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Long-term impact on environmental attitudes and knowledge assessed over three semesters of an environmental engineering sequence

Abstract

The pedagogy employed in a three-course environmental engineering sequence is investigated to determine the efficacy of enabling long-term improvement of knowledge and attitudes toward the environment. These three courses incorporate concepts of the five grand challenges released by the National Academy of Engineering and National Academy of Sciences and increase the breadth of knowledge for T-professionals. Previous studies of lengths from a few weeks to semester long courses evaluated the potential causality among various demographics and environmental knowledge and attitudes. The research presented herein contrasts and compares changes in environmental knowledge based upon a 12-question survey and changes in environmental attitude based upon a seven-question survey administered at the beginning and end of the environmental engineering sequence courses taught to over 200 students from a variety of disciplines. Survey results demonstrate that a positive increase (9.27%) in knowledge occurred from the start to the end of the first course and the elimination of statistical differences among numerous demographics such as sex and race. After 18 months of environmental education, an 8.6% increase in knowledge was retained compared to the initial knowledge where the female and non-white demographics increased the most but retained the least. Results regarding environmental attitudes suggest that a focus on learning about environmental issues decreased positive attitudes toward the environment, whereas focusing on solutions to environmental issues increased positive attitudes toward the environment. Evaluating changes or sustainment of improved environmental attitudes over three semesters demonstrates the potential for an environmental engineering education to have a multi-year impact on the values and environmental ethos of students across many disciplines.

Background and Introduction

The environmental problems of today have recently been organized into the five grand challenges released by the National Academy of Engineering (NAE) and National Academy of Sciences (NAS) in "Environmental Engineering for the 21st Century: Addressing Grand Challenges" [1]. The five grand challenges are (1) sustainably supply food, water, and energy; (2) curb climate change and adapt to its impacts; (3) design a future without pollution and waste; (4) create efficient, healthy, resilient cities; and (5) foster informed decisions and actions [1]. These grand challenges align with the issues presented and discussed in the Engineer of 2020 [2] and the United Nations' Sustainable Development Goals (SDGs) [3]. The Engineer of 2020 called for engineers to not only be technical experts but be leaders in business and government to help build a more sustainable future [2]. The SDGs seek to transform our world by increasing the environmental and social equality of the developing world through sustainable, multidisciplinary innovation [3]. Many of the world's leading industries take social, economic, and environmental impacts of their work into consideration. This is evident in the triple bottom line approach, referred to with the three P's of people, planet, and profit [4], [5]. Incorporating environmental, economic, and social responsibility into a profitable business requires multidisciplinary teams with diverse competencies. Professionals who not only have a great depth of knowledge in their field, but also broad experiences in other fields, will thrive best in this multidisciplinary team setting [6]. One illustrative and helpful model that industry has embraced is the idea of a T-professional [6]. T-professionals acquire a breadth of multi-disciplinary experiences as well as disciplinary depth. This is accomplished by developing competencies that span all professions, including teamwork, communication, and critical thinking, while simultaneously gaining exposure to many disciplines and systems [6]. Finally, T-professionals achieve disciplinary depth, while retaining the ability to interact with the broader competencies to which they were exposed [6]. They can then use this diverse experience and knowledge to interact with others in different disciplines [6]. Engineering programs at universities have begun to adopt this concept more specifically as the T-shaped engineer, enabling technical professionals to better interact with a variety of stakeholders, such as lawyers, scientists, decisionmakers, politicians, and other engineering professionals [7]. We have applied this model to develop the "T-shaped professional" which we define as a non-engineer professional with technical engineering experience (breadth) to complement their disciplinary depth.

Previous studies have looked at how knowledge and attitudes toward the environment have changed based on the educational experiences of students. Prior research has included the effects of high school students taking a dedicated 10-day environmental course [8] and undergraduate students within a variety of educational experiences [9], [10]. One study evaluated the impact of a dedicated, semester long environmental course on the attitudes and knowledge of students from diverse backgrounds [11]. In that study, Martinez found that taking a semester long environmental course enabled previous demographic differences in students' knowledge and attitudes to become statistically similar, resulting in improved knowledge across all demographics as well as increases in environmentally conscious attitudes [11]. Previously, the diversity metrics evaluated by Martinez had been investigated separately, including student age [9], hometown [12], [13], major [13], [14], and parents' education [15]. Another study looked at the same changes in attitudes through a second environmental course that focused on environmental engineering design in the developed world [16]. In that study, Plante found no statistical decrease in environmentally-friendly attitudes of the students after the second semester of the environmental engineering sequence course, despite the transition for non-engineering majors from a science-focused course to a math-focused course. While this was certainly desired, it was surprising because non-engineering majors were anecdotally much less comfortable in the second course (EV350) [17] of the sequence than in the first course (EV300) [16].

