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Sustainable, Global, Interdisciplinary and Concerned for Others? Trends in Environmental Engineering Students

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Abstract

In this study the four affective attributes of sustainability value, global interest, interdisciplinary value, and concern for others were explored among engineering students. The research questions were: (1) to what extent are incoming environmental engineering students motivated by sustainable engineering, interested in global work, value interdisciplinary skills, and recognize the importance of consideration for others in the context of engineering; (2) to what extent are environmental engineering students similar to or different from civil and architectural engineering students in these attitudes; and (3) are there correlations between these attitudes. To answer these research questions, a survey consisting of 7-point Likert items was given to students at the beginning of the semester in courses designed to introduce first year students to environmental, civil, and/or architectural engineering at the University of Colorado Boulder. Twenty-five survey items were used to measure four sub-components of sustainable engineering motivation, single items were used to measure global interests and interdisciplinary value, and nine items evaluated consideration for others. Sustainable engineering self-efficacy, value, and negative attitudes were similar among students in all three majors. Environmental engineering students had higher scores than civil and architectural engineering majors in sustainable engineering affect and overall motivation. Interest in working on projects outside the U.S. was high, without significant differences between environmental, civil, and architectural engineering students. Interdisciplinary value was the higher among environmental and civil engineering students than architectural engineering students at the start of the semester. Architectural engineering students increased their value for interdisciplinary contexts during the semester. Concern for others was the highest among environmental and civil engineering students, and lower among architectural engineering students. There were weak positive correlations between these attitudes that were statistically significant, with differences between disciplines. For example, correlations between sustainable engineering value and concern for others was moderately positive among environmental engineering students (0.60 correlation coefficient), and lower for civil and architectural engineering students (0.44 and 0.49, respectively). Comparing responses to the survey at the end of the semester, environmental engineering students increased their sustainable engineering self-efficacy but decreased in sustainable engineering value and concern for others. On the post survey, sustainable engineering value and concern for others were positively correlated with intent to graduate in engineering for environmental engineering students. Therefore, it appears that emphasizing elements of sustainable engineering, global opportunities, and how engineering can benefit others may be synergistic and also yield benefits for encouraging students to stay in engineering.

Introduction

The explosive growth of participation in Engineers Without Borders (EWB) over the past decade may indicate that the unique combination of EWB attributes is attracting student interest.[1-2] EWB at its core involves helping others in primarily global settings through sustainable development in an interdisciplinary context. Other organizations embrace similar ideals, including Engineers for a Sustainable World (ESW)[3], Engineering World Health (EWH)[4], and

Bridges to Prosperity (B2P)[5], as well as efforts at numerous individual institutions.[6-11] Do students and professionals involved in these activities have values and interests that align to an equal extent with all four of these attributes -- sustainability, global, interdisciplinary, and concern for others? Are these attitudes similar to or different from the majority of engineering students? These questions led to the development of a pilot study with first year students at the University of Colorado Boulder. The next section provides information that grounds the study in published literature, which is followed by the research methods, results, and discussion.

Background

The Environmental Engineering Body of Knowledge (BOK) discusses the skills and attributes required for environmental engineers to be successful and productive professional engineers who are best equipped to benefit society.[12] Sustainability and global issues are specified as outcomes, and interdisciplinary interactions are also discussed in the context of teamwork. These same outcomes are present in the Civil Engineering BOK.[13] The BOK for both of these disciplines focuses on the cognitive domain. However, affect is important in determining how cognitive knowledge and skills are applied. The Civil Engineering BOK discusses the affective domain and includes an attitudes outcome that encompasses consideration of others, fairness, respect, sensitivity, thoughtfulness, and tolerance.[13] Many of these attitudes can be characterized as relating to concern for others. In this study the four affective attributes of sustainability value, global interest, interdisciplinary value, and concern for others were explored among first-year engineering students.

There are myriad linkages between the ideas of sustainability, concern for others, global issues, and interdisciplinarity in the literature. A few examples are highlighted here. The United Nations' Decade of Education for Sustainable Development (ESD) is just coming to a close. Its primary goal was to "encourage changes in knowledge, values and attitudes… enabling a more sustainable and just society for all."[14, pg. 9] It promoted interdisciplinary approaches as crucial to address "key sustainable development issues… [which] are characterized by uncertainty, complexity, and a high degree of systemic interconnection."[14, pg. 20] ESD is also inclusive of concern for others: "ESD is based on values of justice, equity, tolerance, sufficiency and responsibility. It … emphasizes care… and human well-being."[14, pg. 21] The UN's new Global Action Programme (GAP) on ESD has an objective "to reorient education and learning so that everyone has the opportunity to acquire the knowledge, skills, **values and attitudes** that empower them to contribute to sustainable development"[15] [emphasis added by author]. Andrzejewski and Alessio[16] linked the ideas of global citizenship, concern for others, and sustainability in 1999, asking "Are teachers prepared to help their students develop the global consciousness needed to support human rights and ecological sustainability?" The global citizen approach was advocated for sustainability education by Parker et al.[17]

