A Systematic Review of Sustainability Assessments in ASEE Proceedings

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Abstract

Engineers are increasingly called upon to develop innovative solutions while balancing competing economic, environmental, and social design constraints. Consequently, many educators and professional organizations are calling for improvements in undergraduate engineering education to include sustainability content in order to equip students to engage in sustainable design. Indeed, ABET requires that engineering programs prepare students to consider sustainability constraints during design. Furthermore, accreditation of civil engineering programs by ABET now requires documentation that students more stringently include sustainability principles in the design process. To quantify the effectiveness of educational interventions aimed at developing sustainability-conscious engineers, appropriate assessment methods and tools are needed. Due to the broad, ill-defined, and often subjective nature of sustainability, assessment of related knowledge and design skills has proven challenging for many engineering educators. A variety of sustainability assessments, ranging from indirect to direct measures of student learning, are available but a comprehensive review of the field is needed to make the assessments more accessible and implementable by educators from across engineering disciplines.

A systematic review of ASEE conference proceedings was conducted to identify and discuss the quality of available methods for assessing student knowledge of and interest in sustainability. First, a search of the ASEE PEER database for the terms “sustainability + assessment” yielded 1001 results. Records with relevance indexes above 1.0 were screened based on their abstracts and appraised by their full texts according to four inclusion criteria: (1) The study was published during 2011 to 2016, (2) the study was published in English, (3) The study used or presented a tool that assesses interest in, knowledge of, and/or ability to apply sustainability concepts and/or principles, and (4) The tool is generalizable to contexts beyond the presented study. Assessment tools presented in the 29 retained records were categorized according to assessment target: (1) conceptual knowledge about sustainability, (2) ability to engage in sustainable design, or (3) attitudes/beliefs/interests related to sustainability. Records and related assessment tools were further synthesized according to ASEE division, number of targets assessed, directness of assessments, validity, and/or presence of scoring rubrics. Results revealed that survey items are most commonly used as indirect measures across all three assessment targets. Furthermore, analysis of records supported that several assessment tools across multiple targets are need to accurately capture the impact of educational interventions on student learning. In addition, there are gaps in the literature related to validated survey items and reproducible rubrics and scoring methods for direct assessment of sustainability-related knowledge and skills.
Introduction

Numerous engineering societies and organizations have made calls to update undergraduate curricula to train engineers who can better analyze the sustainability of systems, products, and processes. Further, ABET requires all accredited engineering programs to assess students’ abilities to design within sustainability constraints and to identify economic, environmental, and social impacts of their projects. Integral to the design and monitoring of reform efforts will be the availability of accurate and reliable tools for assessing students’ knowledge of sustainability and ability to apply that knowledge in design\(^1\). Effective assessments are characterized by objectivity, reliability, minimal influence on student responses, and portrayal of knowledge structure\(^2\)\(^-\)\(^3\). At the 2016 ASEE Annual Conference, a special session addressed the question of whether there were effective assessment methods for sustainability and other “hard to measure” topics in engineering education. The session stimulated discussion of which assessment tools were available and appropriate for sustainability knowledge, design applications, and attitudes. The purpose of this study was to synthesize the types of sustainability assessments that are readily available to engineering educators, and to identify future needs for effective and transferable tools.

For this review, assessments were classified according to the types of learning objectives and tasks that they would map to using three broad categories: knowledge assessments, design/skill assessments, or belief/attitude/interest assessments. Knowledge assessments indicate to what extent students can recall or organize conceptual knowledge about a given topic, reflecting lower-order cognitive processes designated in the revised Bloom’s taxonomy\(^4\). Knowledge tasks could include defining sustainability or answering objective questions (e.g., multiple choice). Assessments of design skills capture higher-order cognitive processes which may require both conceptual and procedural knowledge; for example, students applying sustainable design to their capstone projects. Assessments of beliefs, attitudes, or interests reflect self-knowledge and are more indicative of motivation to perform sustainable design or act sustainably, rather than a demonstrated ability to do so.

Accordingly, the research questions guiding this review were:

1. What tools are available for assessing students’ (a) conceptual knowledge, (b) design skills or application of knowledge, and/or (c) beliefs/attitudes/interests related to sustainability?
2. Which fields of engineering are most commonly assessing students’ knowledge, skills, and attitudes related to sustainability?
3. What practices for effective sustainability assessments are illustrated in the literature?
4. What gaps exist in the literature related to available tools or approaches for sustainability assessments?
Systematic Review Methods

A review of sustainability assessment tools was completed based on the guidelines presented by Borrego, Foster, and Froyd. The research questions specified above, as well as additional inclusion criteria, were used to search for, screen, and appraise records retrieved from the ASEE PEER database. Relevant full texts were critically reviewed to identify and classify reproducible assessment tools that could be used in sustainability education.

Guiding Questions and Inclusion Criteria

While there are numerous studies focused on sustainable engineering education, the purpose of this review was to focus on publications that present relevant assessment tools for capturing students’ knowledge, skills, and beliefs/attitudes/interests related to sustainability. Several inclusion criteria were specified to aid in identifying records that pertain to the research questions. Specifically, the inclusion criteria related to the record content and publishing details:

1. The study was published during 2011 to 2016 (without restriction to geographical area).
2. The study was published in English.
3. The study presents an assessment tool for capturing student knowledge, design skills, and/or beliefs/attitudes/interests related to sustainability.
4. The tool is presented in sufficient detail to allow for reproduction and is applicable to contexts beyond the original study.

Searching, Screening, and Appraising

The ASEE PEER database was searched to identify potential records detailing relevant assessment tools. The search terms used were [sustainability + assessment]. Initially, 1001 records were identified (Figure 1). Subsequent screening and appraising occurred in three phases. In phases one, two, and three, records with a relevance index of 2.0, 1.5, and 1.0 or above were examined, respectively. Of the 24, 26, and 26 records retrieved during phases one through three, only 13 (54%), 11 (42%), and 5 (19%) records were retained after appraisal, respectively. Due to the decreasing applicability of records, those with relevance indexes of less than 1.0 were not examined.

Overall, 76 records were retained for abstract screening (Figure 1). After screening abstracts, 15 records were excluded since they did not pertain to sustainability. Most of these records referenced the term sustainability, but not in the sense of sustainable development. For example, one record was focused on sustainable (i.e., long-term, repeatable) outcomes assessment for mechanical engineering.

In total, 61 records were appraised based on their full texts (Figure 1). During appraisal, three additional records were excluded because they did not pertain to sustainability. In addition, 11 records were excluded because their subject matter did not require assessment. Many of these
records were seeking to compile data on sustainability learning objectives, courses, and/or degree programs across publications and/or institutions. Also, 13 records were excluded because, while they discussed some intervention related to sustainability education, no assessment tool was presented. Many of these records discussed assessment relative to course evaluations and/or anecdotal observations that were not reproducible and/or applicable beyond the study context. Finally, five records discussed assessment tools, but did not provide sufficient details to allow for them to be reproduced in other contexts.

**Figure 1. Summary of searching, screening, and appraisal phases of systematic review.**

**Synthesis of Sustainability Assessments**

After full text appraisal, 29 records were retained for further synthesis (Figure 1). Based on notes recorded during the appraisal phase, emergent categories of assessment tools related to knowledge, skills, and attitudes/beliefs/interests were identified. During synthesis, full texts were re-examined twice and all applicable assessment tools were classified according to the emergent categories. In addition, excerpts of assessment tools from each of the 29 retained records were compiled to provide an inventory of potential tools for instructors and researchers (Appendix A).
Categories of Knowledge Assessments

Through the appraisal phase, five categories of knowledge assessments were identified (Table 1). Self-report surveys were used to ask students to reflect on and rate their knowledge of sustainability broadly, or specific aspects of sustainability. Direct assessments included relatively objective multiple choice and/or true/false questions, as well as more complex short answer or essay questions. Rather than use written text to gather insights into sustainability knowledge, some authors prompted students to depict their knowledge using concept maps.

Table 1. Categories of sustainability knowledge assessments identified during full text appraisal.

<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-report survey items</td>
<td>Students rate their knowledge using a provided scale</td>
</tr>
<tr>
<td>Multiple choice, True/False questions</td>
<td>Students answer closed-ended, objective questions about sustainability</td>
</tr>
<tr>
<td>Short answer questions</td>
<td>Students respond in their own words to a prompt about sustainability</td>
</tr>
<tr>
<td>Essays/Reports</td>
<td>Students prepare a longer composition (usually an argument) about a sustainability topic.</td>
</tr>
<tr>
<td>Concept Maps</td>
<td>Students draw descriptive linking lines to show relationships between sustainability-related concepts.</td>
</tr>
</tbody>
</table>

Categories of Design Skills Assessments

Through the appraisal phase, six categories of design skills assessments were identified (Table 2). Self-report surveys were used to ask students to reflect on and rate their abilities to engage in different aspects of sustainable design using a provided scale. Other authors asked students to describe in their own words their sustainable design abilities. More directly, short answer or longer essay questions were sometimes used to ask students to engage in varying levels of analysis related to sustainable design. Occasionally, closed-ended problems were presented to capture students’ abilities to engage in design analysis. More authentically, some authors developed and applied rubrics to score student design reports.
<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category 1: Self-report survey items</strong></td>
<td>Students rate their design skills using a provided scale. Using a 4-point scale, students responded to: I am confident in my ability to create environmentally sustainable solutions in my field.</td>
</tr>
<tr>
<td><strong>Category 2: Self-report short answer questions</strong></td>
<td>Students describe their design skills in their own words. Do you (or have you) applied any of the concepts from the Green Design Apprenticeship in your studies, work, everyday life?</td>
</tr>
<tr>
<td><strong>Category 3: Short answer questions</strong></td>
<td>Students respond in their own words to a prompt requiring design analysis. You are charged with selecting a site for a building project. You have two alternatives, and you already evaluated them based on cost, suitability, and other factors. You wish to evaluate them based on sustainability. List three factors that you should consider and specify why each is important.</td>
</tr>
<tr>
<td><strong>Category 4: Essays/Reports</strong></td>
<td>Students prepare a longer composition (usually an argument) requiring design analysis. Paraphrased: A friend in the Peace Corp has asked you what you would do as an engineer to improve the quality of life in a town in Tanzania. What major technical and non-technical issues would impact your recommendations? What are some examples of products or services that you might design for the community? What would be the potential impacts of these changes? What are the foreseeable challenges? Rubric provided for scoring.</td>
</tr>
<tr>
<td><strong>Category 5: Closed-ended problems</strong></td>
<td>Students solve a problem related to a sustainability issue. Paraphrased: A family is considering two homes for purchase. Although it has a higher up-front cost, Alternative 2 is designed to be more energy efficient. Alternative 2 also has technologies which will reduce natural gas usage. Data for the two homes are provided. Assuming a 40-year time span and i=5%, perform a present worth cost comparison to determine if the additional up-front cost for Home 2 is justified over the long-term.</td>
</tr>
<tr>
<td><strong>Category 6: Design projects</strong></td>
<td>Student design reports are scored based on their consideration of sustainability. Sustainable entrepreneurship projects are scored according to 24 criteria grouped according to five categories: hands-on project/research experience, interdisciplinary curriculum, entrepreneurship, global dimension, and service learning.</td>
</tr>
</tbody>
</table>