At the U.S. Military Academy, all students are required to either major in an engineering field of study or take three courses in an engineering discipline [18]. The three engineering courses taken by a non-engineering student are all in one field of engineering and referred to as an engineering sequence. This research focuses on the approximately 200 students (nearly 20% of each graduating class) who take the environmental engineering sequence. Since none of the students in the sequence are environmental engineering majors, this sequence adds to their breadth of competencies and supports one of the academic goals of our institution that upon graduation, all students have the competency to "apply an engineering design process" to achieve "effective and adaptable" solutions [19]. When they serve as professionals in other fields in the future, they will be in a better position based upon knowledge and attitudes to effectively work with environmental professionals on complex, multidisciplinary environmental challenges that require sustainability-focused attitudes [1], [6].

The environmental engineering sequence consists of three courses. The first course (EV300) covers a broad spectrum of the science behind environmental issues that align with the first two grand challenges. The students learn of earth as system and how human interactions permeate issues of strained resources and energy usage and how these challenges lead to modern problems like climate change. These experiences are punctuated with engaging guest lecturers, in-class debates on current topics, problem sets requiring students to apply learned knowledge on each topic, and successful completion of a group scientific research project [16]. The second course (EV350) focuses on the environmental engineering design solutions needed to address these problems in the developed world, which provides students with the framework to understand the design solutions for the third and fourth grand challenges while still considering the first two grand challenges. They are introduced to these design problems through engaging classroom experiences and in-class demonstrations, practice through working an individual engineering design project, and solidify their understanding through group lab experiences and field trips to both drinking water and wastewater treatment plants [17]. The third course (EV450) allows the students to employ innovative engineering solutions to constrained environments in the developing world. This allows students to apply the fifth grand challenge, which incorporates aspects of the first four grand challenges. A complete description of the content of each course is available in the Red Book [19]. See Figure 1 for a depiction of how the environmental engineering sequence addresses the grand challenges.

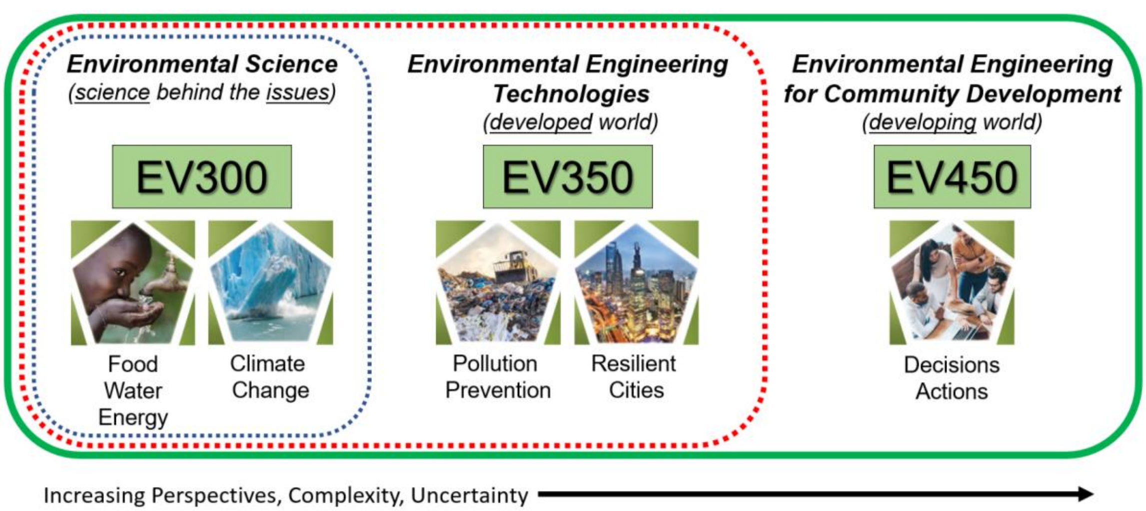

Figure 1: The three-course environmental engineering sequence addresses each of the five grand challenges.

