Student Perceptions of Sustainability and Engineering Mechanics in Undergraduate Civil and Environmental Engineering Education at Virginia Tech

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Abstract

Engineering curricula across the U.S. have been undergoing changes in order to effectively train engineers to address sustainability concerns. An important aspect of implementing curricular change is having useful tools to evaluate their impact. In this study, a survey was used to measure student perceptions of engineering mechanics and sustainability in order to compare responses across subject areas as a means for gaining perspective on student perceptions of their sustainability knowledge and skills. The survey was administered to students enrolled in required introductory and senior level courses in the Via Department of Civil and Environmental Engineering (CEE) at Virginia Tech. The results revealed that while students are interested in sustainability and believe it is important to engineering, their knowledge of sustainability considerations lags behind their knowledge of traditional engineering mechanics. Student knowledge of engineering mechanics increases steadily with academic standing; however, knowledge of sustainability remains unchanged until the senior year. In addition, the results indicate students may value the environment over economy or society. Overall, the response suggests that additional curricular improvements are needed to reduce the disparity between students’ confidence ratings for engineering mechanics and sustainability skills. Improvements could include increased coverage in the sophomore and junior years and additional emphasis on economic and societal impacts.

Introduction

Sustainability is an issue that civil engineers are increasingly required to consider in their work, balancing environmental, social and economic concerns in order to meet present human needs while not compromising the ability of future generations to do the same. Therefore, undergraduate civil engineering education should provide instruction in how to consider the aspects of environment, society and economy in design. For instance, the first canon of the American Society of Civil Engineers (ASCE) code of ethics was updated in 1996 to include sustainable development. ASCE’s Body of Knowledge recommends that upon completion of an undergraduate degree, engineers should have knowledge and comprehension of sustainability, and understand applications of sustainability.

In 1996, ABET revised its accreditation criteria from being a set of detailed prescriptive guidelines to focusing more on student outcomes in attaining certain technical and professional skills. ABET's accreditation Criterion 3 outcome (c) includes considerations of sustainability in design. The ABET outcome is less specific about sustainability than ASCE’s Body of Knowledge; ASCE is currently coordinating changes to the ABET Civil Engineering Program Criteria that will require undergraduate students to make applications of sustainability principles in design. The emphasis on sustainability by both ABET and ASCE underscores the importance of including the subject in civil engineering education, understanding how well civil engineering
education has performed at achieving the outcomes in graduates, and making continuous improvements in curricula.

Based on the need to include sustainability in engineering education, the subject has gradually entered into the mainstream of engineering curricula in the U.S., as indicated by national studies. Since it is relatively new, it is important to evaluate the effectiveness of sustainability education for continuous quality improvement. One method of evaluating sustainability education is through student perceptions and feedback. To this end, many researchers have employed student surveys. Three of these studies involved the use of surveys to specifically understand civil engineering students’ perceptions of sustainability, and/or their skills in applying sustainability principles. One weakness of these past survey studies is that they do not question students about their perceptions of traditional engineering curriculum topics. Responses to such questions provide a “control” to which responses to questions about sustainability can be compared, thus increasing the value of student surveys for evaluating sustainability in civil engineering education.

**Research Goal and Key Questions**

The primary goals of the study described in this paper were to: 1) Evaluate the effectiveness of education in sustainability topics in the Civil and Environmental Engineering (CEE) department at Virginia Tech (VT) from the perspective of students by comparing survey responses between sustainability and engineering mechanics subject areas. 2) Evaluate general student interest in various sustainability related topics in order to identify which topics students may be most interested in learning about in CEE curricula. 3) Determine what students believe is the primary source of their sustainability knowledge.

Key questions that this study seeks to answer in order to address its main goals are:

1) Is there a difference between students’ perceptions of the importance of engineering mechanics and sustainability skills, and their perceived confidence in their ability to demonstrate those same skills?
2) Is there a difference in student responses between the engineering mechanics and sustainability subject areas? What may be inferred about the CEE curriculum and the potential need for changes based on student responses?
3) Are there differences in student responses based on gender, academic standing, or academic major?
4) In what sustainability related topic(s) are civil engineering students most interested?
5) What do CEE students credit as the primary source of their sustainability knowledge?

**The CEE Curriculum at Virginia Tech**

The CEE department at VT offers a Bachelor of Science in Civil Engineering (BSCE). Unlike some institutions, Environmental Engineering does not constitute a separate undergraduate major from Civil Engineering at VT. The Myers-Lawson School of Construction is a joint venture between the colleges of engineering and architecture. The school offers a Bachelor of Science in Construction Engineering and Management (CEM). The curricula for the CEE and CEM degrees
are similar, but the CEM degree provides more focus in construction engineering; some courses required of CEE students are not required of CEM students.

All freshman engineering students are housed within the Department of Engineering Education and matriculate into a degree granting program in the sophomore year. Once in the department, CEE students are required to take several sophomore level courses, including CEE 2804-Introduction to Civil and Environmental Engineering. Normally, CEE 2804 is taken in the first semester of students’ sophomore year.