Previous research has measured the sustainable engineering motivation of students based on Expectancy Value Theory.[18] An instrument comprised of Likert-items was developed and evaluated four attitudes toward sustainable engineering motivation: self-efficacy, value, affect, and negative attitudes. Self-efficacy related to a student's level of confidence that they possessed knowledge and skills related to sustainable engineering. Sustainable engineering value items assessed both the intrinsic and extrinsic values of the students. Affect measured student actions related to sustainable engineering. Finally, some of the items were negatively worded, stating that the student believed that sustainability knowledge was not important or would not be useful in their future career. While it was expected that these negatively worded items would fall into the value or affect constructs when reverse coded, the items were actually found to cluster into their own construct. The results of the study found that student participation in enriching learning experiences, such as internships or undergraduate research, correlated with differences in sustainable engineering motivation. Gender differences were also found in sustainable engineering value.

There are significant challenges and opportunities for sustainable development and engineering around the world. Global opportunities for engineers abound, and it has been argued that today's engineering students need to acquire global competency.[19,20,21] However, to what extent are today's engineering students interested in global opportunities? Global interest among engineering students might be a contributing factor to the popularity of Engineers Without Borders (EWB) - USA, which has grown to over 14,000 members since its inception in 2002.[22] In a previous study of global interests among first year civil and environmental engineering students from 2008 to 2011, global value and interests were higher among environmental engineering students than civil engineering students.[23] Global work interests were higher among female than male first year civil engineering students.[23] In a large study of undergraduate engineering students with over 1900 respondents from 17 institutions representing a broad diversity of engineering disciplines, 48% of the students placed some importance on living outside the U.S. as a desirable job quality (unpublished data from Bielefeldt and Canney 2014). This interest varied somewhat between disciplines; 56% of environmental engineering students, 52% of civil engineering students, 46% of mechanical engineering students, and 43% of electrical engineering students indicated some importance for living internationally.

The interdisciplinary interests among environmental engineering students have not been widely explored. Knight[24] explored interdisciplinary skills using on a survey distributed to undergraduate students at 31 institutions with over 5000 respondents; the results found differences between disciplines in their interdisciplinary skills – with the average self-reported interdisciplinary skills of civil engineers falling below general engineering, biomedical engineering, and industrial engineering, similar to mechanical engineering, and higher than electrical and chemical engineering. Curriculum factors were found to be influential to students' interdisciplinary skills. The study did not include environmental engineering students.

The ideas of incorporating social issues into engineering design as promoted by sustainable engineering coincides with ideas of concern for others. Concern for others is a general idea that relates to issues such as empathy, caring, and social responsibility; ideas that may typically be poorly emphasized within engineering.[25,26,27] A model to describe the development of professional social responsibility in engineering students based on the Ethic of Care has been developed.[28] The model includes eight dimensions of social responsibility, including an individual's sense of *connectedness* that personal action is needed to help needs in society or the community, can *analyze* the importance of community input and cultural context in engineering, and a sense of *professional connectedness* that their engineering skills should be applied to solve community problems. Research based on this model and a related survey found that environmental engineering students had more positive social responsibility attitudes than students majoring in civil or mechanical engineering.[29]

There is some indication that interest and value for these somewhat non-traditional areas of engineering – sustainability, global issues, interdisciplinary, and care for others -- might coincide. For example, the outcomes criteria in ABET group a variety of attributes together. Criterion 3 Outcome h is "understand the impact of engineering solutions in a global, economic, environmental, and societal context."[30] Environmental, economic, and social are the three pillars of sustainability. So here global and sustainable seem to be linked. And as one considers social impacts, this begins to bridge into concern for others. A study by Knight[31] explored the creation of the Engineer of 2020, measuring skills in nine areas which included contextual awareness (including "an ability to use what you know about different cultures, social values, or political systems in engineering solutions) and interdisciplinary skills. However, in their analysis contextual awareness clustered with design skills, while interdisciplinary skills clustered with reflective behavior practice, and recognizing disciplinary perspectives. A small pilot study at the University of Canterbury among students majoring in civil engineering and natural resources engineering in fall 2013 found correlations between sustainable engineering motivation and concern for others (Bielefeldt unpublished data).

The research questions explored in this study were: (1) to what extent are incoming environmental engineering students motivated by sustainable engineering, possess an interest in global work, value interdisciplinary skills, and recognize the importance of consideration for others in the context of engineering; (2) to what extent are environmental engineering students similar to or different from civil and architectural engineering students in these attitudes; and (3) are there correlations between these attitudes. Changes in these attitudes over the course of the first semester were also explored.