Environmental problems, like those identified in the grand challenges, inherently require interdisciplinary solutions. As noted by James Madison University in 2000, environmental problems are best addressed by a team with knowledge of technology, science, economics, and politics, as opposed to a team consisting solely of elite environmental professionals [20]. Environmental engineers often synchronize among engineers, lawmakers, business leaders, and communities to achieve sustainable solutions that solve problems [1]. This is where the value of the T-shaped environmental engineer is most profound. Figure 2 shows where the engineering sequences aligns within the complete developmental experience at our institution. The students in our three-course curriculum are undergraduate non-engineers, so the vertical part of their T is not engineering; it is the 15 courses they will take in their disciplinary depth. They gain a variety of other multidisciplinary experiences through the 22 core curriculum courses. The engineering sequence gives them a STEM breadth, which builds their knowledge of the environment and has the potential to influence their environmental ethic [21]. We educate these students to view challenges from an environmental perspective. These T-professionals of other disciplines who take the environmental engineering sequence bridge the divide among disciplines that would otherwise be accomplished by environmental engineers. Examples of these contemporary issues include addressing urgent vapor intrusion risk at a Naval base in California [22], characterizing the potential risk of food irrigated with hydraulic fracturing flowback water [23], or mitigating the impacts of sea-level rise on a major economic port, like New York City [24]. The focus of this study is to evaluate the ability of an environmental engineering sequence to enable students from multidisciplinary fields of study and a range of diverse demographic backgrounds to gain environmental engineering disciplinary breadth that provides background to mature their attitudes toward environmental issues over an 18-month period.

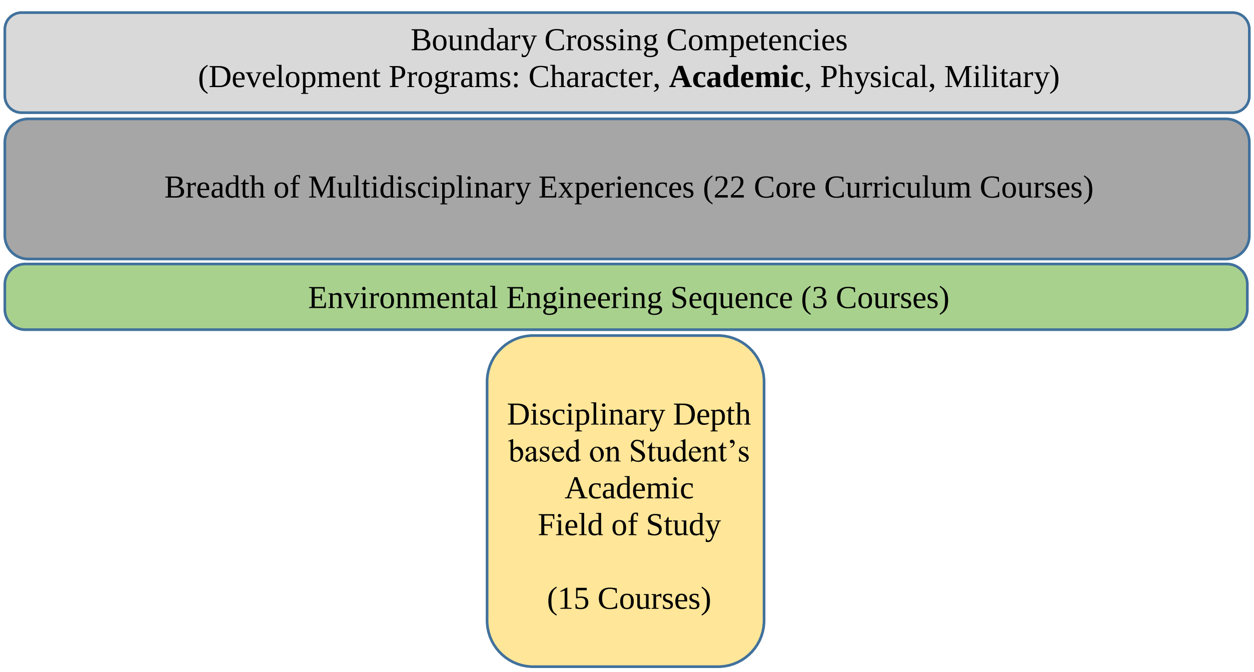

Figure 2: T-shaped professional model augmented with the environmental engineering expertise through the environmental engineering sequence and showing all 40 undergraduate courses.