**Categories of Beliefs/Attitudes/Interests Assessments**

Through the appraisal phase, two categories of beliefs/attitudes/interests assessments were identified (Table 3). Self-report surveys were used to ask students to reflect on and rate their affect related to different aspects of sustainability using a provided scale. Alternatively, short answer questions were used to gather insights into students’ beliefs/attitudes/interests.
Table 3. Categories of sustainability beliefs/attitudes/interests assessments identified during full text appraisal.

<table>
<thead>
<tr>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-report</td>
<td>Students rate an aspect of their sustainability using a provided scale</td>
</tr>
<tr>
<td>survey items</td>
<td>Using a 5-point scale, students responded to: I am very committed to sustainability.</td>
</tr>
<tr>
<td>Short answer</td>
<td>Students describe their beliefs/attitudes/interests in their own words</td>
</tr>
<tr>
<td>questions</td>
<td>Below are the topics covered on the various days of the program. Which topic or activity still resonates with you? Why?</td>
</tr>
</tbody>
</table>

Systematic Review Results

Analysis of Retained Records by ASEE Division

The 29 retained records pertaining to sustainability assessments were published in 16 different divisions of ASEE (Table 4). Most commonly, sustainability assessment records were published in the environmental (24.1%) or civil (20.7%) engineering divisions. Other common divisions were liberal education (17.2%), multidisciplinary engineering (13.8%), and education and research methods (10.3%).

Table 4. Retained records analyzed by ASEE division.

<table>
<thead>
<tr>
<th>Division</th>
<th>No. Retained Records</th>
<th>Percentage of Retained Records (N = 29)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Engineering</td>
<td>7</td>
<td>24.1</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>6</td>
<td>20.7</td>
</tr>
<tr>
<td>Liberal Education</td>
<td>5</td>
<td>17.2</td>
</tr>
<tr>
<td>Multidisciplinary Engineering</td>
<td>4</td>
<td>13.8</td>
</tr>
<tr>
<td>Educational and Research Methods</td>
<td>3</td>
<td>10.3</td>
</tr>
<tr>
<td>Engineering Economy</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>Engineering Ethics</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>Engineering Management</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>Industrial Engineering</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>NSF Grantees Poster Session</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>Aerospace Engineering</td>
<td>1</td>
<td>3.4</td>
</tr>
<tr>
<td>Architectural Engineering</td>
<td>1</td>
<td>3.4</td>
</tr>
<tr>
<td>College Industry Partnerships</td>
<td>1</td>
<td>3.4</td>
</tr>
<tr>
<td>Electrical and Computer Engineering</td>
<td>1</td>
<td>3.4</td>
</tr>
<tr>
<td>K12 and Pre-College</td>
<td>1</td>
<td>3.4</td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>1</td>
<td>3.4</td>
</tr>
</tbody>
</table>
Analysis of Retained Records by Category

Of the 29 retained records, 86.2%, 62.1%, and 51.7% included items and/or tools to capture student knowledge, skills, and beliefs/attitudes/interests related to sustainability, respectively. Assessment tools identified in the 29 retained records were further categorized.

Retained records reporting assessment items related to sustainability knowledge were binned according to five categories (Table 5). Most commonly, records reporting knowledge assessments \((n = 25)\) included self-report surveys (56.0%). The most common direct measures included short answer questions (32.0%) and multiple choice and/or true/false questions (24.0%). Concept maps (12.0%) and essays/reports (8.0%) were other direct measures used less often.

Retained records reporting assessment items related to sustainability design skills were binned according to six categories (Table 5). Most commonly, records reporting design skills assessments \((n = 18)\) included self-report surveys (55.6%), while less frequently they included self-report short answer questions (11.1%). Unique to the assessment of design skills was the use of rubrics to judge student projects (22.2%) and closed-ended problems (16.7%).

Retained records reporting assessment items related to sustainability beliefs/attitudes/interests were binned according to two categories (Table 5). Most commonly, records reporting beliefs/attitudes/interests assessments \((n = 15)\) included self-report survey items (93.3%), while less frequently they included short answer questions (7.1%).

Table 5. Retained records analyzed by category.

<table>
<thead>
<tr>
<th>Records with Knowledge Assessments</th>
<th>No. Retained Records</th>
<th>Percentage of Records within Target(^a)</th>
<th>Percentage of Retained Records(^a) ((N = 29))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-report survey items</td>
<td>14 56.0</td>
<td>48.3</td>
<td></td>
</tr>
<tr>
<td>Short answer questions</td>
<td>8 32.0</td>
<td>27.6</td>
<td></td>
</tr>
<tr>
<td>Multiple choice, True/False questions</td>
<td>6 24.0</td>
<td>20.7</td>
<td></td>
</tr>
<tr>
<td>Concept Maps</td>
<td>3 12.0</td>
<td>10.3</td>
<td></td>
</tr>
<tr>
<td>Essays/Reports</td>
<td>2 8.0</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Records with Skills Assessments</td>
<td>18 55.6</td>
<td>34.5</td>
<td></td>
</tr>
<tr>
<td>Self-report survey items</td>
<td>10 55.6</td>
<td>34.5</td>
<td></td>
</tr>
<tr>
<td>Design projects</td>
<td>4 22.2</td>
<td>13.8</td>
<td></td>
</tr>
<tr>
<td>Short answer questions</td>
<td>3 16.7</td>
<td>10.3</td>
<td></td>
</tr>
<tr>
<td>Closed-ended problems</td>
<td>3 16.7</td>
<td>10.3</td>
<td></td>
</tr>
<tr>
<td>Essays/Reports</td>
<td>2 11.1</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Self-report short answer questions</td>
<td>2 11.1</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Records with Beliefs/Attitudes/Interest Assessments</td>
<td>15 51.7</td>
<td>48.3</td>
<td></td>
</tr>
<tr>
<td>Self-report survey items</td>
<td>14 93.3</td>
<td>48.3</td>
<td></td>
</tr>
<tr>
<td>Short answer questions</td>
<td>1 7.1</td>
<td>3.4</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Percentages do not add to 100% because many records included multiple assessment tools.
Many retained records reported use of assessment tools across multiple targets. Over one-third of records included assessment items related to two different targets (37.9%), most commonly knowledge and skills (24.1%). Nearly one-third (31.0%) of all retained records reported use of assessment tools across all three targets. Nearly one-third (31.0%) only included items related to a single target, most commonly knowledge (17.2%) (Table 6).

<table>
<thead>
<tr>
<th>Records with Assessments for One Target</th>
<th>No. Retained Records</th>
<th>Percentage of Retained Records (N = 29)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>5</td>
<td>17.2</td>
</tr>
<tr>
<td>Skills</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>Beliefs/Attitudes/Interests</td>
<td>2</td>
<td>6.9</td>
</tr>
<tr>
<td>Records with Assessments for Two Targets</td>
<td>11</td>
<td>37.9</td>
</tr>
<tr>
<td>Knowledge &amp; Skills</td>
<td>7</td>
<td>24.1</td>
</tr>
<tr>
<td>Knowledge &amp; Beliefs/Attitudes/Interests</td>
<td>4</td>
<td>13.8</td>
</tr>
<tr>
<td>Skills &amp; Beliefs/Attitudes/Interests</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Records with Assessments for Three Targets</td>
<td>9</td>
<td>31.0</td>
</tr>
</tbody>
</table>

A variety of direct and indirect assessment tools were reported across the 29 retained records (Table 7). Indirect assessment tools included those that required students to self-report on their knowledge, skills, or beliefs/attitudes/interests; all other tools were considered direct measures. Overall, 41.4%, 37.9%, and 20.7% of all retained records presented only indirect, only direct, or indirect and direct assessments, respectively. Within those records that presented knowledge assessments, there was an equal distribution between indirect only (44.0%) and direct only (44.0%) assessments. Within those records that presented skills assessments, half (50.0%) presented only indirect assessments. Within those records that presented beliefs/attitudes/interests assessments, most (93.3%) presented only indirect assessments.
Table 7. Retained records analyzed by target (knowledge, skills, and/or beliefs/attitudes/interests) and type (direct vs. indirect).

