectly believed or were unsure that the ozone hole in the upper atmosphere is a cause of global warming. About half of civil engineering students (51%) and other engineering students (55%) recognize that livestock production is a cause of global warming. More than seven in ten civil engineering students (75%), and students from other engineering disciplines (77%), believed or were unsure dumping trash into our oceans is a cause of global warming and half (49%) did not recognize that the methane from the waste rotting in landfills is a cause of global warming. Table 3 provides the percent correct for civil engineering students compared to students from other engineering disciplines.

The second survey item asked about students' understanding of ways to reduce or slow down climate change. Civil engineering and other engineering students both correctly answered just half (54%) of the questions about ways to reduce or slow down climate change. Civil engineering students (46%) were more likely to be unsure, disagree, or strongly disagree that building more nuclear power stations instead of coal power stations can reduce or slow down climate change compared to students from other engineering disciplines (38%; $\chi^2(1) = 8.578$, $p = 0.003$). The overwhelming majority of students, both civil and others, associated reducing the effects of climate change with recycling. Similarly, the majority of students, both civil and

others, associated reducing the effects of climate change with fertilizing the oceans to make algae grow and limiting the use of aerosol spray cans. Yet, both civil engineering students and students from other disciplines did not associate eating less meat with reducing the effect of climate change.

Students misunderstand climate science

In addition to misunderstanding methods for reducing or slowing down climate change, civil engineering students did not understand the fundamental science and mechanisms of climate science. No significant differences were found in several areas. The overwhelming majority of civil engineering students (90%) and other engineering students (86%) did not recognize the most abundant greenhouse gas is water vapor. Additionally, the majority of civil engineering students (70%) and other engineering students (65%) incorrectly believed the most abundant greenhouse gas is carbon dioxide. Civil engineers (62%) and other engineers (61%) also did not recognize that methane gas amplifies the greenhouse gas effect more than carbon dioxide and only half of civil engineers (51%) and other engineers (56%) believed carbon dioxide is the greenhouse gas society should be most concerned with when thinking about global warming. The majority of civil engineering students (53%) and other engineering students (52%) also did not recognize that 90-100 percent of climate scientists think that human-caused global warming is happening.

The majority of civil engineering students (54%) believed or were unsure global warming is happening because too many of the sun's rays get to the earth. The majority of both civil engineering (56%), and other engineering students (58%), strongly disagreed, disagreed, or were unsure that global climate change is accelerated by the melting of snow and ice-covered surfaces. The majority of civil engineering students (55%) incorrectly believed if human civilization had

never developed, there would be no greenhouse effect. This misunderstanding is significantly ($\chi^2(1) = 8.103$, $p = 0.004$) more than students from other engineering disciplines (47%). The percent correct of the items about statements on Earth's climate among civil engineering students and students from other engineering disciplines are listed in Table 5.

Engineering students overwhelming believe that global warming is more of a technical issue than a social issue

Both civil engineering students and students from other engineering disciplines saw global warming as a technical issue (civil $M = 3.24$, $SD = 0.85$; other $M = 3.17$, $SD = 0.91$) rather than a social issue (civil $M = 2.03$, $SD = 1.06$; other $M = 1.97$, $SD = 1.06$). Figure 2 illustrates the distribution of scores between strongly disagreed (0) and strongly agreed (4). The items broadly about technical issues have a negative skew compared to items related to social issues, which are more normally distributed with floor and ceiling effects.

Similar to other engineers, the percentage of civil engineering students that associated global warming with the technical aspects (environmental, scientific engineering, health, economic, and agricultural issue) is higher than the percentage of students who associated global warming with social aspects (social justice, national security, or poverty). Table 6 provides the percent frequency for each of the eleven aspects for civil engineering students. The distribution and percent frequency of civil engineering students was similar to students from other engineering disciplines.