CEE 2804 provides a civil engineering overview with lectures on historical events and modern challenges. The course encourages students to form opinions and think critically about civil engineering design and actions from scientific, social, and symbolic perspectives. The class breaks into small discussion sections where students write and present on civil engineering projects and topics while experiencing their new profession first-hand through faculty-led field trips. A specific sustainability module was added to CEE 2804 beginning in the Fall 2013 term. Prior to Fall 2013, CEE 2804 primarily focused on civil engineering as a profession and the CEE curriculum requirements.

Sophomore CEM students take CNST 2104-Introduction to Constructing Engineering and Management. CNST 2104 focuses on CEM as a profession and the CEM curriculum requirements. Students in CNST 2104 complete a semester design project addressing an infrastructure need in a developing country, and receive a lecture and an assignment about sustainability, particularly as it relates to building construction and building systems.

In the junior year, CEE students take at least seven “fundamentals” courses that span the breadth of civil and environmental engineering. Then they take at least four advanced elective courses in any three of eight program areas. Students have 12 credits of electives that they may take, half of the credits are for courses outside of CEE and the remaining credits can be in CEE or in another department.

To complete a BSCE or CEM degree, CEE 4804-Professional and Legal Issues in Engineering is required of all students in the senior year. CEE 4804 covers professional practice topics such as ethics, professional registration, legal principles, business practices, leadership, communication and the importance of public policy to civil engineering. CEE 4804 does not include specific sustainability content. Therefore, since the number of students actually enrolling in elective courses with sustainability topics is unknown, the module in CEE 2804 is presently the only sustainability coverage known to be received by all CEE students.

Methods

This study seeks to evaluate the effectiveness of sustainability education via a student perceptions survey. Recently, the results of a survey performed at Georgia Tech (GT) that evaluated senior civil engineering students’ perceptions of sustainability in their education were published. It was found that while students highly rated the importance of engineers having skills and abilities with issues associated with sustainable development and sustainable design, they rated their confidence with exercising these skills significantly lower than the importance.
These findings are significant, and raise questions regarding the effectiveness of education for sustainability within civil engineering curricula. However, the GT study only investigated student perceptions of importance and confidence with sustainability topics. In terms of civil engineering curricula, the incorporation of the modern understanding of sustainability is relatively new compared to traditional engineering mechanics. Without measuring student ratings with regard to traditional skills, there is no basis against which to compare and interpret student ratings for sustainable development and design skills.

To address the goals of this study, the survey used in the GT study\textsuperscript{16} was modified to include questions related to perceptions of Engineering Mechanics in addition to Sustainable Development and Sustainable Design. The Engineering Mechanics questions serve as a point of reference to which questions related to Sustainable Development and Sustainable Design can be compared. The survey asked students to rate how important they felt certain engineering skills and abilities in all three areas are, and how confident they are in their abilities to exercise those skills on a 7-point scale. Students were also asked to rate their interest in a variety of sustainability topics and reflect on the source of their sustainability knowledge. Additional modifications from the GT survey were made to address differences in the curricula of the two institutions. Questions that were included in both the GT study and the present study provide a direct comparison over institutions.

The survey was administered to students enrolled in CEE 2804 and CEE 4804 in the fall 2013 semester and to students enrolled in CEE 4804 in the spring 2014 semester. In both semesters, the survey was administered near the end of the term. This sampling scheme measured the perceptions of students just entering/early in their CEE studies and those approaching graduation. Since these two courses are required of all students completing the BSCE degree, they provide the largest, most diverse and readily accessible population of students within the program.

Statistical tests used for data analysis were conducted with a significance level, $\alpha = 0.05$. Differences were detected by comparing the $p$-value resulting from the statistical test with the significance level, $\alpha$. Nonparametric tests were used on the raw response data because: 1) the survey used a 7-point rating scale, which results in ordinal rather than continuous data\textsuperscript{19}, and 2) the distribution of response ratings was anticipated to be skewed, not following the normal distribution. Skewness is likely because the response ratings are limited to 1 through 7, and students were anticipated to generally ascribe either high or low ratings of importance and confidence to a particular prompt. For illustrative purposes, the proportion ($\pi$) of students providing high ratings (6, 7) are shown in the tables and text of this paper.

The survey was designed such that related questions were grouped together (e.g., questions 2A through 2G related to Engineering Mechanics). Since student ratings of the importance of various engineering skills and their confidence in their ability to exercise those skills were on a 7-point scale, it was possible to follow Likert’s method\textsuperscript{20} to measure general student attitudes in Engineering Mechanics, Sustainable Development and Sustainable Design and make comparisons to discover if students rate these subjects differently. The comparison amongst these three subject areas was made by taking the mean response of each student to all questions related to a particular subject (e.g., Engineering Mechanics).
Results

A total of 320 useful survey responses were analyzed (n = 320). Based on student reporting in the survey, CEE 2804 respondents included 95 sophomores, 51 juniors and 6 seniors. CEE 4804 respondents included 12 juniors and 156 seniors. A total of 28 students enrolled in CEE 4804 reported CEM as their academic major. Of the 320 respondents, 242 identified as male, 72 as female and 6 did not select a gender. Based on the survey participation, there was sufficient data to explore differences based on gender, academic standing and academic major.