<table>
<thead>
<tr>
<th>Target</th>
<th>No. Retained Records</th>
<th>Percentage of Records</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Retained Records (N = 29)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indirect only</td>
<td>12</td>
<td>41.4</td>
</tr>
<tr>
<td>Direct only</td>
<td>11</td>
<td>37.9</td>
</tr>
<tr>
<td>Indirect &amp; Direct</td>
<td>6</td>
<td>20.7</td>
</tr>
<tr>
<td>Records with Knowledge Assessments (n = 25)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indirect only</td>
<td>11</td>
<td>44.0</td>
</tr>
<tr>
<td>Direct only</td>
<td>11</td>
<td>44.0</td>
</tr>
<tr>
<td>Indirect &amp; Direct</td>
<td>3</td>
<td>12.0</td>
</tr>
<tr>
<td>Records with Skills Assessments (n = 18)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indirect only</td>
<td>9</td>
<td>50.0</td>
</tr>
<tr>
<td>Direct only</td>
<td>6</td>
<td>33.3</td>
</tr>
<tr>
<td>Indirect &amp; Direct</td>
<td>3</td>
<td>16.0</td>
</tr>
<tr>
<td>Records with Beliefs/Attitudes/Interests Assessments (n = 15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indirect only</td>
<td>14</td>
<td>93.3</td>
</tr>
<tr>
<td>Direct only</td>
<td>1</td>
<td>6.7</td>
</tr>
<tr>
<td>Indirect &amp; Direct</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Analysis of Self-Report Survey Items

Across all assessment targets (knowledge, skills, and beliefs/attitudes/interests), self-report surveys were the most commonly employed tool. Of the 14 records including the use of self-report surveys for knowledge assessment, only 14.3% were validated. Of the 10 records including the use of self-report surveys for skills assessment, only 10% were validated. Of the 14 records including the use of self-report surveys for skills assessment, only 21.4% were validated (Table 8).

Table 8. Retained records analyzed by validation and targets (knowledge, skills, and/or beliefs/attitudes/interests).

<table>
<thead>
<tr>
<th>Target</th>
<th>No. Records using Self-Report Survey</th>
<th>No. Records using Validated Survey</th>
<th>Percentage of Records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge Assessments</td>
<td>14</td>
<td>2</td>
<td>14.3</td>
</tr>
<tr>
<td>Skills Assessments</td>
<td>10</td>
<td>1</td>
<td>10.0</td>
</tr>
<tr>
<td>Beliefs/Attitudes/Interests Assessments</td>
<td>14</td>
<td>3</td>
<td>21.4</td>
</tr>
</tbody>
</table>

Analysis of Open-Ended Assessment Tools

Several records reported the use of different categories of open-ended assignments to assess students’ sustainability knowledge, skills, and/or beliefs/attitudes/interests. Over 50% of records reporting on the use of open-ended assignments provided relevant scoring rubrics. All records
describing the use of concept maps or design reports provided scoring rubrics. Of the records describing the use of short answer questions, 50% provided rubrics for knowledge assessments and 66.7% provided rubrics for skills assessments. Of the records describing the use of essays/reports for knowledge and/or skills assessment, only 50% provided a scoring rubric (Table 9).

Table 9. Retained records analyzed by category.

<table>
<thead>
<tr>
<th>No. Records Providing Scoring Rubric(s)</th>
<th>Percentage of Records within Category</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge Assessments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short answer questions ($n = 8$)</td>
<td>4</td>
<td>50.0</td>
</tr>
<tr>
<td>Concept Maps ($n = 3$)</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>Essays/Reports ($n = 2$)</td>
<td>1</td>
<td>50.0</td>
</tr>
<tr>
<td>Skills Assessments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design projects ($n = 4$)</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>Short answer questions ($n = 3$)</td>
<td>2</td>
<td>66.7</td>
</tr>
<tr>
<td>Essays/Reports ($n = 2$)</td>
<td>1</td>
<td>50.0</td>
</tr>
</tbody>
</table>

Discussion of Available Sustainability Assessments

Overall, the systematic review indicated that while there are a variety of assessment tools available, a large percentage of records reporting on sustainability education lacked appropriate assessment methods or presented an assessment approach that would not be transferable to another context. Nevertheless, the 29 records that passed the screening and appraisal process provide insights into each of the guiding research questions and present assessment options for a variety of curricular and co-curricular contexts.

What tools are available for assessing students’ (a) conceptual knowledge, (b) design skills or application of knowledge, and/or (c) beliefs/attitudes/interests related to sustainability?

Across all assessment targets, self-report survey items were the most common. Perhaps survey items are commonly used because the domain of sustainability and sustainable design is broad, ill-defined and somewhat normative. In addition, surveys are easy to administer inside or outside of class. However, survey items are only indirect measures of students’ knowledge and/or skills and prior work has shown that students often over-report their capabilities. Survey items, however, could be considered direct measures of beliefs/attitudes/interests, which may support why they are most commonly used for this assessment target in the literature.

Related to direct knowledge assessments, domain-specific and domain-independent tools were identified in the literature. For example, some researchers (e.g., Watson et al.) designed and applied assessments to capture students’ holistic knowledge about sustainability by asking them to “define sustainability” or construct a concept map on “What is sustainability?” To score these
student constructs, several judges were asked to apply one or more rubrics. In contrast, other researchers (e.g., Chen et al.\textsuperscript{15}) devised (objective) multiple choice, true/false, and/or closed-ended problems to test students’ knowledge of specific topics related to sustainability (e.g., life cycle analysis). Consequently, capturing students’ holistic knowledge of sustainability may require the use of more subjective assessment tools than capturing students’ understanding of a particular sustainability topic.

Related to direct skills assessments, the most common assessment tools used rubrics or other scoring conventions to rate student projects or written analysis of sustainability-related challenges. Given the intention to capture students’ sustainable design abilities, all of these direct assessments essentially required students to actually conduct a design or analysis task. The quality of such skills assessments really depends on the authenticity of the task that students were asked to complete. For instance, actually scoring the sustainability of students’ design projects (e.g., Watson et al.\textsuperscript{24} and Dancz et al.\textsuperscript{16}) may be more authentic than asking them to solve a closed-ended problem (e.g., Chen et al.\textsuperscript{15}).

\textit{Which fields of engineering are most commonly assessing students’ knowledge, skills, and attitudes related to sustainability?}

Across ASEE, the Civil and Environmental Engineering Divisions are most frequently reporting on the use of various assessment tools for sustainability education. However, many of the tools reported across the divisions are applicable for many disciplines. For example, several knowledge assessments (e.g., the \textit{Assessment of Sustainability Knowledge} instrument applied by Fraser et al.\textsuperscript{18}) is discipline-independent. In addition, the rubrics presented by Watson et al.\textsuperscript{24} and Dancz et al.\textsuperscript{16} could be adapted for a variety of engineering projects. Also, several survey items related to beliefs/attitudes/interests could be of interest to educators across disciplines (e.g., Hess et al.\textsuperscript{19}).

Some assessment tools, however, were developed to be discipline-specific. Specifically, one group of collaborators designed a set of modules specifically for civil engineering, mechanical engineering, and industrial engineering\textsuperscript{13, 15, 27, 28}. Consequently, many of the related assessment tools provided by these researchers are indeed discipline-specific, although they could be applied within disciplines across institutions.

\textit{What practices for effective sustainability assessments are illustrated in the literature?}

Analysis of the literature suggests that assessments should be clearly aligned with the particular learning objectives outlined for students. For instance, Sattler et al.\textsuperscript{27} present a set of modules developed for civil engineers, which include topics of probability, transportation, life cycle economics, and waste as a resource. Consequently, the assessment tools created for these modules (e.g., multiple choice questions) are directly related to these topics. In contrast, some researchers sought to gather information on students’ holistic sustainability knowledge in order to inform the improvement of courses and curricula (e.g., Watson et al.\textsuperscript{10}). Consequently,
students were asked about their holistic knowledge of sustainability, rather than their knowledge of specific topics.

Second, many records illustrated that multiple targets should be assessed in order to fully capture the impacts of a particular educational intervention. For example, to assess the impacts of a nation-wide initiative, Hess et al.\textsuperscript{11} used survey items to capture changes in students’ beliefs/attitudes/interests, concept maps to capture changes in knowledge, and a rubric to score design reviews. Attempting to gage changes across multiple targets allows researchers to identify specifically how interventions impact students.

What gaps exist in the literature related to available tools or approaches for sustainability assessments?

Two major gaps were identified in the sustainability assessment literature. First, many of the assessment tools, especially survey items, are not validated. In fact, in many cases, no attempt at validation is reported. This is problematic because without validation, researchers and readers cannot be certain that knowledge, skills, and/or beliefs/attitudes/interests were actually captured. Some records, however, went through extensive validation. Of note, are the survey items used and/or developed by Hess et al.\textsuperscript{19} and Fraser et al.\textsuperscript{18}.

Second, for direct assessments, the quality of rubrics used to score student constructs vary in specificity and consequently the ability to be applied in new contexts. For open-ended (low-directed) assessments of student knowledge, some authors (e.g., Hess et al.\textsuperscript{11} and Watson et al.\textsuperscript{10, 22}) present rubrics that could reasonably be applied by other researchers. Similarly, some rubrics are presented in the literature for assessment of authentic design projects (e.g., Watson et al.\textsuperscript{24}, Hess et al.\textsuperscript{11}, and Dancz et al.\textsuperscript{16}). Nevertheless, if direct assessments are to be widely used by the sustainable engineering education community, then clear and specific rubrics are needed.

Conclusions and Future Work

The systematic review resulted in rich findings of both the diversity and quality of sustainability assessments in the three target areas of conceptual knowledge, design skills, and beliefs/attitudes/interests. For each target, recent literature presents multiple examples of assessment tools that could be implemented by different institutions leading similar courses or transferred to completely new contexts. However, the effectiveness of assessment methods (in terms of objectivity, reliability, etc.) varied considerably across the records. In particular, the results suggest a need for validated survey instruments across the three target areas. Additionally, there is an opportunity to develop more options for direct assessment of sustainability knowledge and project artifacts.

To supplement the results of this systematic review, the research team plans to broaden the search of engineering education literature to include journals and other conference proceedings within and beyond the United States. Using the same research questions and a similar
screening/appraisal process, the team hopes to build on the categories identified in the ASEE proceedings either through additional examples or new sub-categories of assessment types. Any remaining gaps could help direct future research projects. Ultimately, improving the quality and accessibility of sustainability assessments can help engineering educators enhance learning activities for future engineers.

Acknowledgement

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References


APPENDIX A:  
Excerpts of Sustainability Assessments from Retained Records

Please note that assessment tools below are excerpted and/or paraphrased from the sources cited. Citations are provided after the title of each record, which are listed in order of decreasing relevance index (as determined by ASEE PEER).