Methods

This study took place over three semesters with 116 respondents taking the survey throughout their environmental engineering education. Demographic factors examined included students' self-identified gender (male, female), hometown population (urban, suburban, rural), race (white, non-white), field of study (STEM, HSS), and parents' highest educational attainment (less than a bachelor's degree, bachelor's degree, graduate degree). The non-white demographic included students who identified as Hispanic/Latino, Black/African American, Asian/Pacific Islander, Native American/American Indian, Other, or no response preferred. However, these demographics were grouped under the umbrella of non-white students to enable a larger population for consideration. The field of study categorized as STEM included such majors as life science, math, environmental science, and geospatial information science), whereas HSS related to majors such as defense and strategic studies, human geography, sociology, history, languages, and law.

Student environmental knowledge was evaluated using 12 multiple choice questions, and attitudes towards the environment were assessed using a seven-question survey (see Table 1) adapted from the 2000 National Environmental Education and Training Foundation (NEETF)/Roper Survey [25]. Using the NEETF/Roper survey helps standardize assessments and make them more comparable to previous research. Robelia identified a lack of standardization among researches as a significant issue and encouraged future researches to be more consistent in the questions to ask assessed populations [25]. The attitudes survey asked students to express their attitudes on the environment compared to economic considerations for the first two questions, on environmental laws for the third question, and on aspects associated with deriving environmental solutions for questions four to seven using a Likert scale from one to four. Students' knowledge was captured at deliberate points along their environmental education journey which included the start of the first course (EV300 Start), the end of the first course (EV300 End), and the end of the third course (EV450 End). Students' attitudes were captured as the changes from the start to the end of the first course (EV300), the start to the end of the third course (EV450), and from the start of the first course to the end of the third course (sequence). Surveys were administered over the first and last two lessons of the applicable semesters. The numbers of respondents for each demographic are different between the knowledge and attitudes assessment due to individual student participation and availability during the various periods of time when the surveys were administered. This study hypothesis focused on determining if a sustained increase in knowledge and improved environmental attitude occurs equally across a variety of demographics as a result of three courses dedicated to understanding the issues and available solutions to environmental challenges through environmental engineering education.

Table 1. The seven questions and their response choices in the environmental attitudes survey. Adapted from the 2000 National Environmental Education and Training Foundation (NEETF)/Roper Survey [25].

Question	Response Choices
1. Most of the time, do you think environmental protection and economic development can go hand in hand, or that we must choose between environmental protection and economic development?	Can go hand in hand
	Must choose between environment and development
	Depends
	Don't know
2. When it is impossible to find a reasonable compromise between economic development and environmental protection, which do you usually believe is more important: economic development or environmental protection?	Economic development
	Environmental protection
	Depends
	Don't know
3. There are differing opinions about how far we've gone with environmental protection laws and regulations. At the present time, do you think environmental protection laws and regulations have gone too far, or not far enough, or have struck about the right balance?	Gone too far
	Not far enough
	Struck about right balance
	Don't know
4. Technology will find a way of solving environmental problems	Strongly agree
	Mostly agree
	Mostly disagree
	Strongly disagree
5. The condition of the environment will play an increasingly important role in the nation's economic future	Strongly agree
	Mostly agree
	Mostly disagree
	Strongly disagree
6. Private companies should train their employees to solve environmental problems	Strongly agree
	Mostly agree
	Mostly disagree
	Strongly disagree
7. Government agencies should support environmental education programs for adults	Strongly agree
	Mostly agree
	Mostly disagree
	Strongly disagree

Results and Discussion

Knowledge

Environmental knowledge shows a statistical increased from the beginning to the end of EV300 regarding overall scores evaluated using a t-test ($t=5.66$, $t_{crit}=1.97$, 230 d.f., $p=4.38\times10^{-8}$). Compared to the knowledge gained at the end of EV300 (9.27% increase), the mean knowledge score decreased by the end of EV450; however, there was no statistical difference between the knowledge gained during these two time periods. Therefore, knowledge retained at the end of

EV450 was statistically different from the beginning of EV300 ($t=3.52$, $t_{crit}=1.97$, 230 d.f., $p=2.62x10^{-4}$). As shown in Figure 3, across the demographics of gender (male or female), race (white or non-white), and field of study classification (STEM or HSS, humanities and social sciences), knowledge scores were statistically different at beginning of the environmental engineering sequence.

