Education for Sustainable Civil Engineering: A Case Study of Affective Outcomes among Students

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Abstract

It is important that civil engineering students are educated about sustainable and resilient design. The updated *Civil Engineering Body of Knowledge Third Edition* (CEBOK3) has added affective domain outcomes for sustainability. This acknowledges the fact that while engineers may have the knowledge to take sustainability into account, their attitudes ultimately determine the extent that sustainability issues are thoroughly considered in their work. This philosophy of targeting affective domain outcomes aligns with the global "education for sustainability" movement. The CEBOK3 affective rubric indicates that upon completing undergraduate education individuals should "acknowledge the importance of" and "comply with the concepts and principles of sustainability in civil engineering" (levels 1 and 2). This research explored the attitudes of civil engineering (CE) students toward sustainability, both as incoming first-year students and as seniors at a single institution, including cross-sectional and longitudinal measures. The research utilized an existing survey instrument that measured: (1) the extent students' value sustainable engineering (including beliefs of importance, interest, and utility value to achieve future career goals; 6 items, 7-point scale); (2) affect and behavior related to sustainable engineering (4 items, 7-point scale); and (3) students' self-efficacy or confidence in their ability to understand and incorporate societal, economic, and environmental sustainability issues (6 items; 0 to 100 scale). The value items map most closely to the CEBOK3 rubric for the affective domain of the sustainability outcome, while self-efficacy relates to personal perceptions of cognitive domain outcomes. Sustainable engineering (SE) value was high among both CE seniors and incoming first-year students from 2015-2018; the median value of 6.3 indicates students believed SE is important. Among a smaller sample of longitudinal data, SE value increased between FY and senior year. SE affect was not significantly different between incoming first-year and senior CE students, with a median of 5.0 for both. The SE self-efficacy among incoming first-year CE students had a median of 68, compared to a median among the CE seniors of 70 (marginal statistical difference). Some incoming first-year students appeared over-confident with average SE self-efficacy ratings of 100. Some differences between male and female students and international versus domestic students were found. Ultimately, non-survey based methods may be better suited to measure and explore the sustainability outcomes in the CEBOK3 affective domain rubric.

Introduction

Civil engineering (CE) has been a leader in endorsing the importance of sustainable engineering. ASCE's Policy 418 *The Role of the Civil Engineer in Sustainable Development* was first approved in 1993 [1]. ASCE added a mandate to "strive to comply with the principles of sustainable development" into its Code of Ethics in 1996 [2]. Sustainability was one of the 24 outcomes in the second edition of the *Civil Engineering Body of Knowledge* (CEBOK2 [3]), in addition to being embedded within other outcomes such as design. The outcome statements in the CEBOK2 were mapped to levels in the cognitive domain of Bloom's taxonomy. The CE program criteria in ABET first included sustainability in reviews during the 2016-2017 accreditation cycle [4] (proposed in 2014 [5]). Thus, civil engineering is committed to preparing students to incorporate sustainability principles into their work as ethical engineers. The articulated outcomes associated with the sustainable learning objectives in civil engineering (CE) and the closely related discipline of environmental engineering (EnvE) are shown in Table 1.

Table 1. Sustainable Engineering Objectives and Outcomes

Reference	Bachelor's level	Professional level
CEBOK2 ASCE 2008 [3]	**Apply** the principles of sustainability to the design of traditional and emergent engineering systems **Design** a system… to meet desired needs within such realistic constraints as… sustainability.	**Analyze** systems of engineered works… for sustainable performance
EnvE BOK AAEE 2009 [5]	**Explain** the need for and ethics of integrating sustainability throughout all engineering disciplines and the role [of] environmental engineers…. **Quantify** environmental releases or resources consumed for a given engineered process	**Design** a complex system, process, or project to perform sustainably **Evaluate** the sustainability of complex systems….
ABET 2015 [4]	Criterion 3, c: design a system… within realistic constraints such as … sustainability. CE: Include principles of sustainability in design EnvE: …design environmental engineering systems that include considerations of risk, … sustainability, life-cycle principles, and environmental impacts	
CEBOK3 ASCE 2018 [7]	**Apply** concepts and principles of sustainability to the solution of complex civil engineering problems. (Cognitive Level 3) **Acknowledge** the importance of sustainability in civil engineering (Affective Level 1) **Comply** with the concepts and principles of sustainability in civil engineering (Affective Level 2)	**Analyze** the sustainable performance of complex CE projects from a systems perspective. (Cognitive Level 4) **Value** the benefits of sustainability in the practice of CE (Affective Level 3) **Integrate** a commitment of sustainability principles in the practice of CE (Affective Level 4)