1. Sustainable Engineering Internships: Creation and Assessment

   Self-report survey items to test knowledge and skills

   *Students answered the following items using the following scale: To a great extent, To a moderate extent, To a small extent, or Not at all.

   1. The internship increased my ability to explain sustainability concepts and terminology.
   2. The internship increased my ability to recognize impacts of engineering project/designs on sustainability.
   3. The internship increased my ability to identify mitigation strategies for reducing negative impacts on sustainability.
   4. The internship increased my ability to evaluate potential engineering solutions based on sustainability.
   5. The internship increased my ability to work effectively in multidisciplinary teams.

   *Students answered the following items using the following scale: Strongly agree, Agree, Disagree, Strongly Disagree

   6. Participation in the internship will make me more likely to consider sustainable design options in my future.
   7. I would recommend future students to participate in sustainable engineering internships.

2. Exploring Contemporary Issues in Sustainable Energy

   Self-report survey items to test knowledge and attitudes/beliefs/interests

   1. I understand what fracking is: (A) Strongly agree, (B) Agree somewhat, (C) Not really, (D) No
   2. Fracking is a topic of local discussion (*where I am from): (A) major issue, discussed extensively, (B) A minor issue, discussed but not extensively, (C) Not an issue at all, (D) Don’t know
3. I support or oppose fracking: (A) Strongly support, (B) Support, (C) Neutral/Don’t know, (D) Oppose, (E) Strongly oppose
4. I am from an area with fracking: (A) Yes, (B) No, (C) Don’t know
5. Which of these factors is most important to fracking: (A) Societal, (B) Political, (C) Economical, (D) Environmental, (E) Technological
6. Which of these factors is least important to fracking: (A) Societal, (B) Political, (C) Economical, (D) Environmental, (E) Technological
7. Who should have the most authority in decisions regarding fracking regulations? (A) Federal government, (B) State government, (C) Local government, (D) Land owners, (E) Don’t know
8. This format was effective in my learning: (A) Strongly agree, (B) Agree somewhat, (C) Neutral, (D) Disagree somewhat, (E) Strongly agree

3. Exploring Student Sustainability Knowledge using the Structure of Observed Learning Outcomes (SOLO) Taxonomy

Short answer to assessment of knowledge

Open response: *In your own words, what is sustainability?*

Responses classified according to the SOLO Taxonomy (table excerpted from):

<table>
<thead>
<tr>
<th>SOLO Stage</th>
<th>Overview of SOLO Stage</th>
<th>Features of Sustainability Definition Typical of Each Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Structural</td>
<td>Student demonstrates no understanding of the desired learning.</td>
<td>Either did not know what sustainability was or provided a broad, non-specific response.</td>
</tr>
<tr>
<td>Uni-Structural</td>
<td>Student demonstrates understanding of only one item relevant to the desired learning.</td>
<td>Provided one definitive example of something concrete or abstract with relevance to sustainability.</td>
</tr>
<tr>
<td>Multi-Structural</td>
<td>Student demonstrates understanding of more than one relevant item, but items are seen as independent or unrelated to each other.</td>
<td>Provided two or more qualitatively different examples of concrete and/or abstract things relevant to sustainability.</td>
</tr>
<tr>
<td>Relational</td>
<td>Items are described as part of an overall structure and as being interrelated (not necessarily a greater number of items nominated than in multi-structural).</td>
<td>Constructed a cohesive, internally consistent statement about sustainability by relating two or more concrete and/or abstract things related to sustainability.</td>
</tr>
<tr>
<td>Extended Abstract</td>
<td>Items are described as part of an overall structure, and elements of the structure are seen to be applicable in other situations (i.e. transferrable or generalizable).</td>
<td>Constructed a cohesive, internally consistent statement about sustainability by relating two or more concrete and/or abstract things related to sustainability, and provided evidence of critical thinking, ethical judgment, consideration of context or creative/original thinking relevant to sustainability.</td>
</tr>
</tbody>
</table>
4. Nature/Society: Situating Student Learning Outcomes in a First-Year Sustainability Studies Course

Self-report survey items to test knowledge and attitudes/beliefs/interests

The following questions are answered on a five-point Likert scale of 5 = Strongly agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly disagree

**Environmental Interests**

1. I am very committed to sustainability.
2. I was involved with environmental causes, clubs, or organizations while in high school.
3. I enjoy the outdoors.
4. I was exposed to a lot of environmental or nature education when I was young.
5. I consider one or more of my parents to be environmentalists.

**Substantive Attitudes**

6. Technology is an essential part of future solutions for sustainability.
7. Innovation is the most important means for achieving sustainability.
8. As a society, we much reduce consumption in order to achieve sustainability.
9. We need the humanities & social sciences to understand technology and its consequences.
10. Sustainability is a complex social problem.

**Substantive Knowledge**

11. There are two sides to every issue.
12. The findings of scientists in universities and research institutes should be trusted.
13. Sustainability is a complex problem for which there are few definite answers.
14. Politics is a part of the problem not the solution.
15. It will be difficult to achieve sustainability in a capitalist society.
16. I believe the humanities and social sciences will be important to my future professional identity as a scientist, engineer, or architect.

5. The Wicked Problems in Sustainable Engineering (WSPE) Imitative: Pilot Results of a Cross-Institutional Project-Based Course Offering

Concept maps for knowledge assessment

1. Get out a blank piece of paper, a writing instrument, and write and circle ‘Sustainability’ in the center of the paper.
2. The general form of your map should be a series of connected bubbles, with the ‘Sustainability’ bubble at the center. These bubbles do not have to be strictly hierarchical,
and can include anything from words to phrases to images. They can be nested if that fits your understanding of concepts. Don’t try to put too much into any single bubble. You can label connected lines (often with words describing the relationship) though you do not have to. You should not consult outside sources or others’ maps during this exercise – this is to show what you currently think.

3. Set a time for 30 minutes and start writing/drawing. You do not have to use the entire time, but if you’re still writing after 30 minutes it’s OK to stop – you’ve got enough details!

Responses scored using the following rubric (excerpted from\textsuperscript{17} and originally published in\textsuperscript{30}):

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensiveness—covering completely/broadly</td>
<td>The map lacks subject definition; the knowledge is very simple and/or limited. Limited breadth of concepts (i.e., minimal coverage of coursework, little or no mention of employment, and/or lifelong learning). The map barely covers some of the qualities of the subject area.</td>
<td>The map has adequate subject definition but knowledge is limited in some areas (i.e., much of the coursework is mentioned but one or two of the main aspects are missing). Map suggests a somewhat narrow understanding of the subject matter.</td>
<td>The map completely defines the subject area. The content lacks no more than one extension area (i.e., most of the relevant extension areas including lifelong learning, employment, people, etc. are mentioned).</td>
</tr>
<tr>
<td>Organization—to arrange by systematic planning and united effort</td>
<td>The map is arranged with concepts only linearly connected. There are few (or no) connections within/between the branches. Concepts are not well integrated.</td>
<td>The map has adequate organization with some within/between branch connections. Some, but not complete, integration of branches is important. A few feedback loops may exist.</td>
<td>The map is well organized with concept integration and the use of feedback loops. Sophisticated branch structure and connectivity.</td>
</tr>
<tr>
<td>Correctness—conforming to or agree with fact, logic, or known truth</td>
<td>The map is naive and contains misconceptions about the subject area; inappropriate works or terms are used. The map documents are inaccurate understanding of certain subject matter.</td>
<td>The map has few subject matter inaccuracies; most links are correct. There may be a few spelling and grammatical errors.</td>
<td>The map integrates concepts properly and reflects an accurate understanding of subject matter meaning little or no misconceptions, spelling/grammatical errors.</td>
</tr>
</tbody>
</table>

Self-report survey items to test knowledge, skills, and attitudes/beliefs/interests

Students respond to the following items with: (A) Strongly disagree, (B) Disagree, (C) Agree, or (D) Strongly agree.

1. I feel confident in my ability to create socially just solutions in my career.
2. The potential to develop sustainable solutions drives my career motivations.
3. Financial considerations drive my career motivation.
4. I feel that it is my duty to ensure my professional actions are socially acceptable.
5. There are global implications for every individual design.
6. It is my professional responsibility to maximize the potential profit of my designs, even if there are environmental trade-offs to that design.
7. I am confident in my ability to create environmentally sustainable solutions in my field.
8. I feel good when I imagine myself designing solutions that have a lasting positive impact in my local community.
9. Sustainability is a necessary goal for any project.
10. I feel confident in my understanding of metrics for measuring the sustainability of a project or solution.
11. I feel that it is my professional obligation to ensure that my designs are economically, environmentally, and socially sustainable.
12. Advances in technology provide the means for unlimited sustainable progress.
13. I am driven to pursue my career so that I may have positive impact on others.
14. I care about the effect that professional decisions have on the planet.
15. I feel that my decisions have an effect on the planet.

Rubrics used to assess student design products

Preliminary Design Review Rubric (excerpted from\textsuperscript{17}):

<table>
<thead>
<tr>
<th>Component</th>
<th>Factors to Score</th>
<th>Score (1-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Defined Statement of Problem</strong></td>
<td>Effectiveness of <strong>problem</strong> description</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clarity and value of envisioned <strong>solution</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Appeal and impact of <strong>benefits</strong> from solution</td>
<td></td>
</tr>
<tr>
<td><strong>Defined Specifications</strong></td>
<td>Value and specificity of <strong>functional</strong> specifications</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value and competitiveness of <strong>financial</strong> specifications</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clarity and correctness of <strong>technical</strong> feasibility specs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Breadth and suitability of <strong>social</strong> responsibility specs</td>
<td></td>
</tr>
</tbody>
</table>
## Critical Design Review Rubric and Questions (excerpted from\textsuperscript{17})

<table>
<thead>
<tr>
<th>Component</th>
<th>Factors to Score</th>
<th>Score (1-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Realization &amp; Testing Processes</td>
<td>Diversity and value of resources used in solution development</td>
<td></td>
</tr>
<tr>
<td>Defined Statement of Problem</td>
<td>Value of analysis, testing and modeling to evaluate concepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value added by validating problem definition with stakeholders</td>
<td></td>
</tr>
<tr>
<td>Proposed Solution</td>
<td>Effectiveness of problem description</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clarity and value of proposed solution description</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Appeal and impact of benefits from solution</td>
<td></td>
</tr>
<tr>
<td>Design Documentation</td>
<td>Proof of solution’s functional performance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proof of solution’s financial benefits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proof of solution’s technical feasibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proof of solution’s safety, responsibility, societal acceptance</td>
<td></td>
</tr>
<tr>
<td>Reflection and Plans</td>
<td>Record quality for problem and concept review processes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quality of problem definition history/records</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quality of proposed solution history/records</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequacy of assessment of progress, process, products</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequacy of plan for and necessary revisions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequacy of plan for project continuation</td>
<td></td>
</tr>
</tbody>
</table>

6. **Students and Sustainability: Assessing Students’ Understanding of Sustainability from Service Learning Experiences\textsuperscript{14}

Essay questions (“challenge questions”) to test knowledge and skills

Please answer one following questions. Please use the full page for your response.