By the end of EV300, knowledge increased across all demographics, and the increase resulted in there being no statistical difference between any of the demographics except for STEM and HSS as noted in Figure 3 due to EV300 end error bars not overlapping. Both populations increased by about 9%. The STEM students exhibited the ability to retain the gains made over the year from the end of EV300 to the end of the sequence (two courses later) as their decrease in the mean of their knowledge was less than 1% and remained more than 8.25% higher than the initial knowledge into the sequence. During each time studied, knowledge was greater for the HSS demographic compared to the STEM demographic. Therefore, the HSS population increased knowledge at a higher rate than STEM which demonstrates the capability of HSS students in engineering focused courses. The most significant increase in knowledge, about 15%, occurred for the demographics of female and non-white students. At the end of the environmental engineering sequence, all demographics remained statistically significantly higher than the knowledge scores at the beginning of the sequence. There was a decrease in mean knowledge score from the end of EV300 to the end of EV450 for all demographics; however, the decrease remained statistically similar to the increase made from the start to the end of EV300 except for the demographics of female, non-white, and HSS students. Although there was a decrease, there still remained a retention in knowledge that exceeded the initial environmental knowledge by 8.6%.

The significance of the results demonstrates that environmental education enabled normalization of performance across almost all demographics. Although there were statistical differences initially, the environmental engineering sequence enabled all demographics to increase their knowledge and demonstrate an ability to retain that knowledge after three courses even though the material evaluated for the knowledge survey was only taught as part of EV300. This retained environmental knowledge provided the background to enable students to mature in their attitudes toward environmental issues. In other words, the breadth of the T-shaped professional was statistically increased based upon comparison with initial environmental knowledge. The deliberate, inclusive classroom environment used throughout the sequence includes activities and group assignments which focus on equal participation by all students. As a result, potential stigmas in the classroom may be lifted in order to allow all to flourish. As stereotypes break down, initial differences in performance from different demographics decrease through the ability of students to perform and learn based upon their capabilities versus pre-conceived capabilities.