Methods

A written survey was developed to assess students' attitudes toward sustainable engineering, global work, interdisciplinary value, and concern for others. The survey began with an informed consent statement, followed by 41 questions. First, statements were taken from the Engineering Professional Responsibility Assessment (EPRA)[32], with five items that mapped to *base skills*, five items to *analyz*e, and four items to the *professional connectedness* dimensions of the Professional Social Responsibility Development Model (PSRDM).[28] The *analyze* and *professional connectedness* questions were used to evaluate concern for others. Students responded to these questions using a 7-point Likert scale, either from very unimportant (1) to very important (7) or from 1 (strongly disagree) to 7 (strongly agree). The survey included one item to measure interest in working outside the U.S. and one item to measure students' value of interdisciplinary learning, with a 7-point agreement scale (1 = strongly disagree, 2 = disagree, 3 = slightly disagree, 4 = neutral, 5 = slightly agree, 6 = agree, 7 = strongly agree). The next part of the survey were the items from the Sustainable Engineering Motivation Assessment (SEMA).[18] There were five items to evaluate students' value of sustainable engineering, seven items to evaluate students affect toward sustainable engineering and three negatively worded sustainable engineering value/affect items. These SEMA items again used the 7-point agreement scale. The survey concluded with ten items to measure sustainable engineering self-efficacy, asking them to rate their degree of confidence to perform various tasks on a scale of 0 (no confidence) to 100 (fully confident). Scores for the various constructs within the survey were calculated for each student by averaging the responses to the multiple survey items that mapped to that area. On the 7-point scale, average scores below 3.5 were considered negative (or disagree) responses, averages between 3.5 and 4.5 were considered neutral, and averages above 4.5 were considered positive (or agreement).

The survey was given to incoming first year students at the University of Colorado Boulder in fall 2014. The survey was administered in class on the second day in the Introduction to Environmental Engineering course. The survey was also administered in class on the first day in an Introduction to Civil and Architectural Engineering course. Responses were received from 70 students in the environmental engineering course, 50 students in the civil engineering course, and 37 students in the architectural engineering course. This represents response rates of 95%, 96%, and 97%, respectively. The percentages of women among the respondents were 51%, 36%, and 41% for the environmental, civil, and architectural engineering students, respectively. International students comprised 13%, 22%, and 16% of the environmental, civil, and architectural engineering student respondents, respectively. Differences between the responses of students in different disciplines were initially evaluated using ANOVA for attitudes that were measured by averaging more than one Likert question. For single Likert items (global and interdisciplinary) chi-squared tests were conducted. If significant differences were found, heteroscedastic t-tests were conducted rather than post-hoc tests to determine differences between two majors. Correlations between response categories or scores were evaluated using Spearman's rho correlations, a non-parametric test that is superior to the traditional Pearson's correlation for data that is ordinal and/or non-normal. Correlation coefficients of 0.7-0.9 were considered strong, 0.4-0.6 were considered moderate, and 0.1-0.3 were considered weak.[33] Statistical analyses were conducted using IBM SPSS Statistics version 22.

The survey was administered again at the end of the semester to the same students. Note that some students had dropped the courses between the pre- and post- survey. Students in civil and architectural engineering were offered extra credit points to take the survey online during the final week of the semester; the response rate was 72% for civil engineering students and 80% for architectural engineering students (n = 38 and 28, respectively). Students in environmental engineering were given the survey during the final class meeting time of the semester; the response rate was 97% (n=72). The end-of-semester survey included all of the initial questions, as well as three additional questions to assess students' level of interest in working outside the U.S. after graduation. The question asked students to rate their interest in working on projects outside the U.S. in three settings: developed countries (for example Europe, Australia), rapidly developing countries (for example India, China, Middle East), or developing countries (for example in Africa, South America, and Asia). The students indicated their level of work interest in these settings: never, via distance collaboration methods, short term assignments in-country, 1 year or more in-country, the bulk of their career. The post survey for civil and architectural engineers also contained 2 additional questions related to interdisciplinary interest; these were taken from Knight.[24] On the survey at the end of the semester students were also asked to rate their confidence that they would graduate with a degree in architectural, civil, or environmental engineering. This data was used to infer which students intended to persist in their major. In the civil and architectural engineering course, students also wrote a reflective essay where they indicated their intent to stay or leave engineering; this information was used to compare with the survey data.

Data analysis to compare the pre- and post- survey results used two methods. First, Wilcoxon tests were used to compare pre- and post- responses from the same students. The Wilcoxon test was used because it is suitable for ordinal data and does not require normally distributed responses; this is in contrast with the more traditional paired t-test. In the case of the civil and architectural engineering survey, a number of students did not provide identifying information and therefore pairing of responses was not possible. In that case, the Mann-Whitney U test was conducted. Statistical analyses were conducted using IBM SPSS Statistics version 22.

Results and Discussion

Sustainable Engineering Motivation

Four dimensions of sustainable engineering motivation were evaluated (self-efficacy, value, negative attitudes (reverse coded), and affect). The pre-survey results (Table 1) will be described first. On average, the students had moderate levels of confidence in their sustainable engineering knowledge and abilities. The levels of confidence of sustainable engineering knowledge between individual students varied a lot, ranging from a low of 0 to a high of 100. There were not differences between the environmental, civil, and architectural engineering disciplines in terms of sustainable engineering self-efficacy, with confidence scores averaging 65 to 66. There were weak positive correlations between sustainable engineering self-efficacy and affect (0.31), value (0.27), and negative attitudes (reverse coded; 0.15).