**Question A:** As an engineering consultant, you were recently put on a team for a new project, and the client is your alma mater (the university you attended). The job involves providing recommendations on all aspects of new construction on campus and on the potential renovation of existing facilities, such as buildings and dormitories. The task is particularly important given the challenging economic climate. What major technical issues would impact your
recommendations? What major nontechnical issues would impact your recommendations? What types of changes would you like to make to address these challenges? What will be the potential impact(s) of your recommendations? What are the foreseeable consequences of implementing your ideas?

**Question B:** A friend of yours (who is not an engineer) has recently returned from the Peace Corp work she was doing in a small village in Tanzania. She discussed the challenges the people there were facing and asked what you would do as an engineer to improve the quality of life. What major technical issues would impact your recommendations? What major nontechnical issues would impact your recommendations? What are some examples of products or services that might you design for the community? What would be the potential impacts of these changes? What are the foreseeable challenges?

Abbreviated Scoring Rubric (excerpted from\(^{14}\)):
7. Sustainable Industrial Engineering Modules

Self-report survey items to test knowledge and skills

After participation in a module entitled “How Can Engineering Probability Help to Achieve Sustainability?” students answered the following questions with: Strongly not confident, Not confident, Confident, Strongly Confident.

1. I can identify the current sustainability issues for a given topic.
2. I can identify knowledge that would be helpful for improving/understanding these issues.
3. I can identify potential sustainability factors and research questions.
4. I can identify data collection opportunities and practical issues.
5. I can identify appropriate probability and statistics tools for analyzing data to answer the research questions.

After participation in a module entitled “Life Cycle Sustainability Economics” students answered the following questions with: Strongly not confident, Not confident, Confident, Strongly Confident.

1. I can give an example of a Tragedy of the commons and a possible solution.
2. I can give an example of pollution creating an externality and a possible solution.
3. I can compare advantages and disadvantages of triple bottom line accounting.
4. I can compare advantages and disadvantages of traditional emission limits and emissions trading systems.
5. I can explain a way to determine the value of environmental benefits.
6. I can list phases of a project or product life to consider in life cycle analysis.
7. I can perform a cost-benefit analysis that includes environmental benefits.

After participation in a module entitled “How Can Operations Research Help to Achieve Sustainability” students answered the following questions with: Strongly not confident, Not confident, Confident, Strongly Confident.

1. I can identify the current sustainability issues for a given topic.
2. I can identify relevant objectives (sustainability metrics) and goals (maximize, minimize, meet target).
3. I can identify potential actions to improve sustainability.
4. I can identify constraints and practical considerations for implementation of these actions.
5. I can identify appropriate deterministic operations research tools for guiding more sustainable decisions.
Objective (multiple choice, true/false), short answer, and closed-ended problem assessment of knowledge and

Objective assessments and short answer questions were used to test knowledge gained through the modules outlined above (available at: http://www.uta.edu/ce/ese/IE%20Modules04.htm). Sample questions are provided below.

1. Which of the following are possible objectives that could be considered in green building? Example of multiple choice to test knowledge.
   A. building style
   B. water use
   C. indoor air quality
   D. acreage of property
   E. none of the above

2. Briefly discuss two (2) factors on the inside of a house that should be considered as possibly affecting energy consumption. Example of short answer to test knowledge.

   Grading:
   • Exceeds expectations: If two relevant factors are discussed.
   • Meets expectations: If two factors (not necessarily relevant) are discussed.
   • Needs improvement: If fewer than two factors are discussed.

3. Consider the design of a wastewater treatment system. Processing of wastewater occurs sequentially in 3 different stages. The characteristics of the wastewater as it is processed are represented by the concentrations of various pollutants, such as chemical oxygen demand (COD) and pathogens. The following table shows the 3 stages of wastewater treatment with two treatment options in each stage and their corresponding percent reductions of COD and pathogens. The last column provides the life cycle cost and the robustness index of each treatment option. Consider only Stage 1. Which of the two treatment options would you recommend and why? Example of short answer to test skills.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Treatment</th>
<th>% Reduction COD</th>
<th>% Reduction Pathogens</th>
<th>Life Cycle Cost</th>
<th>Robustness Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vortex SSO</td>
<td>15</td>
<td>70</td>
<td>4,000</td>
<td>4.25</td>
</tr>
<tr>
<td>1</td>
<td>Chemical Precipitation</td>
<td>35</td>
<td>90</td>
<td>3,000</td>
<td>4.60</td>
</tr>
<tr>
<td>2</td>
<td>UASB System</td>
<td>90</td>
<td>30</td>
<td>33,000</td>
<td>3.40</td>
</tr>
<tr>
<td>2</td>
<td>Reed Bed System</td>
<td>70</td>
<td>99</td>
<td>380,000</td>
<td>4.00</td>
</tr>
<tr>
<td>3</td>
<td>Microfiltration</td>
<td>80</td>
<td>99</td>
<td>6,000</td>
<td>3.5</td>
</tr>
<tr>
<td>3</td>
<td>Reverse Osmosis</td>
<td>90</td>
<td>95</td>
<td>30,000</td>
<td>3.75</td>
</tr>
</tbody>
</table>

Answer: Chemical Precipitation is better across all 4 objectives.
Grading:
- Exceeds expectations: Correct answer with correct justification.
- Meets expectations: Correct answer with incorrect justification.
- Needs improvement: Incorrect answer.

4. A family is considering two homes for purchase. Although it has a higher up-front cost, Alternative 2 is designed to be more energy efficient, via better insulation, double-paned windows, and a radiant barrier under the roof. Alternative 2 also has low-flow toilets and faucets, to reduce water use, and a tankless water heater, which will reduce natural gas usage.

Details regarding the 2 homes are shown below. Assuming a 40-year time span and \( i=5\% \), perform a present worth cost comparison to determine whether the additional up-front cost for Home 2 is justified over the long-term. Example of closed-ended problem to test skills.

<table>
<thead>
<tr>
<th></th>
<th>Home 1</th>
<th>Home 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cost</td>
<td>$150,000</td>
<td>$180,000</td>
</tr>
<tr>
<td>Salvage value</td>
<td>$150,000</td>
<td>$180,000</td>
</tr>
<tr>
<td>Electricity</td>
<td>$200/month</td>
<td>$100/month</td>
</tr>
<tr>
<td>Natural gas</td>
<td>$40/month</td>
<td>$25/month</td>
</tr>
<tr>
<td>Water</td>
<td>$50/month</td>
<td>$35/month</td>
</tr>
</tbody>
</table>

8. Engineering Sustainable Civil Engineers

Self-report survey items to test knowledge, skills, and attitudes/beliefs/interests

After participation in a module entitled “Waste as a Resource” students answered the following questions with: Strongly not confident, Not confident, Confident, Strongly Confident.

1. I can define sustainability and clearly explain it to someone else.
2. I can list four (4) general strategies that help to foster sustainable development.
3. I can clearly explain the concept of the “triple bottom line.”
4. Given several waste management alternatives such as resource recovery, recycling, and treatment, I can prioritize them based on a solid waste management hierarchical system.
5. I can differentiate among recycling, waste minimization and recovery.
6. I can differentiate among recycling, waste minimization and recovery.
7. I can list commonly recycled materials and discuss issues related to each.
8. I can clearly explain the terms higher heating value and lower heating value.
9. I can prioritize materials’ usefulness as fuels based on net heating values.
After participation in a Biodiesel Refinery Project, students answered the following questions with: To a great extent, To a moderate extent, To a small extent, or Not at all.

1. The biodiesel design project increased my ability to explain sustainability concepts and terminology.
2. The biodiesel design project increased my ability to recognize impacts of engineering projects/designs on sustainability.
3. The biodiesel design project increased my ability to identify ways to mitigate potential negative impacts on sustainability.
4. The biodiesel design project increased my ability to evaluate potential engineering solutions based on sustainability.
5. The biodiesel design project increased my ability to work effectively in multidisciplinary teams.

After participation in a Biodiesel Refinery Project, students answered the following questions with: Strongly agree, Agree, Disagree, or Strongly disagree.

6. Participation in the biodiesel refinery project will make me more likely to consider sustainable design options in my future career.
7. I would recommend future students to participate in sustainable engineering senior design projects.
8. I would recommend future students to participate in multidisciplinary engineering senior design projects.

9. **Integrating Sustainability Across the Curriculum: Engineering Sustainable Engineers**

Objective (multiple choice, true/false), short answer, and closed-ended problem assessment of knowledge and skills

Multiple choice, short answer questions, and closed-ended problems were used to test knowledge and skills gained through a variety of sustainable engineering modules (available at: http://www.uta.edu/ce/ese/Learning%20Modules.htm). Sample questions are provided below.