Nonparametric statistical tests on all responses revealed that student importance ratings for every question are higher than their confidence ratings ($p < 0.0001$), as illustrated by comparing the proportion of 6 or 7 ratings ($\pi_{6,7}$) for all respondents in Tables 1, 2 and 3. This result is in agreement with the findings in the GT study\textsuperscript{16}. Among seniors, it is not universally true that importance ratings are higher than confidence ratings. The exception is for ‘Determining the reaction forces on a beam,’ where the importance and confidence ratings are statistically equivalent ($p = 0.2798$).

Engineering Mechanics

The proportion of students highly rating the importance of various Engineering Mechanics skills and their confidence with those skills is presented in Table 1. The skill with the largest proportion of high importance ratings was ‘Determine the reaction forces on a beam’ ($\pi_{6,7} = 78.1\%$). This same skill also received the largest proportion of high confidence ratings among all students ($\pi_{6,7} = 66.7\%$). The skill receiving the smallest proportion of high importance ratings among all students was ‘Determine the head losses of a fluid flowing through a pipe system’ ($\pi_{6,7} = 52.2\%$). While this skill received a low proportion of high confidence ratings ($\pi_{6,7} = 27.0\%$), the lowest proportion of high confidence ratings among all students ($\pi_{6,7} = 26.1\%$) was actually for ‘Define pressure head, elevation head and velocity head of a flowing fluid.’

While there are no statistically significant differences in responses to these questions by gender, differences do exist based on academic standing and academic major. Sophomores and juniors feel it is more important to be able to determine the compression or elongation of a given structural member or material under a specified load than seniors ($p = 0.0095$ and $p = 0.0089$, respectively). Juniors rate the importance of defining pressure head, elevation head and velocity head for a flowing fluid higher than seniors ($p = 0.0108$), but the same as sophomores ($p = 0.1346$). In this skill, seniors’ ratings are also not significantly different from sophomores ($p = 0.1990$). All other topics involve no statistically significant differences in importance rating based on academic standing.

In terms of confidence ratings, seniors are more confident than sophomores in every skill, with $p < 0.0001$. Seniors are more confident than juniors with statistical significance in all but two skills. There is no statistical difference between juniors and seniors for ‘Define and explain the equations of equilibrium for statically determinant members’ (seniors $\pi_{6,7} = 64.8\%$, juniors $\pi_{6,7} = 55.6\%$; $p = 0.1573$), and ‘Determine the reaction forces on a beam’ (seniors $\pi_{6,7} = 77.6\%$, juniors $\pi_{6,7} = 60.3\%$; $p = 0.0641$). As observed in Table 1, there is generally a trend of increasing confidence ratings with increasing academic standing, illustrative of development of student knowledge with progress through the CEE curriculum.
Differences in importance and confidence ratings for Engineering Mechanics topics between CEE and CEM students only exist for the fluid mechanics skills. For defining pressure head, elevation head and velocity head, CEE students rate the importance ($\pi_{6,7} = 53.3\%$) and confidence ($\pi_{6,7} = 29.7\%$) higher than CEM students ($\pi_{6,7} = 35.7\%, p = 0.0066$; and $\pi_{6,7} = 3.6\%, p = 0.0052$, respectively). Likewise, for determining the head losses of a fluid flowing through a pipe system, CEE students rate the importance ($\pi_{6,7} = 52.9\%$) and confidence ($\pi_{6,7} = 30.0\%$) higher than CEM students ($\pi_{6,7} = 39.3\%, p = 0.0180$; and $\pi_{6,7} = 3.6\%, p = 0.0084$, respectively).

Table 1. Proportion of high student ratings (6 or 7 on a scale from 1-7) of importance and confidence with Engineering Mechanics skills.

<table>
<thead>
<tr>
<th>Survey Prompt</th>
<th>Importance, $\pi_{6,7}$ (%)</th>
<th>Confidence, $\pi_{6,7}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Soph</td>
<td>Jr</td>
</tr>
<tr>
<td>Define and explain the equations of equilibrium</td>
<td>72.4</td>
<td>73.7</td>
</tr>
<tr>
<td>Analyze a truss and determine the member forces.</td>
<td>73.7</td>
<td>74.7</td>
</tr>
<tr>
<td>Determine the reaction forces on a beam.</td>
<td>78.1</td>
<td>76.8</td>
</tr>
<tr>
<td>Define stress and strain.</td>
<td>73.4</td>
<td>71.6</td>
</tr>
<tr>
<td>Determine the compression or elongation of a given</td>
<td>70.7</td>
<td>76.6</td>
</tr>
<tr>
<td>structural member or material under a specified load.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define pressure head, elevation head and velocity head</td>
<td>52.8</td>
<td>55.3</td>
</tr>
<tr>
<td>of a flowing fluid.</td>
<td>52.2</td>
<td>47.9</td>
</tr>
</tbody>
</table>