Table 1. Sustainable engineering attitudes measured on the pre-survey

Sustainable Engineering Attitude	Average ± Standard Deviation (% negative / % neutral / % positive)			UNIANOVA Sig.
	Environmental	Civil	Architectural	
Self-Efficacy	66 ± 17	65 ± 19	66 ± 21	0.874
Affect	5.4 ± 0.9 (1 / 16 / 83)	4.5 ± 0.9 (16 / 30 / 54)	4.5 ± 1.1 (19 / 35 / 46)	0.000
Value	6.4 ± 0.6 (0 / 0 / 100)	6.2 ± 0.7 (0 / 0 / 100)	6.1 ± 0.7 (0 / 3 / 97)	0.104
Negative (reversed)	6.2 ± 0.9 (1 / 4 / 94)	5.9 ± 1.0 (2 / 8 / 90)	5.9 ± 0.9 (3 / 5 / 92)	0.321
Overall SE Motivation	5.7 ± 0.6 (0 / 3 / 97)	5.4 ± 0.7 (0 / 12 / 88)	5.4 ± 0.6 (0 / 14 / 86)	0.003

Students possessed a range of sustainable engineering affect, ranging from 2.1 to 7.0. The overwhelming majority of environmental engineering students had a positive average sustainable engineering affect score (greater than 4.5). Only 1 environmental engineering student had a negative sustainable engineering affect (average score below 3.5). Environmental engineering students had higher sustainable engineering affect scores than civil and architectural engineering majors. There was a moderate positive correlation between sustainable engineering affect and value (0.43), and weak correlations between affect and reverse-coded negative attitudes (0.30).

Environmental engineering students had strongly positive sustainable engineering value scores; these scores were much higher than their sustainable engineering affect. Fully 100% of the environmental engineering students had positive sustainable engineering value. There were not significant differences between majors for sustainable engineering value. Value was the least variable sustainable engineering attitude; the average per student scores for value ranged from 4.2 to 7.0.

The negatively worded items toward sustainable engineering were largely value statements; few students showed negative attitudes. There were not significant differences between majors for negative attitudes toward sustainable engineering.

A single combined sustainable engineering motivation score was calculated for each student. This involved scaling self-efficacy to the 1 to 7 scale, and then averaging self-efficacy, affect, value, and reverse-scored negative attitudes. These results show that none of the students had an overall sustainable engineering motivation score that was negative (below 3.5). The environmental engineering students had a statistically higher overall sustainable engineering motivation score than civil and architectural engineering majors. Univariate ANOVA did not find that there were differences between genders or international/domestic students; interactions between major, gender, and international status were also not significant.

The post survey results (Table 2) showed similar trends between majors as the pre-survey, with two notable exceptions. First, the sustainable engineering affect scores of the civil engineering students became more similar to environmental engineering students than architectural engineering students. This change is interesting given that civil and architectural engineering students participated in the same introductory course, which emphasized similarities between these disciplines and executed the same learning modules on sustainable engineering, ethics, and design. Second, civil engineering students had more negative attitudes toward sustainability than the other two disciplines. It is possible that the students were completing the extra credit survey rapidly at the end of the term, and did not carefully read these survey items, which were negatively worded (in contrast to the majority of the other questions on the survey).

Table 2. Results from post-survey on sustainable engineering attitudes

Sustainable Engineering	Average ± Standard Deviation		
Attitude	Environmental	Civil	Architectural
Self-Efficacy	73 ± 11*	75 ± 12*	73 ± 15*
Affect	5.3 ± 0.5	5.1 ± 1.1*	4.6 ± 1.2
Value	6.1 ± 0.7*	6.3 ± 0.6	6.2 ± 0.7
Negative (reversed)	6.1 ± 1.2	5.2 ± 1.8*	5.8 ± 0.9
Overall motivation	5.7 ± 0.6	5.5 ± 0.6	5.5 ± 0.6

* statistically significant difference versus pre survey for the same major

When the data were explored for changes between the pre- and post- survey, it was found that sustainable engineering self-efficacy had increased among all three disciplines. The increases in student confidence toward skills related to sustainable engineering are likely the result of content in these first year introductory courses related to sustainable engineering. The civil and architectural engineering students had a two-week module on sustainability, including a homework assignment to apply sustainable engineering rating systems (ENVISION and LEED, respectively) to a case study. The environmental engineering students had a week-long module on sustainability. Sustainable engineering affect increased among civil engineering students, but negative feelings toward sustainable engineering also increased. On the pre-survey civil engineering students were given time in class to complete the survey; they may have been reading more carefully and picked up on the negative wording of those survey items. In contrast, the post-survey was administered in an online forum on their own time for optional extra credit; with end-of-semester concerns the students may not have been reading items carefully and missed the negative wording of the items. Alternatively, learning more about sustainable engineering in the course may have polarized some of the student opinions related to sustainability. Among environmental engineering students, sustainable engineering value decreased. The decrease was not very large, and the post-survey average was similar to the other majors. The decrease may have been due to the largely technical course content in the first semester curriculum, and only a single week spent on sustainability in the Introduction to Environmental Engineering course. This may have been less sustainability emphasis than the environmental engineering students were expecting, which might have decreased the extent to which they believed that sustainability would be of value in the engineering workplace.