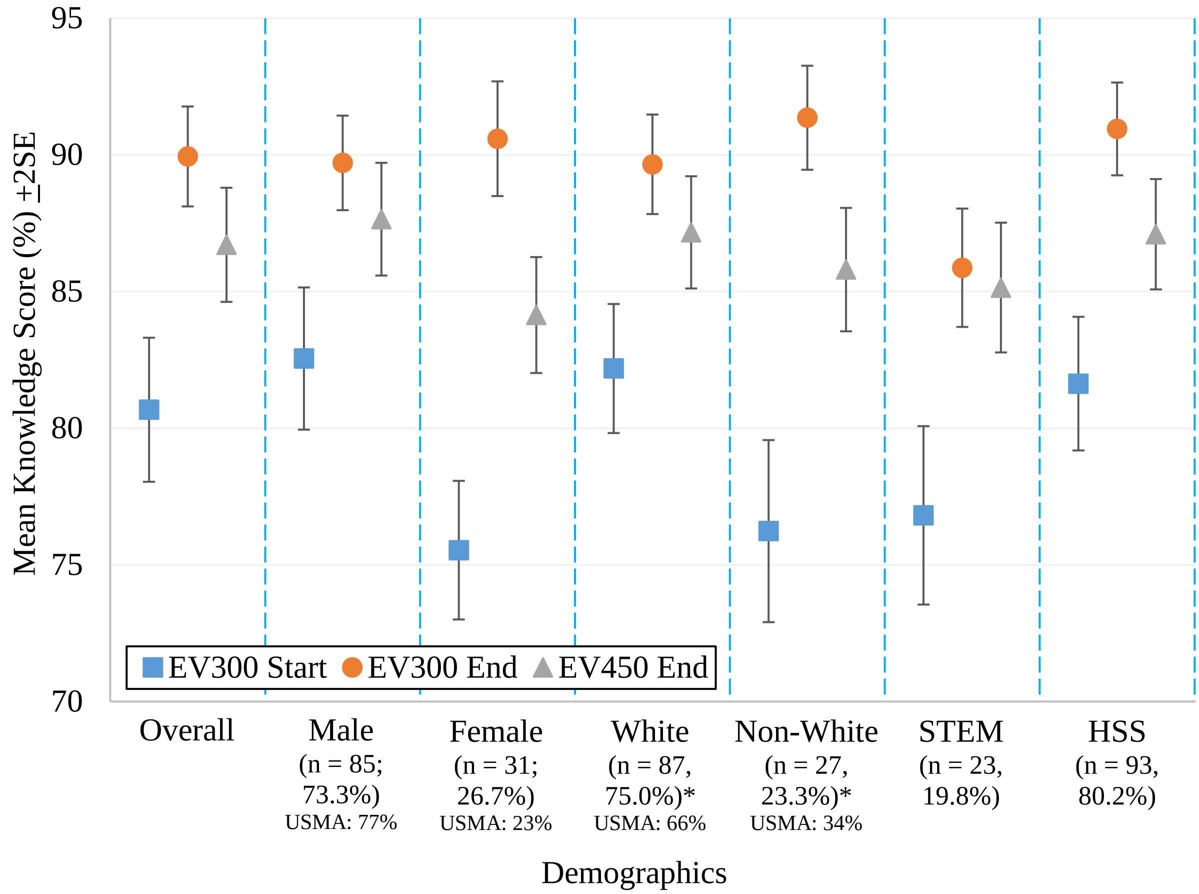

Figure 3. Evaluation of environmental knowledge at various points along the environmental engineering sequence regarding overall performance on all 12 questions as well as performance associated with a variety of demographics. The n-value and percentage of respondents are shown as well as the percentage for the university. The +2SE represents two standard errors which is indicative of the 95% confidence interval. Therefore, error bars that overlap reflect statistically similar data whereas error bars that do not overlap reflect statistically different data. The asterisk denotes percentages that do not add to 100% due to some students not filling out a specific demographic.

Overall, environmental knowledge increased from the beginning to the end of EV300. This is not surprising because EV300 is the course focused on learning environmental knowledge, and this is in line with previous studies [8], [10], [11], [15], [25]. Initial assessments showed that males had more environmental knowledge than females, which has also been found in Robelia's assessment of six previous studies. Statistically significant differences in knowledge were removed by the end of EV300, and although knowledge decreased by the end of EV450, knowledge was still statistically significantly higher after EV450 than it was at the beginning of EV300. No previous study has shown a similar long-term impact of environmental education on increased environmental knowledge based upon consistent survey questions over three semesters.

Attitudes

Overall results of the analysis regarding environmental attitudes yielded similar results across all demographics. As a function of the first course, the overall average change in attitudes exhibited a reduction in environmentally-focused attitudes. Conversely, the overall average change in attitudes occurring after the last two courses of the environmental engineering sequence trended toward more environmentally-friendly responses. These results were still surprising because these non-engineering students took math-based engineering courses in EV350 and EV450. Instead of becoming repelled by the material they were not comfortable with, their attitudes became more environmentally-friendly which aligns with previous research [16]. Perhaps when students focused on learning about environmental issues in EV300, the solutions to environmental issues seemed elusive, and this resulted in a decrease in environmentally-friendly attitudes. And perhaps after studying solutions to environmental issues in EV350 and EV450, the students became more optimistic and enthused about solving environmental problems.

Results for questions four through seven were assessed using a Likert scale of 1 to 4 to denote the relative degree of environmentally focused responses (see Figure 4). Value correlation with responses were 1 for "strongly disagree," 2 for "mostly disagree," 3 for "mostly agree," and 4 for "strongly agree" (see Table 1). The associated value assigned to each response was compared to identify the average change for each time period of interest (beginning to end of EV300, beginning to end of EV450, beginning to end of the sequence). No change in attitude is represented by a value of 0.00, a negative value represents a negative change in attitude toward the environmental, and a positive value represents a positive change in attitude toward the environment. The error bars associated with each marker in Figures 4 corresponds to the 95% confidence interval (two standard errors) for the data pertinent to each specific demographic. The overall change in response and the change in response for each demographic was evaluated.

Figure 4 shows the overall change in response for questions four through seven. The impact of change in attitudes for each demographic generally followed the same trend with very few exceptions and are therefore not specifically shown. The average change in attitude for EV300 across all demographics and each of the four questions displayed the most significant decrease (e.g., -0.55 for question five). The decrease in attitude potentially corresponds to discussing multiple environmental issues throughout EV300 regarding such topics as water shortages, food-water-energy nexus challenges, carrying capacity uncertainty, human health risk concerns, life-cycle analysis considerations, and the tragedy of the commons. EV450 enabled a statistically significant increase in the change in attitude from the beginning to the end of the course as compared to the average change in attitude from EV300 (p value, $0.0029 < 0.05$). The two standard errors represented by the error bars never crossed the zero-line depicting only a positive average change for EV450. The impact of EV450 on the overall attitudes for the sequence resulted in positive attitudes due to significant increases in selection of "strongly agree" and "mostly agree" during EV450 and the sequence with the percent increase in responses ranging from 3.9% to 38.9% for various demographics. The overall percentage decrease in "strongly disagree" responses ranged from -15.4% to -35.3% with an average percent decrease across all demographics of -22.4%. The increase in environmentally-focused attitude stems from the focus of each course. EV300 is focused more heavily on issues whereas EV450 which is focused on solutions. EV450 enables solving environmental issues and simultaneously addressing human needs in the developed world. It is an intensive design course in which the non-engineering students are required to complete several very demanding assignments: engineering design problems (EDPs). Students anecdotally refer to these EDPs as among the most grueling assignments they have ever completed; they complain frequently about how much work is required to complete them. However, the amount of work did not result in decreased environmentally-focused attitudes. In fact, as a result of EV450, the overall impact in change in response for the entire sequence transitioned from primarily negative changes to positive changes toward more environmentally focused attitudes. Therefore, the T-shaped professional demonstrates the ability to incorporate a positive attitude when exploring environmental problems in depth while designing potential solutions.