Sustainable Development

The proportion of all students highly rating the importance of conceptual Sustainable Development skills is shown in Table 2. The skill receiving the largest proportion of high ratings ($\pi_{6,7} = 85.5\%$) was ‘Develop sustainable solutions to engineering problems.’ The lowest proportion of high importance ratings ($\pi_{6,7} = 64.8\%$) was associated with ‘Discussing the connection between poverty, population, consumption and environmental degradation.’ The
The proportion of students highly rating their confidence in Sustainable Development skills ranged from $\pi_{6,7} = 27.3\%$ for ‘Evaluate an engineering design based on sustainability criteria,’ to $\pi_{6,7} = 39.2\%$ for ‘Discuss the concept of sustainable development.’

**Table 2.** Proportion of high student ratings (6 or 7 on a scale from 1-7) of importance and confidence in abilities to address factors related to Sustainable Development.

<table>
<thead>
<tr>
<th>Survey Prompt: &quot;The following statements are related to sustainable development. Indicate how important you think it is for engineers to be able to complete the listed tasks. Also indicate how confident you are in your ability to complete the listed tasks.&quot;</th>
<th>Importance, $\pi_{6,7}$ (%)</th>
<th>Confidence, $\pi_{6,7}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop sustainable solutions to engineering problems.</td>
<td>85.5</td>
<td>82.1</td>
</tr>
<tr>
<td>Discuss the concept of sustainable development.</td>
<td>76.1</td>
<td>71.6</td>
</tr>
<tr>
<td>Discuss the connection between poverty, population, consumption, and environmental degradation.</td>
<td>64.8</td>
<td>58.9</td>
</tr>
<tr>
<td>Discuss economic factors that affect sustainable development.</td>
<td>74.4</td>
<td>65.3</td>
</tr>
<tr>
<td>Discuss environmental factors that affect sustainable development.</td>
<td>77.6</td>
<td>66.3</td>
</tr>
<tr>
<td>Discuss social factors that affect sustainable development.</td>
<td>67.4</td>
<td>67.4</td>
</tr>
<tr>
<td>Evaluate an engineering design based on sustainability criteria.</td>
<td>77.4</td>
<td>73.7</td>
</tr>
</tbody>
</table>

There are no differences based on gender or academic major. The only statistically significant difference in importance ratings based on academic standing is for ‘Evaluate an engineering design based on sustainability criteria.’ In this case, seniors rate this skill as more important than juniors ($p = 0.0208$), but the same as sophomores ($p = 0.1903$). Statistically, sophomores and juniors also rate the importance of this skill the same ($p = 0.7489$).

Confidence ratings differ by academic standing for each Sustainable Development topic, with seniors providing higher ratings than students of lower academic standing. One exception is for ‘Discuss social factors that affect sustainable development,’ where seniors rate their confidence the same as sophomores ($p = 0.0937$), but higher than juniors ($p = 0.0019$). There was no statistical difference in confidence ratings between sophomores and juniors ($p = 0.8976$).

**Sustainable Design**

The proportion of all students highly rating the importance of sustainable design skills is shown in Table 3. The skill receiving the largest proportion of high importance ratings was ‘Protect
human health and well-being' ($\pi_{6.7} = 93.4\%$). The smallest proportion of high importance ratings was associated with 'Incorporate systems analysis' ($\pi_{6.7} = 57.5\%$). These same skills also had the largest and smallest proportion of high confidence ratings.

**Table 3.** Proportion of high student ratings (6 or 7 on a scale from 1-7) for importance and confidence in abilities to apply Sustainable Design criteria.

<table>
<thead>
<tr>
<th>Survey Prompt: &quot;The following statements are related to sustainable design. Indicate how important you think it is for engineers to be able to develop designs that meet the listed criteria. Also indicate how confident you are in your ability to develop designs that meet the listed criteria.&quot;</th>
<th>Importance, $\pi_{6.7}$ (%)</th>
<th>Confidence, $\pi_{6.7}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>Soph</td>
</tr>
<tr>
<td>Address community and stakeholder requests.</td>
<td>66.9</td>
<td>55.3</td>
</tr>
<tr>
<td>Consider local circumstances and cultures.</td>
<td>73.5</td>
<td>66.0</td>
</tr>
<tr>
<td>Incorporate life cycle analysis.</td>
<td>68.7</td>
<td>60.6</td>
</tr>
<tr>
<td>Incorporate environmental impact assessment tools.</td>
<td>68.5</td>
<td>63.8</td>
</tr>
<tr>
<td>Incorporate systems analysis.</td>
<td>57.5</td>
<td>54.3</td>
</tr>
<tr>
<td>Use innovative technologies to achieve sustainability.</td>
<td>75.1</td>
<td>67.0</td>
</tr>
<tr>
<td>Minimize natural resource depletion.</td>
<td>82.9</td>
<td>77.2</td>
</tr>
<tr>
<td>Prevent waste.</td>
<td>82.6</td>
<td>77.4</td>
</tr>
<tr>
<td>Protect natural ecosystems.</td>
<td>80.7</td>
<td>71.0</td>
</tr>
<tr>
<td>Protect human health and well-being.</td>
<td>93.4</td>
<td>90.4</td>
</tr>
<tr>
<td>Use inherently safe and benign materials.</td>
<td>84.4</td>
<td>79.8</td>
</tr>
<tr>
<td>Use renewable energy sources.</td>
<td>75.9</td>
<td>68.8</td>
</tr>
</tbody>
</table>