Globally and across disciplines, there is a movement termed Education for Sustainability (EfS) and the related Education for Sustainable Development (ESD) [8-12]. Within civil engineering, there is a lot of evidence that sustainability has been integrated into courses and curriculum. The ASCE *Journal of Professional Issues in Engineering Education and Practice* has published two special issues on sustainability education [13, 14], as well as 259 technical papers and 41 case studies related to sustainability [15]. In addition, a PEER search of the proceedings of the American Society for Engineering Education (ASEE) conferences found 39 papers from the civil engineering division with "sustainability" in the title [16]. In a survey to characterize sustainability education in engineering, Davidson and Heller [17] characterized where and how sustainability was integrated into curriculum in engineering. The survey seemed to focus on cognitive outcomes (e.g. design, economics, green buildings, life cycle assessment). But EfS extends beyond cognitive and knowledge goals to address affect, including values, attitudes, and behaviors. For example, "ESD is based on values of justice, equity, tolerance, sufficiency and responsibility…" [8, p. 21]. Shephard [18] examined affective learning outcomes associated with EfS, and explored programs explicitly targeting these outcomes. Community engagement (which includes course-based service-learning and informal education via Learning Through Service) may be particularly impactful to the affective domain [19].

The third edition of the *Civil Engineering Body of Knowledge* (CEBOK3) [7] added affective domain outcome rubrics to seven of the twenty-one outcomes, including sustainability (Table 1) and all six of the professional outcomes. The CEBOK3 uses Krathwohl, Bloom, and Masia's concepts for affective domain learning [explained in 7, Appendix E]. For sustainability:

> *Civil engineers must [ ] be expected to internalize and prioritize sustainability in all designs, decisions, and recommendations. For entry into the practice of civil engineering at the professional level, all civil engineers should be at the organize level and have the ability to "integrate a commitment to sustainability principles into the practice of civil engineering." [7, p. 2-38]*

The expected achievement at level 4 (organize) for sustainability is congruent with five of the other outcomes with affective domain rubrics; only ethical responsibilities is higher at level 5 (characterize; the highest level in the affective taxonomy). The expectation is that the first two levels (receive and respond) are achieved during undergraduate education, level 3 (value) during mentored experience as a working engineer, and level 4 (organize) via self-development. This suggested pathway of undergraduate education, mentored experience, and self-development is congruent with the other outcomes with affective domain rubrics.

One concern voiced on the constituent surveys executed while developing the CEBOK3 was the inability and/or difficulty measuring affective outcomes [20]. Social scientists have long been measuring affective outcomes, including those associated with sustainability [21, 22]. However, survey responses may be subject to inaccuracies due to biased responses such as positive response, acquiescence, and social desirability [23-25]. Positive and acquiescence response bias are the tendency of respondents to simply agree with the items, irrespective of their true personal feelings. Some groups are more subject to positive response bias, and some types of surveys are more likely to experience these response patterns. One potential way to combat these tendencies is to include both positively and negatively worded items on surveys, but this may or may not be fully effective at eliminating positive response bias [26].

Sustainability values may be fostered or discouraged through 'hidden curriculum'. Hidden curriculum are implicit messages about what is and should be valued, based on informal signals within courses and institution level structures, including policies and resource-allocation [27]. Students' values may be unconsciously impacted in higher education through the hidden curriculum. Intersections between hidden curriculum and sustainability education have been studied [18, 28-30]. For example, instructors' beliefs and attitudes impact choices about to what extent and how sustainability issues are taught, and their opinions were manifested in subtle ways when moderating student discussions [29]. The campus environment itself conveys messages about the importance of sustainability, such as providing recycling facilities [29]. Relatedly, the null curriculum represents "what students learn via what is ***not*** taught, highlighted or presented"; the absence of particular topics and messages is informative [31].

The sustainability attitudes of students and how they change during college could be viewed through the theory of student socialization. Weidman developed a model of student socialization during higher education [32]. This is a form of Input – Environment – Output (IEO) model. In this research the "output" is the attitudes of the seniors toward sustainable engineering. The "input" is the student attitude toward sustainable engineering upon entering college. This input would be influenced by personal factors including culture and upbringing as well as K-12 education. Socialization factors in the environment during college could include courses, co-curricular activities, extra-curricular activities, living-learning communities, internships, etc.