The results from this study on the comparative sustainable engineering motivation between first year students in different engineering disciplines are different than previous findings. Previous data from among seniors indicated that civil engineers valued sustainability the least, compared to students in architectural and environmental engineering.[34] But the differences in the sustainable engineering attitudes of the seniors may have been driven by content within the different curricula. Further research is needed to track longitudinal changes in student attitudes as they progress through undergraduate engineering degrees, and how different curricular designs between institutions differently impact longitudinal changes.

Global Interests

Table 3 summarizes the student interest in working globally. At the beginning of the semester (pre), over 75% of the students in all three disciplines agreed at least to some extent that they were interested in working on projects outside the U.S. About 5% of the students were not interested in working on projects outside the U.S. during their career. There were not significant differences between environmental, civil, and architectural engineering majors based on the chi-square test. However, there were significant differences based on gender (chi-square 0.018), with greater interest among female students (88% of the females on the agreement side of the scale compared to only 76% of the male students). At the end of the semester (post), there appeared to be little change in student interest in working on projects outside the U.S. during their career. Both of the introductory civil/architectural and environmental engineering courses included discussions of global issues, but given the already strong student interest in these areas the lack of an increase in student interest on the post survey is not surprising.

Table 3. Interest of first-year engineering students in global work

Statement	Time	Major	% disagree (Likert response 1-3)	% neutral (Likert response 4)	% agree (Likert response 5-7)	Average
I am interested in working on projects outside the U.S. during my career	pre	Environmental	6	11	83	6.1
		Civil	4	12	84	5.8
		Architectural	5	19	76	5.8
	post	Environmental	8	10	82	5.9
		Civil	5	11	84	5.8
		Architectural	4	14	82	5.9

More detail on the student interest in working on projects outside the U.S. was gathered on the post survey. Students were asked if they were interested in different contexts / locations, and to what extent (ranging from never to an entire career). Results are summarized in Table 4. Similar to the simple question, most students demonstrated some interest in engineering projects outside the U.S.; however, preferences for different locations and/or contexts became evident. Among the civil and architectural engineering majors, no students checked “never” for all three global contexts; a single environmental engineering student checked “never” for all three global contexts.

Table 4. Student interest in working on engineering projects in various global contexts

Response Statement	Major	% Never	% From the U.S. using distance collaboration methods	% For a few short term assignments abroad	% Living abroad for 1 or more years	% Living abroad for the bulk of my engineering career	Average total weighted score
Interest in working on projects for first world countries such as Canada, Australia, or Europe	Envir.	3	17	53	40	22	6.0
	Civil	0	24	53	63	24	7.3
	Arch.	0	32	68	64	25	8.4
Interest in working on projects for rapidly developing countries such as India, China, or in the Middle East	Envir.	8	31	43	35	15	4.9
	Civil	3	29	45	34	24	5.7
	Arch.	4	61	61	39	14	6.0
Interested in working on projects for poorer developing countries in Africa, South America, or Asia	Envir.	7	17	44	38	31	6.4
	Civil	3	26	45	45	29	6.7
	Arch.	4	54	68	43	11	6.0
Any of 3 above non-U.S. contexts	Envir.	11	36	72	71	43	
	Civil	5	39	74	74	45	
	Arch.	4	64	82	82	36	

A weighted scoring system was developed in order to compare the total student interest for each global context; the weights were: never = 0, distance = 1, short term assignments = 3, one or more years = 5, bulk of career = 10. The total weighted score across all three global contexts was moderately correlated with the student response to the Likert item on interest in working outside the U.S. during their career (correlation coefficients for environmental, civil, and architectural engineering students were 0.30, 0.61, and 0.47, respectively).

Among the civil and architectural engineering students, there was the strongest interest in working abroad in first world countries (71% and 78% of the students ranked this first or tied for first, respectively); this was the second most popular context for environmental engineering students (64% ranked this first or tied for first). Among environmental engineering students, working in poorer countries was the most popular global context (68% of the students ranked this first or tied for first). Poorer communities were the second most popular context among civil engineering students (66% of the students ranked this first or tied for first), and significantly less popular with architectural engineering students (33% ranked this first or tied for first). The popularity of working in developing countries is not unexpected, given the popularity of EWB nationwide and at the University of Colorado Boulder in particular. Environmental and civil engineering students had the least interest in projects for rapidly developing countries (40% and 39% of the students ranked this first or tied for first, respectively); interest was similarly low among architectural engineering students (37% ranked this first or tied for first). Note that many students had an identical interest in the three international contexts, based on the same weighted score for all three areas; this was true for 25% of the environmental engineering students, 29% of the civil engineering students, and 15% of the architectural engineering students.