Unlike for Engineering Mechanics and Sustainable Development, differences based on gender emerge in the importance responses for Sustainable Design skills. In all cases where differences by gender exist, females rate importance higher than males. This occurred for ‘Incorporate environmental impact assessment tools’ (males $\pi_{6.7} = 66.7\%$, females $\pi_{6.7} = 75.0\%; p = 0.0219$),
‘Incorporate systems analysis’ (males $\pi_{6,7} = 54.6\%$, females $\pi_{6,7} = 66.7\%$; $p = 0.0176$), ‘Minimize natural resource depletion’ (males $\pi_{6,7} = 81.5\%$, females $\pi_{6,7} = 88.9\%$; $p = 0.0226$) and ‘Use inherently safe and benign materials’ (males $\pi_{6,7} = 82.8\%$, females $\pi_{6,7} = 90.3\%$; $p = 0.0109$). The only Sustainable Design skill with significant differences in confidence ratings based on gender is ‘Protect human health and well-being,’ with males rating their confidence higher than females (males $\pi_{6,7} = 48.9\%$, females $\pi_{6,7} = 31.9\%$; $p = 0.0159$).

There are four Sustainable Design skills where there are significant differences in importance ratings based on academic standing. In all four cases, seniors rate the skills as more important than sophomores (see $\pi_{6,7}$ values in Table 3). These skills include ‘Address community and stakeholder requests’ ($p = 0.0115$), ‘Use innovative technologies to achieve sustainability’ ($p = 0.0121$), ‘Protect natural ecosystems’ ($p = 0.0168$) and ‘Protect human health and well-being’ ($p = 0.0127$). Despite the statistically significant differences between seniors and sophomores, there are no significant differences between seniors and juniors and sophomores and juniors.

There are only three Sustainable Design skills where there are not significant differences in confidence ratings based on academic standing. These include ‘Consider local circumstances and cultures,’ ‘Prevent waste,’ and ‘Use renewable energy sources.’ In all cases where differences in confidence rating exist, seniors rate their confidence higher than sophomores.

**Comparing Engineering Mechanics, Sustainable Development and Sustainable Design**

Descriptive statistics regarding the mean response of student importance ratings for the three major subject areas are summarized in Table 4. Statistical testing confirmed that students rate Engineering Mechanics as less important than Sustainable Development ($p = 0.0041$) or Sustainable Design ($p = 0.0004$). Given that so much of the curriculum is based on Engineering Mechanics, it is somewhat surprising that students believe it is more important for engineers to have skills in Sustainable Development and Sustainable Design than in Engineering Mechanics.

**Table 4.** Descriptive statistics of mean importance rating from all questions in each subject.

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>All Responses</th>
<th></th>
<th>Senior Responses</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion of</td>
<td>Overall Mean</td>
<td>Proportion of</td>
<td>Overall Mean</td>
</tr>
<tr>
<td></td>
<td>Mean Ratings</td>
<td>of Student Ratings</td>
<td>Mean Ratings</td>
<td>of Student Ratings</td>
</tr>
<tr>
<td>≥ 6</td>
<td></td>
<td></td>
<td>≥ 6</td>
<td></td>
</tr>
<tr>
<td>Engineering Mechanics</td>
<td>54.9%</td>
<td>5.94</td>
<td>51.6%</td>
<td>5.84</td>
</tr>
<tr>
<td>Sustainable Development</td>
<td>63.9%</td>
<td>6.06</td>
<td>70.2%</td>
<td>6.15</td>
</tr>
<tr>
<td>Sustainable Design</td>
<td>66.9%</td>
<td>6.08</td>
<td>72.7%</td>
<td>6.17</td>
</tr>
</tbody>
</table>