Research by Cech [33] characterized a culture of disengagement in engineering education. This might be expected to diminish commitment to sustainable engineering. However, educational models such as Vanasupa et al.'s Four Domain Develop Diagram (4D) [34] indicate conditions that might impact affective domain learning, including social aspects of learning, motivation, context, and autonomy. Thus, it is difficult to predict how college might change students' attitudes toward sustainable engineering. Engineering students might become more or less favorable in their attitudes toward sustainable engineering, as a result of both formal curriculum and hidden curriculum.

Research Questions

Given the new expectations for affective outcomes related to sustainability as part of undergraduate education specified in the CEBOK3, the research aimed to demonstrate the use of simple Likert-type survey questions to measure sustainability attitudes in civil engineering students. The specific research questions explored were:

To what extent do first-year (FY) and senior civil engineering (CE) students value sustainable engineering?

RQ1. Has this changed significantly between 2014 and 2018?
RQ2. Does this differ between FY and senior students?
RQ3. Does this differ based on gender?
RQ4. Does this differ between international and domestic students?
RQ5. For individual students, did this change between FY and senior year?

Methods

Case study context.

Because the research was conducted among students in a single major (CE) at a single institution (large, public, highest research activity) it can be considered a case study. Thus, it is important to consider the local context. The institution has a reputation for embracing sustainability (e.g. among the 20 'best green colleges' [35]), and includes activities on sustainability during orientation for incoming students. The majority of engineering students at the institution are admitted directly into specific engineering majors. All incoming first-year CE students are required to take an *Introduction to Civil Engineering* course. From 2014-2016 the course was two credits, while from 2017-2018 the course was one credit hour. In both cases, sustainable engineering was included as one of seven key learning objectives in the course. In addition to an assignment focused on sustainable engineering, sustainability elements were reinforced in a team bridge project where bridges were judged based on technical, economic, environmental, and social elements. Some students matriculate as "undecided" engineering majors; a small number of those students may enroll in the *Introduction to Civil Engineering* course for first-year students. All CE students take a *Fundamentals of Environmental Engineering* course, typically in fall junior year. Over time this course has increasingly included explicit content on sustainability, specifically the ENVISION rating system. Sustainability is also a learning objective within a required senior-level *Professional Issues in CE* course offered in fall semester. The majority of the students take the course before senior capstone design, but some students graduating in 4.5 years also enroll in the course. Capstone design explicitly includes sustainability elements, congruent with the ABET program-specific criteria for CE.

Measurement.

A survey was previously developed to evaluate sustainable engineering (SE) attitudes based on the elements in Expectancy Value Theory (EVT) [36]. EVT considers that an individual's personal expectances and values impact their behavior, such as learning (for students) or activities (for professionals). Expectancy describes beliefs about successfully executing particular tasks; in this case, self-efficacy or confidence about personal abilities related to SE elements were measured based on statements that included the term sustainability and each of the three pillars (environmental, social, and economic elements). Values in the theory includes intrinsic values based on interest or enjoyment and extrinsic value due to perceived usefulness. A third dimension related to current behaviors and feelings about SE, so-called affect, was also included to explore behaviors and reactions to SE. The full SE attitude survey included 32 Likert-type items (13 mapped to self-efficacy, 11 to value, and 8 to affect). The survey was pilot tested with 515 engineering student responses (multiple institutions, all ranks, dominated by civil and environmental majors), validated and evaluated for reliability using principal component analysis, content validity, and internal reliability evaluated using Cronbach's alpha. The current research used a subset of the items from that sustainability attitudes survey, including six to evaluate SE value (two negatively worded; 7-point scale), four to evaluate SE affect (7-point scale), and six to evaluate SE self-efficacy (0 to 100 scale). The value scale is likely to be more robust against acquiescence bias since it included two reverse worded items. These sustainability items were included with other survey items that assessed professional social responsibility attitudes [37]. A basic check on the reliability of clustering the multiple sustainability affect assessment items into the three EVT constructs was conducted by calculating the Cronbach's Alpha in SPSS (results in Table 2, based on about 400 CE student responses). Higher values indicate stronger clustering among the multiple survey items, and all scales had acceptable internal consistency with alpha values above 0.6.