Discussion

The results of this work provide some useful insight into engineers', both civil and non-civil degrees, belief in and understanding of climate change. The percent of senior civil engineering students (83%) and students from other engineering disciplines (81%) who believed that global

436 warming is happening is higher than the general public (73%; Leiserowitz et al. 2020).
437 Additionally, the percent of senior civil engineering students (74%) and students from other
438 engineering disciplines (71%) that believe climate change is caused by humans is also higher
439 than first-year civil engineering students (53%; Shealy et al. 2017b). This higher percent of
440 senior engineering students that believed in human-caused climate change compared to first-year
441 students is encouraging given the challenges these students, in particular civil engineering
442 students, will face in their careers (NAE 2012; Russell 2019). Overall, many civil engineers have
443 a solid belief in climate change. This increase demonstrates progress towards changing civil
444 engineers' skepticism in anthropogenic climate change (Grubert 2018). However, a limitation of
445 these findings is answering if the increase in belief was a result of education in college or other
446 factors. Belief in climate change is at its all-time high among the general public (Leiserowitz et
447 al. 2020). The time period between data collection between first-year and seniors is also more
448 than six years, and although the sample groups are representative, they do not include the same
449 students. Future research should explore the causes for change in beliefs among civil engineering
450 students as a way to continue to develop sustainably conscious engineers.
451 While the percent of senior civil engineering students who believed in global warming
452 and its effect on the climate is higher than first-year students and the general public, these
453 students still struggled to identify the causes and methods for climate change mitigation. More
454 than half of senior civil engineering students believed nuclear power generation is a cause of
455 global warming and this was significantly higher than other senior engineering students. They
456 were also more likely to believe the hole in the upper atmosphere is a cause of global warming.
457 One explanation is civil engineering students recognize general problems (like nuclear waste and
458 the ozone hole) but they do not link particular causes with particular consequences (Boyes and

459 Stanisstreet 1993). This fits within Chi's (2005) model of misconceptions, which says students
460 naturally categorize concepts into broad ontological categories and have trouble with cause and
461 effect. Overall, these trends are concerning and indicate potential opportunities to correct
462 prevalent misconceptions in engineering education.

463 Similar misconceptions among students about nuclear power generation and the ozone
464 layer were observed more than two decades ago (Boyes and Stanisstreet 1998; Fisher 1998).
465 Though, more recently seventh grade students did not link the ozone hole to global warming and
466 climate change (Shepardson et al. 2009). An explanation for why senior engineering students
467 seemed to hold greater misconceptions about the causes of climate change compared to seventh
468 graders is these misconceptions have become embedded in frameworks of knowledge (Chang
469 and Pascua 2016). Misconceptions built within structurally sound mental models are more
470 challenging to change (Goris and Dyrenfurth 2010). One possible mental model is viewing
471 climate change as an object rather than a process. Students tend to hold an "object bias," a
472 tendency to treat processes as objects. This model can become a mental block, preventing
473 students from adopting appropriate mental models to analyze the process of climate change
474 (Chen 2011). Within the object model, students can use the pattern matching heuristic to make
475 correlations. For example, viewing nuclear waste as related to energy generation and nuclear
476 waste being bad for the environment.

477 This association may explain why nearly half of civil engineering students (46%) were
478 unsure, disagreed, or strongly disagreed that building more nuclear power stations instead of coal
479 power stations can reduce or slow down climate change. Similarly, the overwhelming majority
480 of students, both civil and others, associated reducing the effects of climate change with
481 recycling. On a global scale, recycling can contribute more to reducing global warming, but

individually, its primarily good civic behavior that can lead to other positive ecological choices (van Ewijk et al. 2021; MacBride 2011). Recycling may also have negative effects due to single action bias (Truelove et al. 2016). The association between making good individual ecological choices may help explain why students attributed limiting the use of aerosol spray cans with reducing the effects of climate change. They recognized the effect of aerosol on the ozone and associated its reduction as good for the climate.

Some of these misconceptions may also be related to not understanding basic climate science. The majority of civil engineering students believed global warming is happening because too many of the sun's rays get to the earth and incorrectly believed if human civilization had never developed, there would be no greenhouse effect. Not understanding basic climate science is noted in many other educational studies about climate change among middle and high school students (Monroe et al. 2019). One possible approach to correcting this gap in knowledge is through conceptualizing climate change using systems thinking (Shepardson et al. 2012).

Civil engineering students overwhelmingly believed that global warming is more of a technical issue and less of a social one. Treating climate change as a systems problem can help bridge the divide between technical and social aspects. One reason why civil engineering students may have perceived climate change as more of a technical problem and less of a social one is their focus on technical solutions in engineering (Zummo et al. 2020). Students tend to focus on a solution-oriented discourse when talking about climate change (Zummo et al. 2020). Students also create their engineering identity from the courses they take and their co-curricular experiences (Potvin et al. 2013). Engineers tend to focus more heavily on the technical aspects rather than the context and impact of their engineering solutions on society. For example, framing climate mitigation strategies about the co-benefits for public health is shown to help

students learn (Adlong and Dietsch 2015). Making the connection between engineering and societal problems may also help attract more diverse students to engineering (Klotz et al. 2014).