Gender differences exist in the mean importance ratings for Sustainable Development and Sustainable Design, with males reporting a lower mean importance rating than females (6.02 vs 6.22; $p = 0.0282$). For Sustainable Design, males mean importance rating is 6.05, while females is 6.21 ($p = 0.0427$). Based on academic standing, seniors (mean rating = 6.17) were found to rate the importance of Sustainable Design the same as juniors (mean rating = 6.07), but higher than sophomores (mean rating = 5.95). No significant difference was found in importance ratings for Sustainable Design between juniors and sophomores.
Descriptive statistics regarding the mean response of student confidence ratings for the three major subject areas are summarized in Table 5. Statistical tests revealed that for all students, confidence ratings in Engineering Mechanics and Sustainable Development are not significantly different \( (p = 0.2595) \). However, student confidence ratings in both subjects are higher than their confidence ratings in Sustainable Design \( (p = 0.0005 \text{ for Engineering Mechanics, } p < 0.0001 \text{ for Sustainable Development}) \). For seniors, confidence ratings in Engineering Mechanics are significantly higher than Sustainable Development \( (p < 0.0001) \), which are significantly higher than ratings in Sustainable Design \( (p = 0.0007) \). Seniors were also found to have significantly higher mean confidence ratings in all three subjects than juniors and sophomores. Seniors’ mean confidence ratings are shown in Table 5. While juniors were found to have a greater mean confidence rating than sophomores in Engineering Mechanics \( (\text{juniors} = 4.59, \text{sophomores} = 3.95) \), their mean confidence ratings in Sustainable Development and Sustainable Design are not significantly different from sophomores.

**Table 5.** Descriptive statistics of mean confidence ratings from all questions in each subject.

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>All Responses</th>
<th>Senior Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion of</td>
<td>Overall</td>
</tr>
<tr>
<td></td>
<td>Mean Responses ≥ 6</td>
<td>Mean of Responses</td>
</tr>
<tr>
<td>Engineering Mechanics</td>
<td>21.9%</td>
<td>4.85</td>
</tr>
<tr>
<td>Sustainable Development</td>
<td>16.9%</td>
<td>4.81</td>
</tr>
<tr>
<td>Sustainable Design</td>
<td>12.3%</td>
<td>4.61</td>
</tr>
</tbody>
</table>

Student Interest in Sustainability

Generally, students are interested in both Sustainable Development \( (\pi_{6,7} = 53.8\%) \) and Sustainable Design \( (\pi_{6,7} = 55.7\%) \). It is noteworthy that there were no statistically significant differences in these interest ratings based on gender, academic major, or academic standing. The lack of difference based on gender agrees with the findings of the GT study\textsuperscript{16}.

Students were also asked to rate their interest in a variety of sustainability topics, which spanned all three dimensions of sustainability (environment, society, economy). The topic with the largest proportion of high interest ratings was Sustainable Infrastructure \( (\pi_{6,7} = 58.0\%) \). Other topics with high interest ratings included Green Buildings \( (\pi_{6,7} = 56.8\%) \), Sustainable Cities \( (\pi_{6,7} = 56.3\%) \), Sustainable Transportation \( (\pi_{6,7} = 53.8\%) \), Sustainable Community Development \( (\pi_{6,7} = 49.0\%) \) and Clean/Renewable Energy and Energy Efficiency \( (\pi_{6,7} = 47.9\%) \). The topic with the lowest proportion of high interest ratings was Bioeconomy, Biomaterials and Biorefineries, \( (\pi_{6,7} = 8.5\%) \). The topics with the largest and smallest proportion of high interest in this study are the same as they were among seniors at GT\textsuperscript{16}.

Source of Student Sustainability Knowledge

Survey responses indicate that media sources are the most significant contributor to student knowledge about sustainable development \( (\pi_{6,7} = 38.5\%) \), with CEE courses a close second \( (\pi_{6,7} = 35.5\%) \). When taking into account academic standing, statistical tests revealed that seniors
rated the extent that their knowledge came from CEE courses higher than juniors and sophomores (seniors $\pi_{6,7} = 50.0\%$; $p < 0.0001$). This result is comparable to $\pi_{6,7} = 52.3\%$ at GT$^{16}$. No other differences based on demographics were found.

**Discussion**

**Engineering Mechanics vs. Sustainable Development and Sustainable Design**

The Engineering Mechanics questions related to content taught in statics and deformable bodies courses received high importance ratings from 70.7% to 78.1% of all students, while those relating to fluid mechanics courses received high importance ratings from 52.2% to 52.8% of all students (see Table 1). Likewise, confidence in Engineering Mechanics related to statics or deformable bodies was also higher than for fluid mechanics. The ratings for the Engineering Mechanics skills can likely be explained by three factors: 1) general perceptions of what civil engineering is and what civil engineers should know, 2) when the mechanics courses are taught in the curriculum, and 3) who takes the engineering mechanics courses. General public perceptions of civil engineering tend to associate the profession with structures more than fluids. Therefore, it makes sense that even the least experienced students would feel that mechanics related to structures are important. In terms of academic experience, statics and deformable bodies are sophomore level courses and fluid mechanics is a junior level course. Therefore, sophomores and juniors are likely still developing fluid mechanics skills and may not yet be very confident with them. Likewise, the CEM students were not required to take fluid mechanics; as a result, they likely rate fluid mechanics skills with low importance in addition to low confidence.

The confidence ratings among seniors were higher than for all students of lower academic standing in Engineering Mechanics, Sustainable Development and Sustainable Design. This finding suggests that student skills in all three subjects develop with experience in the CEE curriculum. In Engineering Mechanics, student confidence ratings are significantly different at each academic level, with sophomores providing the lowest ratings and seniors the highest. This finding suggests that steady progress and development of confidence in Engineering Mechanics occurs consistently throughout the curriculum. Similar findings would be expected at other institutions, as Engineering Mechanics courses build on each other and are a major component of sophomore and junior level CEE curricula. Engineering Mechanics principles are then applied to design at the senior level, further reinforcing understanding.