Table 2. Survey questions mapped to Expectancy Value Theory constructs *{CEBOK3 sustainability affective rubric}*

Construct	Survey Item	Cronbach's Alpha
Intrinsic and Extrinsic SE Value	It is important for me to learn how engineers can make the world more sustainable *{Level 1 "acknowledge"}* Engineers play an important role in improving overall quality of life I enjoy the creative aspects of developing solutions to meet present and future needs. In engineering design, assessment of the potential impacts on economy, environment, and society is not important [REVERSE] *{Level 1}* The ability to assess social, economic, and environmental implications of engineering design is a useful skill that will help me be successful at my job *{Level 3 "value"}* Learning about sustainability concepts is a waste of time because I will never use that knowledge [REVERSE] *{Level 2 "comply"}*	0.620

Construct	Survey Item	Cronbach's Alpha
SE Affect	I would prefer to learn about sustainability engineering applications more than many other engineering concepts If income was not a factor, I would prefer a job related to sustainble development over other types of engineering positions Practicing sustainability is a behavior that is a part of my everyday life My future career will likely involve solving local or global problems that may involve social, economic, and environmental issues	0.671
SE Self-Efficacy	Confidence to: Assess the practicality of an engineering design, including the potential impacts on the community and economy Understand the environmental risks associated with engineering projects Identify the economic elements of an engineering project Identify the social elements of an engineering project Understand the interdependency among environmental, social, and economic aspects of engineering Understand the meaning and application of sustainable engineering	0.889

This survey pre-dated the CEBOK3 and is therefore not ideally mapped to the CEBOK3 rubric. Survey questions mapped to the value element of EVT are most directly related to the CEBOK3 affective domain rubric. However, it is somewhat difficult to determine the affective level of achievement being evaluated. Two items asking the students their level of agreement with statements including the word "important" (Table 2) appear to assess the CEBOK3 affective sustainability rubric level 1 (acknowledge the importance of sustainability in civil engineering). The final reverse worded item could be construed to measure level 2 (comply), since if a student is not going to use sustainability knowledge they would not by complying with concepts of sustainability in civil engineering. The item discussing career success might indicate the student 'values' the benefits of sustainability in the practice of civil engineering. The rubric levels could clearly be debated; perhaps all are merely reflecting level 1 of the CEBOK3 rubric. The SE affect items in the survey do not appear to directly measure the elements in the sustainability affective rubric in the CEBOK3. Self-efficacy items reflect students' confidence that they have knowledge and abilities related to sustainable engineering; as such, they are somewhat a self-assessment of the cognitive domain outcomes (e.g. *identify* is cognitive level 1, *understanding* reflects comprehension or cognitive level 2).

Supporting data from the College of Engineering's graduating senior survey has also been included. The College-wide survey asks CE students to rate the importance of an "ability to apply the principles of sustainability to the design of traditional and emergent engineering systems." This item is included within a list of ABET criterion 3 *A to K* outcomes and other CE program-specific criteria. Students respond on a 5-point Likert-type scale: 1-Not at all important, 2-Not very important, 3-Moderately important, 4-Very important, 5-Extremely important. This data provides an overall reference point for the extent that graduating seniors perceive the importance of sustainability, which should be related to value (most likely from an extrinsic perspective as important for their future civil engineering job).

Survey Administration.

The surveys to measure sustainability values were distributed in the *Introduction to Civil*

Engineering class and the senior *Professional Issues* class on the first day of the semester. Per IRB, the surveys began with an informed consent statement. Students could complete the surveys and return them within the first week of the semester for extra credit (about 0.7% of the course grade); there were other opportunities for students to earn extra credit in the course if the students chose not to complete the surveys (e.g. attend career fairs, FY students attend office hours, seniors serve on panel in FY class, etc.). Survey response numbers and rates are shown in Table 3. In a small number of cases the responses from individuals who took the survey as first-year students could be compared to their responses as seniors (represented in the table as "paired"). This small group represents longitudinal data, while the other comparisons are based on cross-sectional sampling. The graduating senior survey is online, with a link emailed from the College to all engineering students in the final month before they graduate. De-identified data is returned from the College to the program for use in outcomes assessment.