1. Consider the water that you use at home (or in your dorm). List the life cycle stages (“cradle to grave”) of domestic water use and give one element of each stage. *Example of short answer question to test knowledge.*
<table>
<thead>
<tr>
<th>Response</th>
<th>Criteria</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exemplary</td>
<td>Is able to list the three life cycle stages discussed in class (creation, use, demolition) and correctly give one example of each.</td>
<td>4</td>
</tr>
<tr>
<td>Competent</td>
<td>Is able to list the three life cycle stages discussed in class (creation, use, demolition) and correctly give one example of two of the three stages.</td>
<td>3</td>
</tr>
<tr>
<td>Nearly Satisfactory</td>
<td>Is able to list two life cycle stages discussed in class (creation, use, demolition) and correctly give one example of one of the three stages.</td>
<td>2</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>Attempts to answer but does not meet the above criteria for “nearly satisfactory.”</td>
<td>1</td>
</tr>
<tr>
<td>No attempt</td>
<td>Does not attempt to answer.</td>
<td>0</td>
</tr>
</tbody>
</table>

2. You are charged with selecting a site for a building project. You have two alternatives, and you already evaluated them based on cost, suitability, and other factors. You wish to evaluate them based on sustainability. List three factors that you should consider and specify why each is important. *Example of short answer question to test skills.*

<table>
<thead>
<tr>
<th>Response</th>
<th>Criteria</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exemplary</td>
<td>Is able to correctly list three factors and clearly explain why each is important.</td>
<td>4</td>
</tr>
<tr>
<td>Competent</td>
<td>Is able to correctly list three factors and clearly explain why two of them are important.</td>
<td>3</td>
</tr>
<tr>
<td>Nearly Satisfactory</td>
<td>Is able to correctly list two or more factors and can clearly explain why one or two of them is important.</td>
<td>2</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>Attempts to answer but does not meet the above criteria for “nearly satisfactory.”</td>
<td>1</td>
</tr>
<tr>
<td>No attempt</td>
<td>Does not attempt to answer.</td>
<td>0</td>
</tr>
</tbody>
</table>

3. Which of the following is the best measure of effectiveness for sustainability to consider when evaluating transportation projects? *Example of multiple choice question to test knowledge.*

A. Material cost  
B. Maximum travel time  
C. Ozone alert days (ANSWER)  
D. Total annual travel time including delay  
E. None of the above

4. A family is considering two homes for purchase. Although it has a higher up-front cost, Alternative 2 is designed to be more energy efficient, via better insulation, double-paned windows, and a radiant barrier under the roof. Alternative 2 also has low-flow toilets and faucets, to reduce water use, and a tankless water heater, which will reduce natural gas usage.
Details regarding the 2 homes are shown below. Assuming a 40-year time span and i=5%, perform a present worth cost comparison to determine whether the additional up-front cost for Home 2 is justified over the long-term. Example of closed-ended problem to test skills.

<table>
<thead>
<tr>
<th></th>
<th>Home 1</th>
<th>Home 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cost</td>
<td>$150,000</td>
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</tr>
<tr>
<td>Salvage value</td>
<td>$150,000</td>
<td>$180,000</td>
</tr>
<tr>
<td>Electricity</td>
<td>$200/month</td>
<td>$100/month</td>
</tr>
<tr>
<td>Natural gas</td>
<td>$40/month</td>
<td>$25/month</td>
</tr>
<tr>
<td>Water</td>
<td>$50/month</td>
<td>$35/month</td>
</tr>
</tbody>
</table>

10. Far-Post Assessment of a Sustainability Engineering High School Outreach Program

Short answer assessment of knowledge, skills, and attitudes/beliefs/interests

1. What is “green design” and/or “sustainability?” How does it relate to engineering?
2. Below are the topics covered on the various days of the program. Which topic or activity still resonates with you? Why?
3. Do you (or have you) applied any of the concepts from the Green Design Apprenticeship in your studies, work, everyday life?

11. Sustainable Water: Development, Delivery and Assessment of K-5 Modules

Multiple choice assessment of knowledge

1. Of the following process, which is most responsible for chemical removal?
   A. Biotransformation, B. Filtration, C. Sorption, D. Dilution
2. __________ is a major source of pollution in the South Platte River just east of Denver, CO.
   A. Treated municipal wastewater, B. Agricultural runoff, C. Chemical plant effluent, D. Oil spills
3. The sector that uses the most water in the US is:
   A. Households (residences), B. Agriculture, C. Manufacturing, D. Power generation
4. The household fixture that uses the MOST water is:
   A. Shower/bathtub, B. Washing machine, C. Dishwasher, D. Toilet
5. Approximately how much of the Earth’s surface is water?
   A. 33%, B. 50%, C. 55%, D. 75%
6. What is desalination?
   A. Removal of salt and other minerals from saline water, B. Forming salt crystals from soil,
   C. When water currents affect the Earth’s rotation, D. None of the above
7. A microorganism that obtains its carbon source from CO₂ gas is a(n):
   A. Autotroph, B. Heterotroph, C. Chemotroph
8. The average American consumes approximately _______ gallons of bottled water every year.
   A. 15, B. 18, C. 21
12. Use of Concept Maps to Assess Student Sustainability Knowledge

Concept maps for knowledge assessment

Students constructed concept maps on the focus question: “What is sustainability?” using CmapTools, a free concept mapping software.

Responses were scored using the following methods (excerpted from\textsuperscript{10}):

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Method & Equation \\
\hline
Traditional\textsuperscript{39} & Total = (NC-NCL) + (HH)*5 + (NCL)*10 \\
Holistic\textsuperscript{21} & Total = Comp. + Org. + Corr. \\
\hline
\end{tabular}
\end{table}

\textsuperscript{a,b} Ten-category taxonomy employed Segalàs et al.\textsuperscript{25}: environment, natural resources, social impacts, values, temporal, spatial, technology, economy, education, and stakeholders.

\textsuperscript{2} Modified from Segalàs et al.\textsuperscript{25}: Environmental mega category: environment + natural resources; Social mega category: social impacts + values + temporal + spatial imbalances + education + stakeholders; Techno-economic mega category: technology + economy.

13. Development and Application of the Sustainability Skills and Dispositions Scale to the Wicked Problems in Sustainability Initiative\textsuperscript{19}

Self-report survey items to test knowledge, skills, and attitudes/beliefs/interests

Students provided responses to the following items using a 6-point Likert scale where 1 = “Strongly disagree” and 6 = “Strongly agree.” Efforts to validate the items below are described in the manuscript.
1. I feel prepared to work with people who define a problem differently than I do.
2. I feel prepared to develop sustainable solutions in future projects.
3. Designers must consider the environmental implications of their designs.
4. The present distribution of the world’s wealth and resources should be maintained because it promotes survival of the fittest.
5. My opinions about national policies include consideration of how those policies might affect the rest of the world.
6. It is a designer’s responsibility to maximize the economic profit of their solutions, even at the expense of increased environmental consequences.
7. Design solutions must have a positive impact in the local community.
8. Generally, an individual’s actions are too small to have a significant effect on the ecosystem.
9. I measure success in my life by how much I contribute to society.
10. All design decisions will have an effect on the planet.
11. I am able to affect what happens on a global level by what I do in my own community.
12. I am prepared to meet and work with individuals from different backgrounds.
13. I care about the effect that my professional decisions will have on the planet.
14. Designers must consider the needs of all stakeholders before coming to a decision.
15. Designers must develop solutions that promote equity between people.
16. I think my personal choices can impact people in other countries.
17. Designers must ensure that their designs are environmentally sustainable.
18. Really, there is nothing I can do about the problems of the world.
19. I put the needs of others above my own personal wants.
20. Designers should only consider local constraints when creating a solution.
21. I feel confident in my understanding of metrics for measuring the sustainability of a project or solution.
22. Designers must consider the effect of their decisions both locally and internationally.
23. I am confident in my ability to create environmentally sustainable solutions in my field.
24. Design decisions will always have social implications.
25. I feel confident in my ability to create socially just solutions in my career.
26. Designers must think about the kind of world we are creating for future generations.
27. It is not really important to me to consider myself as a member of the global community.
28. I often reflect on how my work and actions give back to society.

14. Changing Students’ Knowledge and Attitudes about Sustainable Development and Sustainable Engineering in an Introductory Science and Engineering Class

Self-report survey items to test knowledge, skills, and attitudes/beliefs/interests

Students answered “yes,” “not sure,” or “no” to the following items.

1. Please choose the best response to the following items.
   A. I can define the term “product life cycle.”
   B. I could list most of the stages in the life cycle of a product that I use every day (e.g., something in my backpack or home).
   C. I can define the term “sustainable development.”
D. I can give an example of sustainable engineering.

2. Please choose the best response to the following statement. I can describe what the following environmental problems are (not necessarily what causes them, just what they are).
   A. Global climate change
   B. Acid precipitation
   C. Eutrophication
   D. Ozone layer depletion
   E. Smog formation

3. Please choose the best responses to the following statement. I can list the major types and sources of pollutants that cause the following environmental problems.
   A. Global climate change
   B. Acid precipitation
   C. Eutrophication
   D. Ozone layer depletion
   E. Smog formation

4. Please choose the best response to the following statements.
   A. Using software, I could identify the wastes released in the life cycle of a product or process.
   B. Using software, I could estimate the resources consumed in the life cycle of a product or process.
   C. I could describe to a friend two or three possible ways in which a science or engineering project could adversely impact the environment.

Students answered the following items with “Strongly agree,” “Agree,” “Neutral/don’t know,” “Disagree,” or “Strongly disagree.”

5. Please choose the best response to the following statements.
   A. I think that sustainability needs to be integrated into all science and engineering disciplines.
   B. I can give some examples of how scientists and engineers could integrate sustainability into their professional activities.
   C. Scientists and engineers should consider environmental impacts over the life cycle in designing products and processes.
   D. I think that, through their work, scientists and engineers can affect the quality of life around the globe.
Self-report survey items to test knowledge and attitudes/beliefs/interests

1. Which of the following careers would integrate concepts of sustainability and design for the environment? A. Engineering consulting, B. Construction manager, C. Government position, D. Researcher, E. Teacher, F. Health care professional, G. Marketing/sales, H. None of the above

2. I have heard of the following uses of an infrared camera: A. Evaluating material strength, B. Quantifying temperature differences, C. Measuring vehicle (or object) speed, D. Searching for abnormalities in body tissue, E. Viewing activities through building walls, F. Identifying energy losses in buildings, G. Evaluating green building products for energy efficiency, H. None of the above.