In Sustainable Development and Sustainable Design, seniors rate their confidence significantly higher than all other students. This finding suggests that experience in Sustainable Development and Sustainable Design is concentrated late in the curriculum, rather than throughout like Engineering Mechanics. Ideally, knowledge in sustainability should develop similar to Engineering Mechanics, such that underlying principles and concepts may be applied to design at the senior level, as they are in Engineering Mechanics. Despite the late development of confidence with sustainability observed in this survey, the higher senior confidence ratings in Sustainable Development and Sustainable Design are indicative of greater sustainability knowledge at higher academic levels, which agrees with other survey findings$^{10, 11, 12}$. 

While the presence of increasing confidence ratings with academic standing indicates the CEE curriculum builds student skills in Sustainable Development and Sustainable Design, the ratings are still lower than confidence ratings in Engineering Mechanics. The confidence ratings are also significantly lower than the importance ratings. These findings may point to a need to bring more sustainability content and applications into the curriculum, including instruction on how traditional engineering mechanics topics are essential for developing sustainable designs. In this survey, the Sustainable Design criteria of incorporating systems analysis and environmental impact assessment tools received particularly low confidence ratings. Therefore, these topics may be a good starting point for making adjustments to civil engineering curricula.

Emphasis on Environmental Sustainability

Other researchers have found that students have the most knowledge about environmental issues associated with sustainability, with knowledge gaps centering on social and economic considerations\textsuperscript{13, 21}. In this study, the confidence ratings (an indicator of student perceptions of their knowledge) of all students with Sustainable Development skills favor the environmental dimension of sustainability only slightly. In discussing social factors and economic factors related to sustainable development, the proportion of high confidence ratings among all students is low, with $\pi_{6,7} = 27.7\%$ and $27.4\%$, respectively (among seniors, $\pi_{6,7} = 32.9\%$ and $31.7\%$, respectively). Discussing environmental factors related to sustainable development received high confidence ratings from $33.3\%$ of all students ($41.3\%$ of seniors). In the importance ratings, the difference is more pronounced. Discussing environmental factors affecting sustainable development garnered the highest importance ratings ($\pi_{6,7} = 77.6\%$, seniors $\pi_{6,7} = 86.3\%$), followed by economic factors ($\pi_{6,7} = 74.4\%$, seniors $\pi_{6,7} = 80.6\%$) and social factors ($\pi_{6,7} = 67.4\%$, seniors $\pi_{6,7} = 70.8\%$). Similarly, GT seniors perceived environmental issues and social issues as the most and least important for engineers, respectively\textsuperscript{16}.

These findings indicate that it is likely that the source of students’ sustainability knowledge has emphasized the environmental dimension over the social and economic dimensions. Since seniors attribute most of their sustainability knowledge to the CEE curriculum and exhibit more high confidence ratings in discussing environmental issues than lower academic levels, it is likely the curriculum emphasizes environmental aspects of sustainability. Given the similar trend in ratings between this study and the GT study, Civil Engineering departments and faculty should be aware of the apparent tendency for greater emphasis on environmental sustainability issues over economic and social concerns and should seek to provide coverage of economic and social factors in sustainability modules and discussions within CEE courses.

Emphasis on the environmental component of sustainability also indicates the need for a clear definition of sustainability within the civil engineering profession. Perhaps specific sustainability program criteria from accrediting bodies such as ABET and ASCE could help guide CEE departments in developing curricula that appropriately address all aspects of sustainability.

Student Interest

The sustainability topics garnering the highest interest ratings in this survey are similar to those in the GT study and the results from a similar series of survey questions administered to students.
at the University of British Columbia (UBC)\textsuperscript{14}. While the topics garnering high interest in the UBC survey are similar, the respondents at UBC were from a variety of majors rather than just CEE. The commonality of response from these three survey studies supports a suggestion made by the GT researchers\textsuperscript{16} that there seem to be common interests in sustainability topics regardless of academic major or university.

Sources of Student Sustainability Knowledge

In this study, seniors rate the extent to which they learned about sustainable development from CEE courses significantly higher than students of lower academic standing, indicating sustainability is included in the curriculum primarily in upper division and senior design courses, rather than being included throughout. This finding is in agreement with conclusions regarding student importance and confidence ratings, which show seniors rate confidence significantly higher than sophomores and juniors in Sustainable Development and Sustainable Design.

CEE departments and faculty should be mindful of when, where and how sustainability is incorporated into the CEE curriculum and should seek to build student knowledge of sustainability concepts throughout the curriculum, in both Engineering Mechanics courses and senior design courses. One possible approach to include sustainability in mechanics courses is to provide context for how the mechanics subject is ultimately essential for sustainable design; developing sustainable facilities necessitates that the facilities be mechanically sound.