Table 3. Data from civil engineering students included in the research

Term	First year		Paired	Seniors		Graduating seniors	
	n	response rate, %	seniors, n	n	response rate, %	Year	n
Fall 2018	48	76	--	51	81	--	
Fall 2017	62	91	--	56	88	2017-18	60
Fall 2016	41	93	5	37	66	2016-17	50
Fall 2015	53	90	18	12	67	2015-16	58
Fall 2014	49	92	26	NA	NA	2014-15	59

Data Analysis.
Survey data were input into Excel, where heteroscedastic two-tailed t-tests were conducted for RQ2 rank, RQ3 gender, and RQ4 domestic/international and paired t-tests for RQ5 (longitudinal data). T-tests explore evidence of a significant difference in the mean values between two populations. Averaging the multiple items from the Likert-type responses together makes the data more closely resemble continuous data, and t-tests tend to be robust even if normality assumptions are violated [38]. More rigorous statistical analyses were conducted in IBM SPSS software. Non-parametric tests are more appropriate, given that the data were ordinal rather than continuous and not normally distributed (generally skewed to the positive end of the scales). For comparisons among two conditions (e.g. first-year versus seniors), Mann-Whitney U-tests were conducted. For comparison among multiple conditions (e.g. year), correlations (Pearson correlation which assumes a linear relationship between two continuous variables and Spearman correlation for monotonic relationships between continuous or ordinal variables) and Kruskal-Wallis tests were conducted. For paired data (longitudinal data from FY and seniors), Wilcoxon signed-rank tests were conducted, the non-parametric equivalent of the paired t-test. Statistically significant differences were inferred for p values less than 0.10. P is the probability that in actually there is no difference between the samples, and the null hypothesis was erroneously rejected; the calculated p and significance (sig.) values are provided so that the actual confidence level of differences is explicitly stated. Given the non-normal nature of the data, average and standard deviations are not shown. Rather, median values and inter-quartile ranges (first and third quartile) will be presented.

Results and Discussion

The quantitative results from the survey across the multiple years and two student ranks are summarized in the Appendix; results where all years are combined are summarized in Table 4.

Table 4. First-Second-Third Quartile among Sustainability Survey Scores

Condition	Value (1 to 7 scale)		Affect (1 to 7 scale)		Self-Efficacy (0 to 100 scale)	
	FY	Seniors	FY	Seniors	FY	Seniors
2014-2018	6.0-6.3-6.7*	6.0-6.3-6.8	4.5-5.0-5.5	4.5-5.0-5.8	57 – 68 – 80	62 – 70 – 78
Male	6.0-6.3-6.7*	6.0-6.3-6.7	4.4-5.0-5.5	4.5-5.0-5.5	57 – 70 - 82	62 – 70 - 80
Female	6.2-6.5-6.7*	6.2-6.5-6.8	4.5-5.0-5.5	4.8-5.3-5.8	50 – 64 - 79	53 – 70 - 78
Domestic	6.2-6.3-6.7*	6.0-6.5-6.7	4.5-5.0-5.5	4.5-5.0-5.8	54 – 67 - 80	62 – 70 - 77
Int'l	5.8-6.2-6.3*	5.7-6.2-6.8	4.1-4.8-5.4	4.5-5.0-5.5	66 - 75 - 82	65 – 75 - 82

* Not including 2014

Value

The 2014 FY average value score (4.8) was significantly lower than the other years (2015-2018, 6.3; t-test p <.001; Kruskal Wallis test confirmed with 2014 versus all other years adjusted significance <.001). Therefore, 2015-2018 data from FY and senior students were compared. It was found that the sustainable engineering value scores were not significantly different between FY and senior students (average 6.30; t-test p=0.54). The first-quartile score of 6.0 means that most students (75%) were at the "agree" level or higher regarding the importance of sustainable engineering (4 = neutral; 7 = strongly agree). In addition, the fairly high average sustainability value scores among the incoming FY students represent a "saturation" problem with the scale; it is hard to show an increase when incoming scores are reasonably high. These results for sustainable engineering value are congruent with the graduating senior survey results, where the importance of sustainability in design had an average rating of 4.2 out of 5 (4=very important; see Appendix). Although these high scores may be influenced by social desirability response bias, the fact that students believe that it is socially desirable to value sustainability as civil engineers is still important.

Gender differences were not statistically significant among first year students (p=0.22) and marginally different among seniors (t-test p=0.06; Mann-Whitney U test sig. 0.03); female students had somewhat higher sustainable engineering value than male peers. Among first year students, international students had lower sustainable engineering value than US-peers (average 6.0 vs. 6.3, t-test p=0.005, Mann-Whitney U Test sig. 0.047); differences were not statistically significant among seniors (average 6.1 international vs. 6.3 domestic; t-test p=0.14). The differences among incoming FY students likely reflects cultural desirability and upbringing around sustainability in the US, versus perhaps somewhat less abroad in the countries of most international students (at this institution: Middle East, China, India).