Self-report survey items to test knowledge and attitudes/beliefs/interests

Students rated their knowledge of the following topics using “not heard of,” “hear of but cannot explain,” “have some knowledge,” or “know a lot.”

1. Environmental issues: Acid rain, Air pollution, Biodiversity, Climate change, Deforestation, Depletion of natural resources, Desertification, Ecosystems services, Emerging pollutants, Global warming, Hazardous waste, Ocean acidification, Ozone depletion, Photochemical smog, Planetary boundaries, Pollution prevention, Renewable energy, Salinity, Solid waste, Water pollution


3. Environmental tools, technologies, and approaches: Benchmarking, clean technologies (for example carbon capture), Remediation technologies, Design for the environment, Eco-labelling, Industrial ecology, Life cycle assessment, Product stewardship, Renewable energy technologies, Resiliency, Tradeable permits (emissions permitting, cap and trade), Waste minimization, Energy auditing, Geo Engineering, Fracking/Pollution control

4. Sustainable development: Sustainable development (definition and concept), Components of sustainable development, Approaches to sustainable development, Precautionary principle (GMOs, for example), Population growth, Inter and intra-generational equity, Stakeholder participation, Connections between poverty, population, consumption, and degradation of the environment, Social responsibility, Engineering community’s response to sustainable
development, Actions taken by companies and engineers to promote sustainable development, Energy-water-food nexus

Students answered the following items with “Not important,” “Possible important,” “Important,” or “Very important.”

5. Importance of sustainable development to: (A) You personally, (B) You as an engineer, (C) Your country, (D) The society world-wide, (E) Future generations

17. A Rubric to Assess Civil Engineer Students’ Grand Challenge Sustainable Entrepreneurship Projects

Rubrics used to assess student design products

Rubric used to assess sustainable entrepreneurship projects (excerpted from):
18. The Assessment of Ethical and Sustainable Engineering Studies in Undergraduate University Education

Essay/Report to test knowledge and skills

1. You work for an engineering consultancy firm who has been approached by a major Capital Fund Investor, seeking to invest in technology developments that will assist in the development of new forms of energy supply on a large scale. There are five possible technological proposals that are being considered by this investor: (A) Gas Hydrates, (B) Wind Power, (C) Water Power, (D) Solar Power, (E) Nuclear Fusion. You are to choose one of these five, which you believe could be a viable investment, with the most likely chance of successful implementation and outcomes. Firstly, describe your chosen technological proposal, explaining how it would work. Then discuss its strengths and weaknesses, especially noting any particular opportunities which might be opened up as a result of its development, and any particular problems that might arise from its implementation.

2. Consider the past 60 years in the timeline of the development of sustainability in the world. Choose one particular “adverse event” that has occurred where significant environmental damage resulted (or had been occurring). Think about any positive outcome that may have occurred as a result of addressing the environmental issue you have chosen. Describe the initial cause of the “adverse event”, what actually happened, what the aftermath was, and your chosen positive outcome that came from it.

3. Humanity’s ecological footprint is now believed to be so large, that it takes the earth one year and four months to regenerate what we use from it in a year. Applying the principles of “reduce,” “reuse,” and “recycle,” describe an example of how we could act differently, in order to reduce our ecological footprint in each of the following areas (i.e. a different example for each of a, b, and c): (A) Production, (B) Consumption, (C) Organising ourselves.

Short answer assessment of knowledge

1. Briefly define the term Sustainability and explain why it is important to move towards a sustainable society. (1 mark)

2. The Greenhouse effect is a term used frequently in relation to climate change. What is the major cause of this Greenhouse effect, and why is it of concern to environmental scientists? (1 mark)

3. Explain what is meant by life cycle considerations in the design of engineering applications. (1 mark)

4. Describe the concept of Cleaner Production (CP), and give an engineering example of where this can be applied. (1 mark)

5. Name three of the six barriers to producing differently, and give an example of each. (3 marks)
19. Assessing Engineering Students’ Readiness to Collaborate Sustainable Design: An Open Access Instrument for Experimentation

Self-report survey items to test attitudes/beliefs/interests

Students used a five-point Likert scale to respond to the following validated items: (1) Strongly disagree, (2) Disagree, (3) Neither agree nor disagree, (4) Agree, or (5) Strongly agree.

1. Indicate your level of agreement with the following statements (items randomized):
   A. It is important to me that I use my talents to improve the world around me.
   B. I am personally committed to living in a way that contributes to a sustainable world.
   C. Sustainability is important, but I am not confident that I can live more sustainably.
   D. I am confident that I can do what is needed to create a more sustainable world.
   E. My actions won’t make much of a difference toward a sustainable world.
   F. My commitment to sustainability will influence those around me to live more sustainably.
   G. There are right and wrong ways to view every situation.
   H. My understanding of any situation is limited.
   I. In complex situations, it is possible for contradicting viewpoints to both have validity.
   J. I reach conclusions based on facts that are free of assumptions.
   K. When I hear new information, I quickly categorize it as “true” or “untrue.”

Students used a five-point scale to respond to the following items: (1) Opposed to my principles, (2) Not important, (3) Somewhat important, (4) Important, or (5) Very important.

2. Please indicate how important each of these is as a guiding principle in YOUR life.
   A. Protecting the environment, preserving nature
   B. Unity with nature, fitting into nature
   C. Respecting the earth, harmony with other species
   D. Equality, equal opportunity for all
   E. Social justice, correcting injustices, care for those who are less privileged
   F. A world at peace, free of war and conflict


Self-report survey items to test knowledge and skills

After participation in a module entitled “Life Cycle Sustainability Economics” students answered the following questions with: Strongly not confident, Not confident, Confident, Strongly Confident.

1. I can give an example of a Tragedy of the commons and a possible solution.
2. I can give an example of pollution creating an externality and a possible solution.
3. I can compare advantages and disadvantages of triple bottom line accounting.
4. I can compare advantages and disadvantages of traditional emission limits and emissions trading systems.
5. I can explain a way to determine the value of environmental benefits.
6. I can list phases of a project or product life to consider in life cycle analysis.
7. I can perform a cost-benefit analysis that includes environmental benefits.

Multiple choice, short answer, and closed-ended problem to test knowledge and skills

Multiple choice, short answer questions, and a closed-ended problem were used to test knowledge and skills gained through a module entitled “Life Cycle Sustainability Economics” (available at:  http://www.uta.edu/ce/ese/lifecycle.htm). Sample questions are provided below.

1. When comparing the cost of two alternative products, ideally which of the following should be taken into account? *Example of multiple choice question to test knowledge.* (A) Up front purchase cost, (B) Operations and maintenance costs, (C) Disposal costs, (E) All of the above

2. Give an example of the “Tragedy of the Commons.” *Example of short answer question to test knowledge.*

3. A company is considering two roadway asphalt pavement alternatives. Although Alternative 2 has a higher up-front cost, it is designed to be more sustainable because (A) It can be more easily re-used to make asphalt shingles (and thus has a higher salvage value), (B) It is designed to have a longer lifetime, which reduces long-term the need for paving materials, (C) It requires less maintenance, which reduces energy and materials consumption, as well as maintenance costs. Make a list of factors you would consider in comparing costs of Alternative 1 and Alternative 2. *Example of short answer question to test skills.*

4. A family is considering two homes for purchase. Although it has a higher up-front cost, Alternative 2 is designed to be more energy efficient, via better insulation, double-paned windows, and a radiant barrier under the roof. Alternative 2 also has low-flow toilets and faucets, to reduce water use, and a tankless water heater, which will reduce natural gas usage. Details regarding the 2 homes are shown below. Assuming a 40-year time span and i=5%, perform a present worth cost comparison to determine whether the additional up-front cost for Home 2 is justified over the long-term. *Example of closed-ended problem to test skills.*

<table>
<thead>
<tr>
<th></th>
<th>Home 1</th>
<th>Home 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cost</td>
<td>$150,000</td>
<td>$180,000</td>
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<td>$100/month</td>
</tr>
<tr>
<td>Natural gas</td>
<td>$40/month</td>
<td>$25/month</td>
</tr>
<tr>
<td>Water</td>
<td>$50/month</td>
<td>$35/month</td>
</tr>
</tbody>
</table>
Multiple choice, True/False, and short answer questions to test knowledge

1. What is the main fuel we use to generate electricity in Alabama? (A) Solar power, (B) Oil, (C) Coal, (D) Nuclear
2. What is the main fuel we use for transportation in Alabama? (A) Oil, (B) Water power, (C) Solar, (D) Nuclear
3. What does sustainability mean? (A) To keep doing what we’re doing right now, (B) Using resources in a way that doesn’t hurt the next generation, (C) Using whatever we can to improve our lives today, (D) Drilling for more oil so that we don’t run out
4. Which of the following are examples of sustainable practices? (A) Recycling, (B) Walking or biking, (C) Riding the bus, (D) All of these
5. What are ways we can conserve energy? (A) Use less of it, (B) Walking or biking, (C) Make things more efficient, (D) All of the above
6. List 3 things you can do to use less energy at home.
7. Name something you can do at home to make it more energy efficient.
8. Which one of the following is not a renewable energy source? (A) Solar power, (B) Natural gas, (C) Wind power, (D) Water power
9. How much “Trash” does the average American produce in a day? (A) 0.4 pounds, (B) 40 pounds, (C) 4.0 pounds, (D) 400 pounds
10. Which of the following is not a “Water Pollutant?” (A) Rainwater, (B) Oil, (C) Fertilizer, (D) Dirt

Mark the following statements with True or False:

11. The city of Boston, MA sits on top of an old trash dump.
12. We can stop all forms of air pollution that is harmful to people and the environment.
13. Nature can produce air pollution that is harmful to people and the environment.
14. Rivers and lakes within the United States are clean and suitable for drinking.
15. The most difficult sources of water pollution to control in the environment come from industrial pipes.
16. A bus produces less pollution per passenger than a car.
17. Solar power by itself can power a car.
18. Kids can’t really do much to conserve energy because they don’t pay the bills.
19. Nuclear power pollutes the environment.
20. Compact florescent (CF) light bulbs use less energy than traditional bulbs.