Adding more sustainability concepts into CEE courses could facilitate the CEE curriculum becoming a more significant source of students’ knowledge in sustainability. Adjustments are especially important because based on the survey, the current top source of sustainability knowledge for non-senior students is the media. The media does provide useful information; however, it can be biased and sometimes inaccurate, leaving CEE courses as the most reliable place for students to learn about sustainability\textsuperscript{16}. Therefore, instruction in CEE courses should seek to address any shortcomings and misconceptions in student knowledge, as received from media sources.

Limitations

While the survey provided excellent data regarding student perceptions, there are some key limitations to this research. First, the student provided confidence ratings may not actually be representative of their true knowledge. This same limitation is acknowledged in the GT study, with further explanation that student abilities to understand and apply sustainability principles may be lower than survey responses indicate, thus requiring even more significant changes to the curriculum\textsuperscript{16}. While the comparison of responses in Sustainable Design and Sustainable Development to Engineering Mechanics in this study confirms that improvement is needed at incorporating sustainability into the curriculum, this does not eliminate the issue of student ratings potentially not being representative of actual abilities.

Another limitation in this study is that no identifying information was collected; therefore, it is unknown whether anyone took the survey more than once. It is possible this occurred because students responding to the survey from CEE 2804 indicated academic standings ranging from
sophomore to senior. Since CEE 4804 contained juniors and seniors it is possible that a junior or senior in CEE 2804 was also enrolled in CEE 4804, or that a student enrolled in CEE 4804 in the fall re-took the class in the spring. Such students may have taken the survey twice, though it is unlikely that this occurred.

Finally, students may not have necessarily read the questions carefully or responded correctly or honestly, which could skew the results. Despite these limitations, the line of questioning in the survey provides significant data about the CEE curriculum and education from the perspective of students, and can be used to help CEE departments provide a more satisfying and rewarding educational experience.

Conclusions and Recommendations

A survey study was performed to explore student perceptions of engineering mechanics and sustainability education in CEE at VT for the purpose of evaluating education in sustainability within the CEE curriculum compared to traditional engineering mechanics topics. Questions on the survey addressing sustainability were based on a survey study involving seniors that was conducted at GT\textsuperscript{16} so that the results could be compared between institutions. Questions on the survey addressing engineering mechanics were added in order to compare responses across subject areas, which has not been done in other evaluations of sustainability education via student perception surveys. The findings from this survey agree with the conclusions of the GT study\textsuperscript{16} that students are interested in sustainability but rate their confidence with Sustainable Development and Sustainable Design skills significantly lower than the perceived importance of those skills. The following additional conclusions and recommendations can be made based on these results.

1. Students perceive skills in Sustainable Development and Sustainable Design to be of more importance to civil engineers than Engineering Mechanics. Therefore, CEE curricula should emphasize how Engineering Mechanics skills and knowledge are essential for developing sustainable designs.

2. Senior student confidence ratings are highest in Engineering Mechanics and lowest in Sustainable Design. The difference in confidence ratings between Engineering Mechanics and sustainability subject areas suggests there is room to improve sustainability education in CEE.

3. Seniors rate their confidence in Engineering Mechanics, Sustainable Development and Sustainable Design higher than juniors and sophomores, which indicates advancement in the CEE curriculum impacts knowledge in all three subjects. While there is a steady increase in confidence ratings with academic standing in Engineering Mechanics, juniors and sophomores do not have significantly different confidence ratings in Sustainable Development and Sustainable Design. This finding indicates education in sustainability is likely concentrated late in the CEE curriculum. Educators should be aware of when, where and how sustainability is included in the curriculum and should work toward steady progress in sustainability knowledge and skills, similar to the steady development that occurs in Engineering Mechanics skills.

4. Students viewed the environmental and social dimensions of sustainability as the most and least important, respectively. Students also demonstrated slightly higher confidence
ratings for their ability to discuss the environmental dimension of sustainability, particularly among seniors. Educators should be aware of any tendency to emphasize the environmental component of sustainability over the social and economic components in the curriculum. Specific emphasis on these two aspects of sustainability as they apply to civil engineering may be an area to enhance CEE curricula, perhaps in collaboration with faculty in other disciplines. Accrediting bodies could develop program criteria that bring uniformity to sustainability education within CEE.

5. Based on student ratings, media sources are a significant contributor to student knowledge of sustainability, particularly for non-senior students. Due to potential flaws in media coverage the CEE curriculum may be a more reliable source for student learning about sustainability. Sustainability should be emphasized early in the curriculum to avoid the development of misconceptions that may be generated from media sources.

The survey results suggest the potential exists for future improvements in the CEE curriculum at VT; similar conclusions may be drawn if the survey were used at other institutions. Given the rapidly changing and growing body of knowledge for sustainability, it is also essential that curricula seek to foster lifelong learning skills, such that graduates are able to continue to develop and improve sustainable design in civil engineering practice. As adjustments are made to CEE curricula, departments can quickly and easily explore the impact by asking students to reflect on their education by responding to student perception surveys that include questions related to sustainability and traditional engineering topics.

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