For the types of work on projects outside the U.S., the highest percentage of students were interested in a short term assignment abroad or living abroad for one or more years; architectural engineering students had the greatest interest in this type of work abroad. Architectural engineering students had a greater interest in working on projects outside the U.S. using distance collaboration methods than environmental or civil engineering students.

Almost half of the environmental and civil engineering students had an interest in working outside the U.S. for the bulk of their career; the most popular context for these students was poorer developing communities. This interest likely reflects a unique program at the University of Colorado Boulder.[6] Within environmental engineering, students can elect to focus their technical option in one of seven areas, one of which is Engineering for Developing Communities (EDC). When the environmental engineering students in the first year course were asked what track they would likely pursue, 29% listed EDC as their preferred choice. This is significantly higher than the 9% of the environmental engineering seniors who are in this track. Within civil engineering, a similar concentration is not available, so interest in the track is unknown. EDC is also the foundation of a graduate certificate program.

Previously in fall 2011, there were differences between the attitudes of incoming civil and environmental engineering students toward global issues (unpublished data). When asked to rate the importance of "global context" for professional engineers, civil engineers' average rating was only 5.5 (between slightly important and important) compared to environmental engineers' average rating of 6.2 (between important and very important). In response to the question "It is appropriate that people do not care what happens outside their country", student responses were similar for civil and environmental engineering students, averaging 2.0 and 2.1 (disagree), respectively. This indicates that there are likely differences in how students view global issues in general as opposed to their interest working in a global context.

Interdisciplinary Value

On the pre-survey there was a broad diversity of student opinions about the value of interdisciplinary learning (Table 5). Interdisciplinary opinions were more varied as compared to generally strong consensus about interest in working abroad. The majors were statistically different based on a chi-square test (Pearson chi-square asymp. sig., 2-sided 0.021). While 73-74% of the environmental and civil engineering students agreed that interdisciplinary learning would be valuable, less than half the architectural engineering students agreed with this statement. These results are interesting given how these disciplines are comprised at the University of Colorado Boulder. The environmental engineering degree is offered through a multi-disciplinary program that combines civil, mechanical, and chemical engineering courses. In contrast, civil and architectural engineering are offered through a single department. However, architectural engineering is a combination of knowledge from the more traditional disciplines of civil, mechanical, and electrical engineering, as well as pulling in courses from architecture. At the end of the semester, the attitudes of the environmental and civil engineering students remained unchanged, while the architectural engineering students underwent a dramatic increase in recognizing the value of interdisciplinary learning. The content within the introductory course emphasized the interdisciplinary nature of architectural engineering, combining knowledge from civil, mechanical, and electrical engineering as well as architecture. It seemed that this message had an impact on the student attitudes.

Table 5. Student opinions on the value of interdisciplinary learning

Statement	Time	Major	% disagree (Likert response 1-3)	% neutral (Likert response 4)	% agree (Likert response 5-7)	Average
Interdisciplinary learning is indispensable for my professional development	Pre	Environmental	4	23	73	5.4
		Civil	6	20	74	5.3
		Architectural	19	32	49	4.8
	Post	Environmental	7	20	73	5.2
		Civil	16	8	76	5.3
		Architectural	7	0	93	5.9*

* post survey responses significantly different than pre survey responses for same major

The post survey for civil and architectural engineers contained two additional questions related to interdisciplinary interest. The results from these questions are shown in Table 6. For these elements of interdisciplinary attitude, civil and architectural engineering students are not significantly different. Students in both disciplines generally agreed with these statements about interdisciplinary ideas. In future studies, multiple survey items should be used to assess students' attitudes toward interdisciplinary topics. Longitudinal studies should also be conducted to explore if these attitudes change over time and whether these changes can be linked to particular curricular elements or co-curricular/extracurricular activities (such as involvement in EWB, EPICS, and other multi-disciplinary groups).

Table 6. Student attitudes related to interdisciplinary value on the end-of-semester survey

Statement	Major	% disagree	% neutral	% agree	Average
I enjoy thinking about how different fields approach the same problem in different ways	Civil	5	3	92	5.9
	Arch.	7	4	89	5.8
Not all engineering problems have purely technical solutions.	Civil	0	8	92	5.9
	Arch.	0	14	86	5.9

Concern for Others as an Engineer

The survey measured two elements that relate to concern for others in the context of engineering. First, the *analyze* dimension "addresses the ability to examine social issues from a professional perspective. This dimension is characterized by views of who the stakeholders are for engineering projects and how they should be involved in the decision making process."[28] Second, *professional connectedness* evaluates "a sense of moral obligation to help others because of the professional skills that one possesses."[28] As expected, there was a moderate correlation (0.60) between these two dimensions. Environmental engineering students had average scores for the *analyze* and *professional connectedness* dimensions of 6.0 and 5.7, respectively, which were more positive than architectural engineering students and not significantly different than civil engineering students (Table 7). While 97% of environmental engineering and 98% of civil engineering students had positive attitudes toward concern for others as an engineer, only 84% of architectural engineering students had positive concern for others.