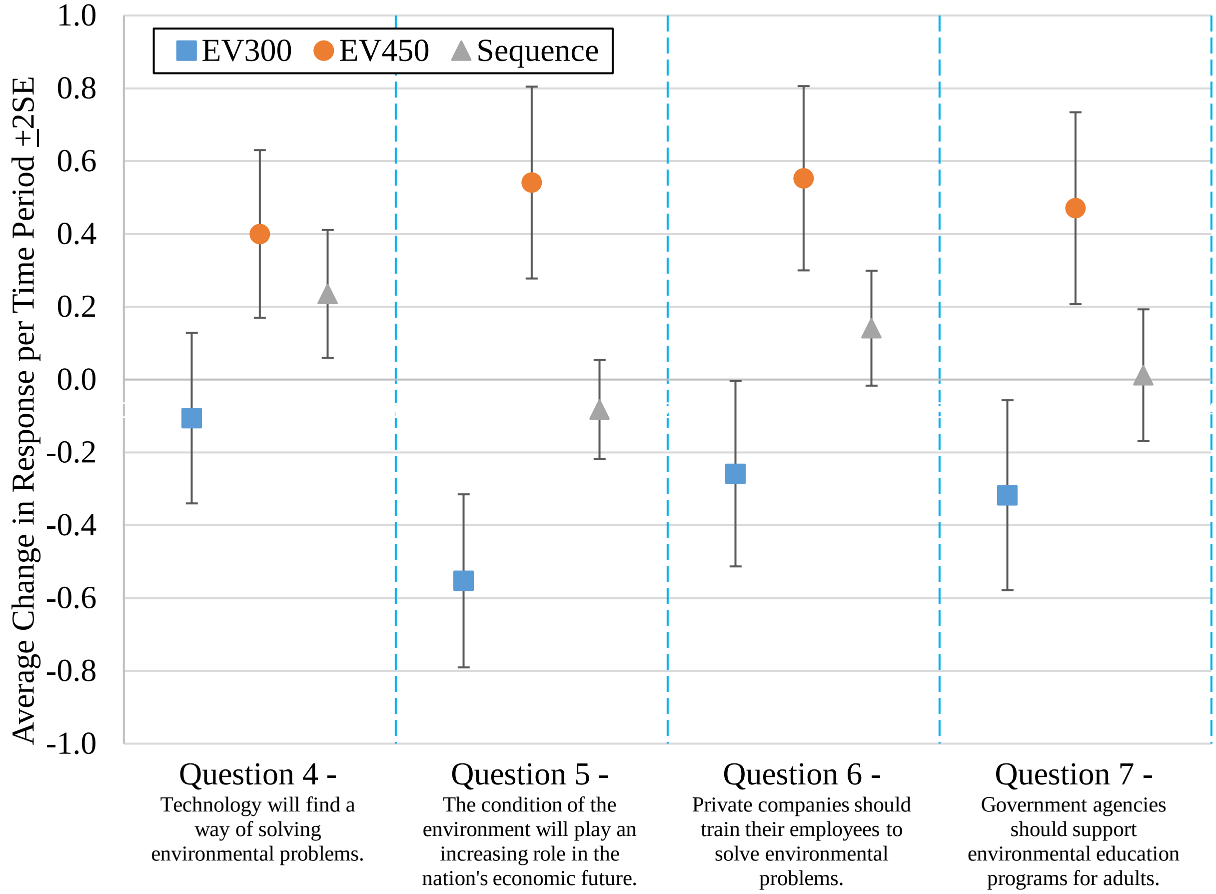

Figure 4. Overall average change in response for questions 4, 5, 6, and 7 regarding environmental attitudes. No change in attitude is represented by a score of 0.00, a negative score represents a negative change in attitude toward the environmental, and a positive score represents a positive change in attitude toward the environment. There were 85 responses for each question from all demographics.