22. A Contextual Approach to Teaching Sustainability

Concept maps for knowledge assessment

Students constructed concept maps on the focus question: “What is sustainability?” using CmapTools, a free concept mapping software. The number of concepts, highest hierarchy, and number of cross-links were used as indicators of knowledge breadth, depth, and connectedness, respectively. Word clouds were used for content analysis.
Self-report survey items to test attitudes/beliefs/interests

Students answered items on the Sustainable Personality Survey twice – once to describe their “real self” and again to describe their “ideal self.” Sample items are provided below, but the entire instrument was not published in this manuscript. Efforts to validate the instrument are mentioned.

1. I am a person who talks to my friends and family about the characteristics and qualities of our relationship.
2. I am a person who expresses myself with appropriate warm physical contact with friends.
3. I am a person who actively addresses health concerns.
4. I am a person who experiences physical discomfort caused by stress and anxiety.
5. I am a person who talks with others about issues that are important to our society.

23. Development and Application of a Sustainable Design Rubric to Evaluate Student Abilities to Incorporate Sustainability into Capstone Design Projects

Rubrics used to assess student design products

The following rubric was used to assess student capstone projects (excerpted from):

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Potential Points</th>
<th>Earned Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Design Criteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimizes natural resource depletion</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Prevents waste</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Protects natural ecosystems</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Uses renewable energy sources</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Uses inherently safe and benign materials (to environment)</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Social Design Criteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Addresses community and stakeholder requests</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Considers local circumstances and cultures</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Protects human health and well-being</td>
<td>3</td>
<td>0-3</td>
</tr>
<tr>
<td>Uses inherently safe and benign materials (to humans)</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Use of Sustainable Design Tools</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorporates life cycle analysis</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Incorporates environmental impact assessment tools</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Incorporates systems analysis</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Uses innovative technologies to achieve sustainability</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Economic Design Criteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consider economic impacts of promoting environmental sustainability</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Consider economic impacts of promoting social sustainability</td>
<td>1-3</td>
<td>0-3</td>
</tr>
<tr>
<td>Conduct a cost and/or cost-benefit analysis</td>
<td>2</td>
<td>0-3</td>
</tr>
</tbody>
</table>

*See Table 3 for potential and earned points rating scales. Values shown below were conventions used for the current investigation.
24. Applying Threshold Learning Theory to Teach Sustainable Business Practice in Post-Graduate Engineering Education

Self-report survey items to test knowledge, skills, and attitudes/beliefs/interests

Students were asked to use responses of “A lot,” “Quite a bit,” “A bit,” “Very little,” or “None” to rate their:

1. Exposure (to sustainability) in learning
2. Exposure (to sustainability) in the workplace
3. Confidence to apply (sustainability) in the workplace

Students were asked to use responses of “A lot,” “Quite a bit,” “A bit,” “Very little,” “None,” or “Unsure” to describe their perceptions of how the following (threshold) concepts affect(ed) them in the workplace:

1. Decoupling
2. Whole system
3. Resource productivity
4. Biomimicry
5. Sustainable business practice

25. Using a Sustainable Infrastructure Rating System in the Civil Engineering Capstone Design Course

Self-report survey items to test knowledge and skills

1. A technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (resource extraction through usage and disposal), is called: (A) an annual review, (B) a life cycle assessment, (C) an energy audit, (D) a thermal system analysis, (E) do not know
2. Define sustainability using one sentence.
3. Identify the rating system used to rate the sustainability of building design projects (circle all correct answers): (A) ESRB, (B) LEED, (C) Envision, (D) SUSTAIN
4. Identify the rating system used to rate the sustainability of non-building infrastructure design projects (circle all correct answers): (A) ESRB, (B) LEED, (C) Envision, (D) SUSTAIN
5. In which phase of a civil engineering project should sustainability be addressed? (A) pre-planning, (B) design, (C) construction, (D) all of the above, (E) none of the above
6. Define sustainable development using one sentence.
7. In one sentence, describe why natural hazards are a sustainability consideration of civil engineering projects?
8. Is climate change important for sustainability of civil engineering projects? If yes, describe in one sentence why climate change is a sustainability consideration of civil engineering projects?
9. The term “Triple-Bottom Line” refers to: (A) the balance of cash-flow, investments, and accounts payable, (B) the three pillars of people, planet and profit, (C) investments that have
a payback period less than 5 years, (D) extra emphasis on safety for civil engineering projects involving the public.

10. What are the sustainability tradeoffs associated with increasing the durability of a civil engineering project? (circle all that apply): (A) it may increase cost, (B) it may make a project less safe, (C) it may cause more environmental impacts, (D) all of the above.

11. What is the objective of life-cycle assessment? (A) monitor life-cycle of infrastructure, (B) guide experiments of infrastructure life-cycle environmental performance, (C) quantify infrastructure life-cycle environmental impacts, (D) determine infrastructure user attitudes.

12. Give an example of environmental justice consideration in a civil engineering project.


14. Give one example of a specific part of a civil engineering project that could earn Envision credits.

15. Which design elements would help achieve a Cradle to CradleTM outcome of a civil engineering project? (circle all that apply) (A) providing child care and universal living considerations, (B) specifying reuse of materials used in the project, (C) locating a nearby landfill to dispose of recyclable material used in the project, (D) seeking to ensure the protection of the safety of children and elderly.

16. Which of the following are principles of systems thinking? (A) it views the measured outcome within the larger, more complex system, (B) it addresses problems in a way that does not create new problems in the future, (C) it considers the impact of actions beyond environmental, economic and social to also include time and space, (D) it can be thought of as the three dimensional ripple effect of your actions where nearly everything is somehow interrelated and interconnected, (E) all of the above.

17. Considering systems thinking in the context of a roadway design project, what other interconnected systems should also be considered in the design? Give two specific examples.

18. Give one example each of how you would apply the economic, social, and environmental dimensions of sustainability to the design of a roadway project.

26. A Sustainability Toolbox for Engineers: Exploring how Students are Likely to Engage in Sustainability Education

Interviews and focus groups to test knowledge and attitudes/beliefs/interests

To engage the student(s) in the focus group or interview, the researcher first asked some icebreaking questions:

“In your <specify> class, identify a technology that is most interesting to you around which you have structured your <design, writing, or similar assignment>.”

From here the researcher asked follow-up questions focusing on the sustainability of the technology introduced by the student(s) in the first question:
1. “If you were working as an engineer in the field of this technology (including design, managing, manufacturing, etc.), what role would you take to promote sustainability?”
2. “If you were working as an engineer but NOT in this field, what would your role be in terms of <this technology’s> sustainability?”
3. “What does it mean for technology, in general, to be sustainable?”
4. “How do you believe technology can be most used or applied to support sustainability?”
5. “What do you believe are the most critical barriers to sustainability in the world today?”
6. “What do you believe are the most underestimated sustainability issues in the world today?”
7. “Now let’s think about an ideal world – if you were the CEO of the biggest company producing <this technology>, how would you address the issue of sustainability?”

27. Teaching Sustainability Analysis in Electronics Lecture Courses

Short answer questions to test knowledge

1. Write one or two definitions of sustainability.

   Scoring: 0 points if misses sustainability all together; 1 point for a vague definition related to sustainability; 2 points for a clear definition close to either the Brundtland definition, Euston and Gibson definition, McDonough & Braungart definition, or another accepted definition.

2. Select one EE 34x experiment and explain how it relates to sustainability issues.

   Scoring: 1 point for each connection to energy, economic, environmental, social and political equity, and ethics; 1 point for each connection to a law of ecology; 1 point for weaving in more than one EE34x experiment.

28. The Sustainable Building Field Trip – Real vs. Virtual

Self-report survey items to test knowledge and attitudes/beliefs/interests

Students used a four-point Likert scale (4 = Strongly agree, 3 = Agree, 2 = Disagree, 1 = Strongly disagree) to respond to the following items (only sample items provided):

1. This field trip increased my interest in learning more about sustainable construction.
2. I learned more information on sustainable construction than I knew before this trip.
3. Based on my field trip experience, I see that sustainable construction is achievable.
4. Having a field trip during class time made it easier for me to attend.
5. This field trip is appropriate to the level of Materials and Methods of Construction I course I am currently taking.
6. I would take an Architecture/Construction Management program course with this type of field trip instead of an Architecture/Construction Management program course with no field trip.
29. Integration of Sustainability in a Multidisciplinary Engineering Department\textsuperscript{18}

Self-report survey items to test knowledge

The validated \textit{Assessment of Sustainability Knowledge} instrument was used to test student knowledge (available at: \texttt{http://ess.osu.edu/research/assessment-sustainability-knowledge-ask}). Only a sample of this instrument is provided below.

1. What is the most common cause of pollution of streams and rivers? (A) Dumping of garbage by cities, (B) Surface water running off yards, city streets, paved lots, and farm fields, (C) Litter near streams and rivers, (D) Waste dumped by factories, (E) Don’t know
2. The wealthiest 20\% of people in the U.S. own approximately what percent of the nation’s privately held wealth? (A) 20\%, (B) 35\%, (C) 50\%, (D) 85\%, (E) Don’t know
3. Which of the following countries has now passed the U.S. as the biggest emitter of the greenhouse gas carbon dioxide? (A) China, (B) Sweden, (C) Brazil, (D) Japan, (E) Don’t know

Rubric used to assess student design products

Rubric used to grade sustainability portion of senior projects (excerpted from\textsuperscript{18}):

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>D</th>
<th>C</th>
<th>B</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not mentioned</td>
<td>Mentioned only as a part of another objective</td>
<td>Section includes a single sentence</td>
<td>Section consists of a single paragraph but is not integrated into the project</td>
<td>Section consists of one or more paragraphs. Sustainability aspects are documented and integrated within the project</td>
<td></td>
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