Actions to correct misconceptions about climate change

Based on the results of this study, implications are provided for civil engineering educators that may help address key concerns related to civil engineering students' misconceptions about climate science and their beliefs about climate change as a technical issue. These actions also leverage some of the positive findings in this work, which found that the majority of graduating civil engineering students believe in human-caused climate change.

Changing the rhetoric in manuals like the Civil Engineering Reference Manual, to not use language associated with climate change skepticism may help students confirm their belief in climate change (Grubert 2018). Adding questions about climate science to the Fundamentals of Engineering (FE) exam and the Principles and Practice of Engineering (PE) exam may motivate students to correct their misconceptions. More than 10,000 engineers take the FE and 9,000 engineers take the PE each year. Offering more continuing education courses to help students after graduation learn about climate science (e.g., Stoner n.d.) may also help.

There should also be more emphasis on training engineering faculty about climate science and providing resources for them to introduce the concept into existing courses. Engineering faculty integrating sustainability topics, like climate change, into their curriculum still struggle with the best methods (Burke et al. 2018). Topics related to sustainability, such as climate change, are also generally taught in the later years of undergraduate students' education (Burke et al. 2018). Incorporating climate science and the effects of climate change earlier into the education process may help address misconceptions before they become rooted within structurally sound mental models (Chen 2011). The research presented in this paper

provides faculty with the types of misconceptions that are common among students. Developing rebuttals and factual content for these misconceptions can be helpful (Sezen-Barrie et al. 2019).

Conclusion

We surveyed 4,364 senior engineering students across the United States (2,658 were used for this analysis, including 408 civil engineering students) about their beliefs and understanding of global warming and its effect on climate change. The responses indicated civil engineering students, and other engineering students, overwhelmingly believed global warming is happening and that humans are causing global warming. Unfortunately, these students misunderstood many of the actions that contribute to global climate change and methods for mitigating it. These misconceptions and the frequency of misconception among civil engineering students is troubling given these students will face increasing challenges due to climate change in their careers. Civil engineering students, and other engineering students, predominately believed climate change is a technical issue and less of a social one. Educational interventions, testing requirements, and faculty training are possible opportunities to help civil engineering students correct misconceptions and faulty mental models before they enter the workforce. Framing climate change as related to people and helping students develop a system view about the climate may help change perspectives and the limited point of view of climate change being predominately a technical problem.

Data Availability

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request. Data available includes the de-identified national sample of student responses to the survey described in the methods. The models available include the models described in the methods section used to generate the results.

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Table 1: Number of students by discipline

Number	Discipline	Counts	% of Total
1	Aerospace/Ocean/Astro	69	2.60
*2	Agricultural/Biological/Biological Systems	16	0.60
3	Bioengineering/Biomedical	127	4.78
4	Civil Engineering	408	15.35
5	Chemical	506	19.04
6	Constructional Engineering/Management	33	1.24
7	Computer	91	3.42
8	Electrical	267	10.05
*9	Engineering Physics	4	0.15
10	Environmental/Ecological	96	3.61
11	Industrial/Systems	108	4.06
12	Materials	52	1.96
13	Mechanical/Manufacturing	600	22.57
*14	Mining	12	0.45
*15	Nuclear	2	0.08
16	Software Engineering/Computer Science	126	4.74
17	Structural/Architectural	90	3.39
18	General	51	1.92
	Total	2658	100

Note: * denotes disciplines removed from analysis because of low sample size

790 Table 2. Factor loading variance

	Technical	Social	Uniqueness
Environmental	0.776	.	0.460
Religious	.	0.679	0.638
Social justice	.	0.744	0.451
Political	.	0.403	0.669
Scientific	0.879	.	0.300
Engineering	0.903	.	0.204
Health	0.705	.	0.328
Economic	0.563	.	0.367
National security	.	0.605	0.463
Agricultural	0.686	.	0.380
Poverty	.	0.689	0.409

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793 Table 3: Percent correct to the question "I believe that a cause of global climate change is…"