Paired, longitudinal comparisons among 49 students between their SE value pre-score in the FY class (average 5.6) and the senior class (average 6.3) found a statistically higher value score among the seniors (paired t-test p<.001). Sixty-seven percent of the students increased their value score, 10 percent did not change, and 22% decreased. This data is compelling, showing that engineering education generally increased civil engineering students' value of sustainable engineering. Interestingly, the students who increased in SE value started at lower SE value scores (average 5.1 in FY class, average 6.4 as seniors) compared to students whose SE value decreased (average 6.5 in FY class, average 5.9 as seniors). The small number of students with no change (n=5) had a very high SE value as FY students (average 6.9); these students strongly felt SE was very important and maintained this perception.

Affect

Overall, SE affect scores (median 5.0) were lower than SE value scores (median 6.3). Looking at the affect data over time (Appendix), among FY students there was a statistically significant correlation between affect score and year (Pearson correlation 0.324, 2-tailed sig. <.001; non-parametric Spearman's rho 0.326, 2-tailed sig. <.001). This trend was confirmed in Kruskal-Wallis tests, where pairwise post-hoc tests found that 2014 was lower than 2016-2018 and 2018 was higher than 2017, 2015, and 2014. Thus, there appears to be a trend that incoming first-year civil engineering students have more personal involvement and interest in sustainability. In addition, there was a correlation between value and affect (Pearson correlation 0.260, 2-tailed sig. <.001; nonparametric Spearman rho 0.286, 2-tailed sig. <.001).

Among seniors, there were not significant differences in affect scores between 2015 to 2018 (based on the Kruskal-Wallis test). The seniors' affect scores correlated with value (Pearson correlation 0.287, 2-tailed sig. <.001; nonparametric Spearman rho 0.334, 2-tailed sig. <.001), with a slightly stronger relationship than was found among first-year civil engineering students.

Comparing FY and senior civil engineering students (across all years of data), differences were not statistically significant (Mann-Whitney U test sig. 0.357). Affect did not differ between female and male students among either first-year or seniors (Mann-Whitney U test sig. 0.115 and 0.24, respectively). Affect also did not differ significantly between international and domestic civil engineering students in the first and senior year (Mann-Whitney U test sig. 0.421 and 0.827, respectively).

Paired, longitudinal comparisons among 49 students between their SE affect pre-score in the FY class (average 4.8) did not change significantly as seniors (average 5.0; paired t-test p=0.41). It is interesting to note that similar percentages of students increased (53%) and decreased (43%) in SE affect scores. Those that increased in SE affect during college averaged lower SE affect scores as incoming FY students (FY 4.4; senior 5.3) versus students who decreased in SE affect score (FY 5.3, senior 4.4); the two students with no change in SE affect had average scores above the third-quartile as incoming FY students (avg. 5.6). This same pattern of change versus incoming score was also found for SE value. Similar patterns were also found in social responsibility, where students with less positive incoming social responsibility attitudes as FY students tended to increase over time while students with more positive incoming social responsibility scores tended to decrease over time [39]. The reasons for these patterns deserve additional attention, perhaps accounting for statistical probability and including qualitative or richer methods such as interviews.

Self-Efficacy

Statistical analysis of the results found that differences between years were generally not statistically significant. Among first year students, Kruskal-Wallis tests retained the null hypothesis (sig. 0.67). Among seniors, the only significant difference was between 2016 and 2017 (adj. sig. 0.017). The self-efficacy data from 2014 to 2018 were combined to explore the remaining research questions.

The majority of the students had fairly high self-efficacy or confidence in their ability to consider sustainability including environmental, social, and economic elements, based on median survey scores of around 69, and first-quartile scores around 60. There was only a moderate increase between the average sustainable engineering self-efficacy scores of the FY and senior students (67 vs 69; t-test p = 0.09). Across the individual items that comprised the sustainable engineering self-efficacy construct, there were significant differences in "ability to identify the economic elements" (FY 64 vs. seniors 69; t-test p=0.02), and "understand the meaning and application of sustainable engineering" (FY 68 vs. seniors 72; t-test p= 0.07). This may be due to over-confidence among some FY students, who don't understand the level of complexity implied by the statements, similar to the Dunning-Kruger effect [40]. Alternatively, students may come to college with significant background in sustainability from their K-12 education, driven to some extent by the Next Generation Science Standards [41]. The seniors should have greater actual knowledge and abilities in these areas, but may not be any more confident in those abilities.