When considering question seven, none of the students to whom the survey was administered selected engineering as their field of study. However, as a function of curriculum requirements, all students must take an engineering sequence as previously mentioned. Arguably, this question impacts the students on a personal level as they are at a government supported university where the engineering sequence taken is focused on environmental engineering education. As with all other questions, the impact of EV450 enabled an increase in environmentally related responses compared to EV300. However, the overall sequence exhibited relatively no significant change in attitudes. All demographics portrayed statistically similar data when comparing EV450 and the sequence except for the overall population sampled depicted in Figure 4 which was statistically different (p value, $0.00552 < 0.05$).

When considering the response selections associated with parents with less than a bachelor's degree, both demographics mirrored each other with some of the most notable percent changes for the overall sequence for questions two, three, four, six, and seven. Potentially there is a link where economic concerns and hardships are associated with families where parents do not have a four-year college degree. Therefore, the focus is on economics for the children as permeated from the parents. The significant changes for question 4 related to the two largest increases in responses of "strongly disagree" for mothers (4.3%) and fathers (5.6%). With respect to question 6, the two largest decreases in response were attributed to mothers (-4.3%) and fathers (5.6%) for selection of "strongly disagree." For question 7, mothers and fathers with less than a bachelor's degree exhibited no change in number of responses as did only two other demographics.

Among essentially all demographics for all of these questions, attitudes from the end of EV300 became more environmentally friendly by the end of EV450. These results are positive but not expected. Further investigation may shed light on why non-engineering students who, when taken out of their element by taking engineering courses, developed more environmentally-friendly attitudes. Perhaps studying solutions to environmental problems that incorporate considerations of technology, economics, and stakeholders, as is the emphasis for EV350 and EV450, provided optimism for dealing with and enabling resolution to the environmental problems investigated in EV300.

The ability of the students across multiple demographics to retain their knowledge from the end of EV300 to the end of EV450 demonstrated maintaining broader competencies (e.g., environmental knowledge) for which they were exposed, which is an essential component of what is expected from T-shaped professionals [6].

Conclusions

Environmental knowledge increased from the start of EV300 to the end of EV300 and from the start of EV300 to the end of EV450. This was seen across all demographics. Additionally, statistically significant differences in knowledge among demographics at the beginning of EV300 were eliminated at the end of EV300 and at the end of EV450. Education for all demographics made all differences in knowledge that were statistically significant change to become no longer statistically significant.

This increase in knowledge adds environmental breadth and effectiveness to the T-shaped professionals. T-shaped professionals equipped with increased environmental knowledge will be more literate in environmental vocabulary and aware of environmental issues. They will, then, have the potential to interact with environmental engineers more effectively to solve environmental issues in the future.

Attitudes across all demographics became less positive toward the environment after EV300, and they became more positive after EV450 and the environmental engineering sequence as a whole. EV300 focuses on identifying and understanding environmental issues. This subject matter can make environmental issues seem severe and difficult to identify solutions. Perhaps this is the reason students became less positive toward the environment after EV300.

We may have a tendency to want to inform people about environmental issues in order to convince them to think more positively toward the environment. The last thing we may think of when trying to change a population's attitude to favor the environment might be to educate the population on environmental engineering. However, our results suggest that a focus on learning about environmental issues decreased positive attitudes toward the environment, whereas focusing on solutions to environmental issues increased positive attitudes toward the environment. Perhaps the focus on learning about solutions, taking an active role in designing solutions, and helping provide basic needs for humanity each had a role in increasing positive attitudes toward the environment in EV450. A sense of accomplishment may also play a role. While the EDPs are very difficult as the students are completing them, the students may have positive feelings after completing them because they feel pride in their efforts.

The increases in environmentally-friendly attitudes were not necessarily expected, as non-engineering majors were expected to become less positive about course material after taking math-based classes as discussed in previous research [16]. Overall, the knowledge and attitudes demonstrate a positive trend that will serve T-shaped professionals to engage with T-shaped engineers to meet future environmental challenges as required in the fifth grand challenge. We often think engineers will solve these challenges; however, NAE and NAS are expanding that aperture by stating that the first four grand challenges require addressing the fifth grand challenge to make a difference. These connections are underscored by the fact that first four challenges were led by engineers, whereas the fifth was led by an economist. The blending of knowledge and attitudes from T-shaped professionals and T-shaped engineers is required in a future of uncertainty and rapid change.

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