Table 7. Concern for others measured on the pre-survey

Concern for Others	Average ± Standard Deviation (% negative / % neutral / % positive)			UNIANOVA Sig.
	Environmental	Civil	Architectural	
Analyze	6.0 ± 0.6 (1 / 1 / 97)	5.9 ± 0.6 (0 / 0 / 100)	5.6 ± 0.8 (0 / 11 / 89)	0.047
Professional connectedness	5.7 ± 0.8 (1 / 6 / 93)	5.5 ± 0.8 (0 / 4 / 96)	5.2 ± 0.9 (3 / 9 / 88)	0.035
Overall Concern For Others	5.8 ± 0.6 (1 / 1 / 97)	5.8 ± 0.6 (0 / 2 / 98)	5.4 ± 0.7 (0 / 16 / 84)	0.015

A more rich Univariate ANOVA found that major, gender, and the interaction of [major * gender * international] were significant determinants of the *analyze* score (sig. 0.021, 0.001, and 0.018, respectively). In contrast, for *professional connectedness* the univariate ANOVA determined that major was not a significant effect (sig. 0.366), but gender was important (sig. 0.000). Thus, the apparent differences in *professional connectedness* between majors in the simple analysis in

Table 7 were confounded by the differential representation of women among the student respondents in each discipline. Overall concern for others was only found to be impacted by gender (sig. 0.000); student major in this larger analysis was not significant (sig. 0.064).

Previously, environmental engineering students were found to have significantly higher scores in the *analyze* and *professional connectedness* elements than civil engineering students.[18] However, those elements were measured in the context of 50 Likert items to measure Professional Social Responsibility, and included 19 questions to measure *professional connectedness* instead of the sub-set of 4 items selected to evaluate *professional connectedness* that were used in this survey.

The concern for others results from the post-survey are summarized in Table 8. For environmental engineering students, the "culture of disengagement"[35] already seems to be occurring in terms of students' attitudes toward *professional connectedness*. Although not statistically significant, it also appears that architectural engineering students had less positive attitudes toward *professional connectedness* (pre survey 88% positive compared to 70% positive on post survey).

Table 8. Student attitudes toward concern for others on the end-of-semester survey

Concern for Others	Average ± Standard Deviation (% negative / % neutral / % positive)		
	Environmental	Civil	Architectural
Analyze	5.9 ± 0.6 (0 / 1 / 99)	6.1 ± 0.6 (0 / 0 / 100)	5.8 ± 0.6 (0 / 4 / 96)
Professional connectedness	5.3 ± 1.0* (4 / 8 / 88)	5.5 ± 0.8 (0 / 9 / 91)	5.1 ± 1.1 (7 / 22 / 70)
Overall Concern For Others	5.6 ± 0.7* (0 / 6 / 94)	5.8 ± 0.6 (0 / 0 / 100)	5.5 ± 0.7 (0 / 4 / 96)

* statistically significant difference compared to pre-survey

Two of the individual items to evaluate attitudes toward *professional connectedness* showed statistically significant decreases from the beginning to the end of the semester for the environmental engineering students, and one item for the civil engineering students (Table 9).

Table 9. Concern for others questions with significant difference between student responses at the beginning and end of the semester

Statement	Major	Pre Survey Average ± Stdev	Post Survey Average ± Stdev
Importance of volunteerism for professional engineers	Environmental	5.8 ± 1.2	5.2 ± 1.3
I feel called by the needs of society to pursue a career in engineering	Environmental	5.6 ±1.2	5.0 ± 1.4
Service should not be an expected part of the engineering profession [reversed]	Civil	5.4 ± 1.2	4.7 ± 1.6

However, some of this change in student concern for others in the context of engineering may be confounded with a decrease in student interest toward pursuing engineering. To test this idea, the environmental engineering students who agreed with the statement "I am confident that I will graduate with a degree in engineering" (by answering 5, 6, or 7 on the Likert scale question; n=52) were compared to the students who disagreed (by answering 1, 2, or 3; n=15); the average *professional connectedness* score among students who agreed was 5.4 compared to only 4.9 among students who disagreed. Further, paired t-tests among the pre- and post- professional connectedness of students who were confident of graduating with an engineering degree found no significant differences (p=0.20); there was a statistically significant difference among students who had low confidence of attaining an engineering degree (p=0.02). There were not significant differences in the *analyze* dimension based on confidence of graduating with an engineering degree.

An interesting interaction was found between average *professional connectedness* score and confidence that the student would graduate with a degree in engineering or environmental engineering. For students likely to leave engineering (both confidence in earning a degree in engineering and a degree in environmental engineering four or below on the Likert scale, representing strongly disagree to neutral; n=18), their pre scores in *professional connectedness* averaged 5.8, somewhat higher than students more confident they would graduate in engineering (average 5.6; n=53; score 5 or above in either confidence in graduating with a degree in engineering or a degree in environmental engineering; difference not statistically significant, p=0.22). This may indicate that those students initially most motivated to help others as evidenced through their *professional connectedness* scores are more likely to leave engineering. This was previously hypothesized as a reason for lower social responsibility scores among female senior students in environmental engineering compared to first year students.[25] On the post survey the average *professional connectedness* scores were lower for those likely to leave engineering at 5.0 compared to individuals more likely to persist with an average score of 5.4 (p-value for 1-tailed t-test 0.03). For civil engineering students, there were not significant differences in the elements of concern for others versus intent to graduate in engineering. For architectural engineering students, the average *analyze* scores and overall concern for others scores for students with low confidence in graduating in engineering were higher than the averages for students with higher confidence of graduating in engineering (average analyze and overall concern for others scores 6.2 and 5.9 among leavers, compared to 5.8 and 5.5 for stayers, respectively). Further research on concern for others and student persistence in engineering is needed.