Among FY students male and female average overall sustainable engineering self-efficacy scores were not significantly different (t-test p=0.20); ability to identify the economic elements of engineering projects was higher among male students (male average 66 vs. female average 58; t-test p=0.02). Among seniors, the overall SE self-efficacy scores were not significantly different (t-test p=0.14), but male students had more confidence in their ability to understand the environmental risks of engineering projects (male average 71 v. female average 63; p=0.02) and identify economic elements of engineering projects (male average 71 vs female average 61; p=0.01). Lower self-efficacy or confidence among female STEM students has been previously identified, such as a study where female students' physics self-efficacy was lower than males with the same class performance [42].

Among FY students, the international students' were more confident in their abilities related to overall sustainable engineering (median 75 vs. domestic students median 67; p<.001); for each of the 6 individual self-efficacy items, international students had higher average scores. Among seniors there was not difference among international and domestic students in their sustainable engineering self-efficacy.

The most interesting data are the paired results from 49 students. The sustainable engineering confidence of the incoming students ranged from 0 to 100 (average 69, standard deviation 20), compared to 47 to 100 (average 73 standard deviation 12) among the seniors (median 73 vs 75). A paired t-test found marginally significant differences between FY and seniors (p=0.097), but the non-parametric related-samples Wilcoxon signed rank test did not identify a significant difference (sig. 0.194). There were 28 students with increased self-efficacy scores, 20 decreased and 1 remained the same. As illustrated in Figure 1, the students with higher sustainable engineering self-efficacy as incoming FY students tended to decrease in their confidence by senior year, while students with initially lower confidence gained. In fact, among students who decreased their confidence the average incoming self-efficacy was 82 compared to an average of 59 among students who increased (Pearson correlation -0.82 with sig. <0.001; Spearman non-parametric correlation -0.717 with sig. <0.001). This likely reflects overconfidence among a number of FY students. However, similar trends were also observed for SE value and SE affect, as previously discussed.

Self-efficacy was found to be weakly correlated with affect among first-year students (Pearson correlation 0.208, 2-tailed sig. <.001; Spearman rho 0.223, 2-tailed sig. <.001). Among seniors, self-efficacy was weakly correlated with value (Spearman's rho 0.194, 2-tailed sig. .013; Pearson correlation 0.148, 2-tailed sig. 0.06). These relationships align with Expectancy Value Theory.

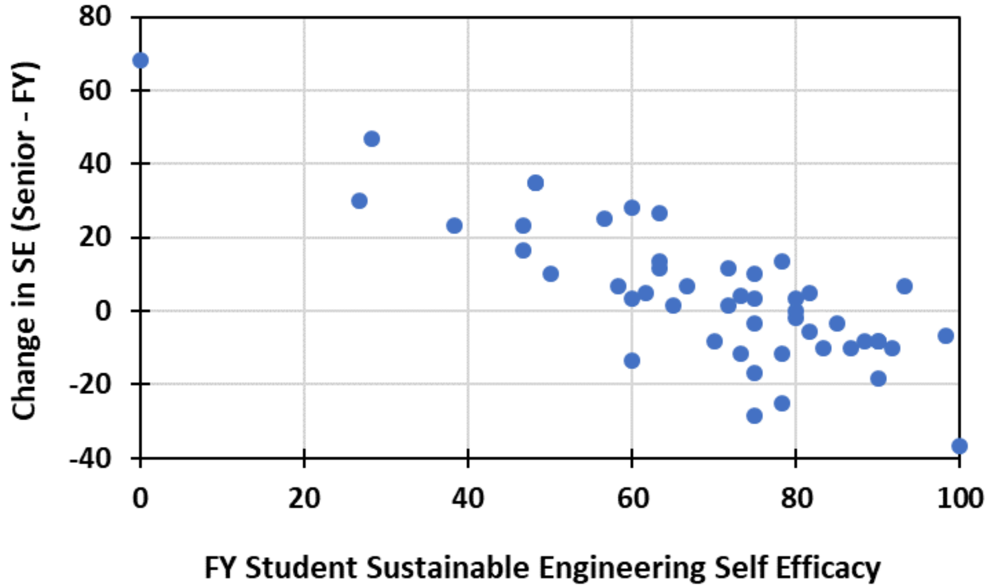

Figure 1. Longitudinal change in CE students' sustainable engineering self-efficacy as a function of their incoming self-efficacy as first-year students