Item	Percent correct civil students (n)	Percent correct other students (n)	χ^2	*p*
Burning fossil fuels	88 (359)	83 (1847)	5.202	0.022
Nuclear power generation	*40 (163)*	*52 (1167)*	*21.768*	*<0.001*
The ozone hole in the upper atmosphere	17 (69)	21 (473)	3.865	0.049
Livestock production	51 (208)	55 (1220)	2.143	0.143
Dumping trash into our oceans	25 (101)	23 (520)	0.249	0.617
Waste rotting in our landfills	51 (208)	51 (1128)	< 0.000	0.98
Agricultural use of chemical fertilizers	22 (90)	25 (547)	1.152	0.282
Deforestation	77 (314)	76 (1672)	0.348	0.554
Volcanic eruptions	19 (76)	20 (447)	0.422	0.515
Acid rain	22 (135)	38 (838)	3.101	0.078

794 Note: Italicized indicates meeting the adjusted confidence interval using Bonferroni Correction
795 ($p < 0.005$).
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Table 4: Percent correct to the question "I believe a way to help reduce or slow down climate change is…"

Item	Percent correct civil students (n)	Percent correct other students (n)	χ^2	*p*
Building more nuclear power stations instead of coal power stations	*54 (220)*	*62 (1369)*	*8.578*	*0.003*
Planting more trees in the world	82 (334)	80 (1771)	0.703	0.402
Making more of our electricity from renewable energy resources	88 (360)	87 (1929)	0.336	0.562
Recycling more	5 (19)	7 (155)	2.675	0.102
Not wasting electricity	77 (316)	78 (1731)	0.054	0.817
Fertilizing the oceans to make algae grow	30 (121)	26 (570)	2.551	0.110
Changing lifestyles to reduce consumption	79 (321)	76 (1688)	1.068	0.301
Limiting the use of aerosol spray cans	19 (76)	17 (379)	0.457	0.499
Increasing public transportation	73 (298)	67 (1481)	5.799	0.016
Eating less meat	37 (152)	38 (847)	0.099	0.753

Note: Italicized indicates meeting the adjusted confidence interval using Bonferroni Correction ($p < 0.005$).

803 Table 5: Percent correct to the question "How much do you agree or disagree with the following
804 statements about Earth's climate?"

Item	Percent correct civil students (n)	Percent correct other students (n)	$\chi 2$	*p*
The Earth's climate has remained pretty much the same for millions of years	64 (260)	66 (1463)	0.706	0.40
The greenhouse effect and global climate change are likely unrelated	71 (288)	72 (1599)	0.346	0.557
Global warming is happening because too many of the sun's rays get to the earth	46 (187)	53 (1170)	6.417	0.011
Global climate change is accelerated by the melting of snow and ice-covered surfaces	44 (181)	42 (939)	0.479	0.49
If human civilization had never developed, there would be no greenhouse effect	*44 (183)*	*53 (1167)*	*8.103*	*0.004*
An increase in the greenhouse effect is causing global climate change	63 (255)	62 (1382)	<0.001	0.997
Climate and weather are basically the same thing	67 (272)	68 (1512)	0.319	0.572
There is no definite proof that either the greenhouse effect or global climate change exist	64 (262)	69 (1529)	3.42	0.064

805 Note: Italicized indicates meeting the adjusted confidence interval using Bonferroni Correction
806 ($p < 0.006$).
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809 Table 6: Percent frequency of civil engineering students' responses for each item

Factor	**Item**	**0-Strongly disagree (%)**	**1**	**2**	**3**	**4-Strongly agree (%)**
Technical	Environmental	2.45	0.74	6.13	19.12	71.57
	Scientific	3.19	1.96	8.33	22.30	64.22
	Engineering	3.19	2.45	10.54	23.77	60.05
	Health	5.15	6.13	12.50	26.23	50.00
	Economic	6.13	9.56	18.38	25.49	40.44
	Agricultural	4.66	2.94	14.71	28.19	49.51
Social	Religious	52.21	15.93	13.97	6.86	11.03
	Social justice	25.74	10.29	22.79	18.87	22.30
	Political	10.78	6.62	15.44	25.98	41.18
	National security	17.89	14.46	28.43	15.44	23.77
	Poverty	19.12	14.46	24.75	17.65	24.02

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Figure Captions

Figure 1: Participants' home locations based on zip code

Figure 2: Number of civil engineering students who strongly disagree (0) to strongly agree (4) global warming is a technical or social issue