Correlations Between Attitudes

There were statistically significant positive correlations between sustainable engineering motivation, global work interests, interdisciplinary value, and concern for others (Table 10). The strongest correlation was between sustainability motivation and concern for others; this positive correlation was moderate. Correlations between the other attributes were weakly positive. Similar results were obtained for correlations between the attributes when the pre- and post-survey data sets were combined; the only significant difference was a lower correlation between global work interest and interdisciplinary value.

Table 10. Correlations between attitudes for all first year students: pre-survey

Attitudes	Total Sustainable Engineering Motivation	Global	Inter-disciplinary	Concern for Others
Total Sustainable Engineering Motivation	1	0.274**	0.352**	0.538**
Global	0.274**	1	0.205*	0.309**
Interdisciplinary	0.352**	0.205*	1	0.314**
Concern for Others	0.538**	0.309**	0.314**	1

* Correlation significant at 0.05 level (2-tailed); ** Correlation significant at 0.01 level (2-tailed)

The strength of the correlations between the various attributes varied between disciplines; results are shown in Table 11. For example, there were positive correlations between sustainable engineering motivation and global work interest for civil and environmental engineering students; there was not a statistically significant correlation for architectural engineering students. Only environmental engineering students had a significant correlation between their global work interests and concern for others as engineers. Only civil engineering students had a statistically significant correlation between interdisciplinary value and concern for others.

Table 11. Correlation coefficients between different attitudes for students in different disciplines on the pre-survey

Attributes being Correlated	Environ-mental	Civil	Arch-itectural
Sustainable Engineering motivation : concern for others	0.54**	0.45**	0.53**
Sustainable Engineering motivation : global	0.25*	0.33*	0.13
Sustainable Engineering motivation : Interdisciplinary	0.34**	0.32*	0.36*
Global : Concern for Others as Engineers	0.48**	0.17	0.09
Global : Interdisciplinary	0.23	0.34*	0.11
Interdisciplinary: Concern for Others	0.22	0.47**	0.25

* Correlation significant at 0.05 level (2-tailed); ** Correlation significant at 0.01 level (2-tailed)

Using data from the post-survey, additional correlations were explored. There was a moderate correlation between the weighted score for interest in working in poorer countries and the *professional connectedness* score; these correlation coefficients were 0.42, 0.32, and 0.41 for environmental, civil, and architectural engineering students, respectively.

Implications and Further Research

The results showed that environmental engineering students generally have very positive attitudes toward sustainable engineering, work in global settings, interdisciplinarity, and concern for others in the context of engineering. It appears that similar students tend to value these "broader" attributes, as indicated by correlations between these attitudes. There are a number of case studies or other teaching methods that may be able to combine these ideas, showing students how these elements can reinforce each other. For example, global development projects such as those conducted by EWB-USA and various programs (i.e. Michigan Tech D80) may illustrate the connections between the need for interdisciplinary collaboration to achieve sustainable designs that are best suited to benefit communities in a diverse range of global settings. Because the level of student attitudes and strength of the correlations between these attitudes varied significantly between disciplines, further research should be expanded to a broader range of engineering disciplines (such as mechanical, electrical, and chemical engineering). Another intriguing question to explore is how student attitudes toward these areas change over time. It is important to determine whether engineering students grow in their value and motivation toward these elements over time, or tend to become enculturated by curricula that tend to focus on technical elements to place less value on these ideas.[35] A previous study found that service-learning had a beneficial impact on professional social responsibility of engineering students (with includes elements of care for others),[37] but similar information on the attributes of global interests, motivation toward sustainability, and valuing interdisciplinary elements is not yet available.

It is also critical to understand whether or not the students who are the most motivated by sustainable engineering, global impacts, interdisciplinarity, and concern for others are retained in engineering at similar rates as students with more traditional interests. It is known that students' identity with engineering impacts retention,[38,39,40] and identity can be associated with alignment of values.[41,42] Therefore, courses that emphasize these elements of the helping others, sustainability, global issues, and/or interdisciplinary approaches early in the curriculum, such as a service-learning design course taught with a developing world focus, [43-44] may be helpful toward retention of students with these interests. However, rigorous studies that have shown increased retention due to service-learning[45] have not yet been conducted in association with engineering. Other pedagogies such as case studies are also ways to infuse these elements into engineering courses and curricula. It is critical that individuals with broader interests are retained and persist in engineering, entering the engineering profession, as these individuals may be best able to help solve the complex problems that face society and our planet.

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