Conclusions, Limitations, and Implications

This research explored the use of a simple, short Likert-based survey grounded in expectancy value theory to measure the attitudes of civil engineering students toward sustainable engineering. Based on longitudinal data from a fairly small number of students at a single institution who took the survey in a class for incoming first-year students and a senior-level course (n=49), the students increased in sustainable engineering value, did not change in sustainable engineering affect, and marginally increased in their confidence in cognitive abilities related to sustainable engineering. To determine the potential effects of the college experience on civil engineering students (including courses, co-curricular activities such as Engineers Without Borders (EWB), and the hidden curriculum), longitudinal data is clearly superior to cross-sectional data. For example, incoming students' SE value, affect, and/or self-confidence may change over time or FY students may leave civil engineering. In this study, the cross-sectional data did not find that SE value differed among FY and senior civil engineering students, which differed from the results using the longitudinal data.

A limitation in the study is that the seniors who participated in the survey were not at a uniform location in the curriculum. Some were at the start of senior year (before taking capstone design), while others were in their final semester (after taking capstone design). It is anticipated that capstone design may have a significant impact on students' perceptions of the importance of sustainable engineering, as well as their confidence (self-efficacy) in SE knowledge.

Further research should be conducted to establish the elements within the civil engineering students' college experience that led to changes in their SE value. Input-environment-output models are a good framework for considering this question. Students bring different attitudes and competencies toward SE into college, which seemed to pre-dispose them to different changes during college. The fact that international students had lower SE value as incoming FY students also points to the importance of considering ‘input’ when exploring sustainability affect. The college environment includes required courses, elective courses, co-curricular activities (e.g. clubs, internships, study abroad), and the wider university / campus culture. The impacts of courses cannot be readily evaluated based on typical artifacts such as syllabi or assignments, due to the likely importance of hidden curriculum. Hidden curriculum is likely to be particularly important to affective outcomes, as compared to formal curriculum that can more reliably achieve cognitive outcomes.

Individuals who want to assess student achievement of the sustainability affective outcomes in the CEBOK3 rubric will likely need to create a specific evaluation instrument. The instrument used in this study based on EVT (pre-dating the CEBOK3) was not a good match to the elements and levels in the CEBOK3 rubric. Some items from the value scale used in this study may be appropriate. Individuals should keep in mind that the development of a rigorously validated survey instrument is not simple. Elements such as social desirability and acquiescence response bias should be considered. More authentic assessment methods like the ‘challenge question’ approach [43] should be less subject to positive response bias. In that approach, students are given an open-ended problem or scenario, and the extent to which students discuss sustainability elements indicates the extent to which they ***acknowledge*** the importance of sustainability and ***comply*** with the concepts and principles of sustainability. Assessing sustainability affect is challenging, but not insurmountable. There are existing instruments and approaches that can be applied or adapted.

Appendix.

Results Summary over Time. First-Second-Third Quartile among Sustainability Survey Scores

Year	SE Self-Efficacy		SE Value		SE Affect	
	FY	Seniors	FY	Seniors	FY	Seniors
2014	55 – 69 – 79	NA	4.5-4.7-5.0	NA	4.0-4.5-5.0	NA
2015	57 – 67 – 81	60 – 63 – 75	6.2-6.3-6.7	5.6-6.2-6.7	4.3-4.8-5.3	4.5-4.6-5.6
2016	55 – 67 – 80	60 – 67 – 73	6.2-6.3-6.7	6.0-6.3-6.7	4.5-5.0-5.5	4.5-5.0-5.8
2017	57 – 68 – 77	67 – 73 – 80	5.8-6.3-6.7	6.0-6.3-6.7	4.4-4.9-5.8	4.3-5.0-5.8
2018	59 – 72 – 82	60 – 73 – 78	6.0-6.3-6.7	6.1-6.5-6.8	5.0-5.5-6.1	4.5-5.3-5.8

Importance ratings of applying principles of sustainability to design by graduating civil engineering seniors over time

Year	Average Importance (1-5)
2014	4.10
2015	4.22
2016	4.18
2017	4.25

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