Advances in Engineering Education

SPRING 2017

A Rubric to Analyze Student Abilities to Engage in Sustainable Design

MARY KATHERINE WATSON
The Citadel, The Military College of South Carolina
Charleston, SC

ELISE BARRELLA
James Madison University
Harrisonburg, VA

THOMAS A. WALL
Georgia Institute of Technology
Atlanta, GA

CAROLINE NOYES
Georgia Institute of Technology
Atlanta, GA

AND

MICHAEL RODGERS
Georgia Institute of Technology
Atlanta, GA

ABSTRACT

As engineering programs have begun to infuse sustainability into their undergraduate curricula, assessment tools are needed to further inform these reform efforts. The goal of this project was to demonstrate the use of a new rubric to examine students' abilities to engage in sustainable design. The rubric includes 16 sustainable design criteria and rating scales to capture student performance and instructor/sponsor requirements. Three judges used the rubric to evaluate 40 capstone design projects completed between 2002 and 2011 by civil and environmental engineering seniors at a large, research intensive university. Results indicate that sustainable design performance in the capstone course changed little over 10 years, despite efforts to integrate sustainability into the curriculum. Students tended to address those criteria that were explicitly required of them by instructors or external project sponsors, which were related to social sustainability more than other sustainability dimensions. As a result, more explicit integration of sustainable design requirements into capstone courses may be needed to ensure that students understand the importance of, and are able to practice, developing designs in a sustainable manner.

Key words: Sustainable design, design rubric, civil engineering

INTRODUCTION

Design is a fundamental component of the engineering profession (Dym et al. 2005) and engineering education (Crismond and Adams 2012). In fact, design is often thought of as "what engineers do" (Dym et al. 2005, p. 104). Many definitions of engineering design have been presented. For instance, Skerlos, Morrow, & Michalek describe it as "a creative decision-making process that aims to find an optimal balance of trade-offs in the production of an artifact that best satisfies customer and other stakeholder preferences" (2006, p. 468). Dym et al. characterize design as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" (2005, p. 104). These definitions highlight the need for engineers to simultaneously understand and accommodate numerous constraints and objectives, a skill that is essential to the practice of sustainable engineering.

Sustainable Engineering Design

Due to alarming global trends (e.g., rising resource consumption and environmental degradation), there have been calls for engineers to take a more sustainable approach to the design process (Bhamra and Lofthouse 2007, Wallace 2005, Thomas 2012, Mueller Price et al. 2012). After all, it is engineers who are responsible for the design phase of projects when critical decisions related to sustainability are made, such as "cost, appearance, materials selection, innovation, performance, environmental impact, and perceptions of quality" (Bhamra and Lofthouse 2007, pg. 37). Sustainable engineering has emerged as a new field aimed at integrating and balancing economic, environmental, and social systems during development (Mihelcic et. al. 2003); yet, there is a need for practitioners from all engineering disciplines to promote sustainability through sustainable design (Clough 2004).

Sustainable design is not an alternative to traditional design; rather, it requires the designer to adapt a more holistic perspective of the design objectives and constraints. For instance, beyond just trying to satisfy end users or clients, sustainable engineers are working more broadly to create projects that strive to improve (or at least not harm) the environment, the economy and society (e.g., Mihelcic et al. 2003). Indeed, Skerlos et.al. (2006) state that sustainable design "brings focus" to the design process, while McLennan (2004) describes that it "expand[s] the definition of good design to include a wider set of issues." Overall, it is critical that design engineers recognize the broader impacts of their projects, rather than focusing narrowly on the preferences of influential stakeholders.

Sustainable Engineering Education

Because engineers are increasingly called upon to develop sustainable solutions, it has become imperative for engineering educators to equip students with the knowledge and skills to engage in sustainable design (Bauer et al. 2012, MacRae 2011, Mueller Price et al. 2012, Stasinopoulos 2009, Thomas 2012). Current curricula in higher education tend to emphasize disciplinary specialization and reductionist thinking (Lozano 2010, Cortese 2003, Seager, Selinger, and Wiek 2012). As a result, many students are "unbalanced, over-specialized, and mono-disciplinary graduates" who use their specific skill sets to solve problems by analyzing system components in isolation (Lozano 2010, p. 637). In contrast, the complex nature of global and local dilemmas necessitates that sustainable engineers exercise interdisciplinary and systems thinking to understand and balance the interrelated technical, economic, environmental, and social dimensions of a problem (Davidson et al. 2007). For instance, alleviation of global problems of resource scarcity and environmental degradation in the context of a growing population requires a broad knowledge base and the ability to analyze problems holistically (Davidson et al. 2007). Recognizing the potential benefits of sustainable engineering, many organizations, including the Accreditation Board for Engineering and Technology (ABET), the American Association of Engineering Societies (AAES), and the American Society of Civil Engineers (ASCE) advocate for curricular reforms (Thompson 2002, Kelly 2008, ASCE 2015a). However, many have proposed that more aggressive efforts are needed for higher education to be a substantial force in furthering sustainable development (Lozano et al. 2013).

Successful educational reform efforts first require effective methods for assessing student abilities to engage in sustainable design. Some work has been done to analyze the conceptual sustainability knowledge of engineering students using surveys (e.g., Kagawa 2007, Watson, Noyes, and Rodgers 2013) and concept maps (e.g., Watson et al. 2014, Segalàs, Ferrer-Balas, and Mulder 2010). While it is critical to ensure that students grasp the complexity of sustainability topics, it is especially important for engineering students to be able to apply this knowledge in the design process. Unfortunately, there has been little discussion in the literature on how to assess students' sustainable design abilities. More generally, rubrics have been used extensively to examine students' design abilities in engineering. Consequently, a sustainable design rubric may prove to be a useful tool for capturing students' sustainable design abilities.

Project Scope

The goal of this paper is to demonstrate the use of a new sustainable design rubric that was developed specifically to examine the abilities of undergraduates to engage in sustainable design. The context for this demonstration is a civil and environmental engineering (CEE) capstone design course at the Georgia Institute of Technology (Georgia Tech). Capstone design projects, which differed based on the project type (e.g., bridge, roadway, etc.) and industry sponsor, were analyzed by judges using the rubric. Results of the rubric's application were used to address the following questions about the CEE program at Georgia Tech: (1) Which aspects of sustainable design are encouraged by instructors and project sponsors? (2) Which aspects of sustainable design are evident in student capstone projects? (3) To what extent do student teams meet sustainable design expectations? (4) To what extent have sustainable design expectations and student performance changed over time? While these findings are especially important for CEE at Georgia Tech, implications for broad application of the rubric in other programs and universities will also be presented.

THE SUSTAINABLE DESIGN RUBRIC

A sustainable design rubric was developed to quantify students' abilities to incorporate sustainability into design projects. In developing the rubric, one goal was to produce a tool that could be easily applied to a variety of CEE-related student projects. Because of the structure of many capstone design courses, the rubric needed to capture the extent to which students engage in sustainable design, as well as the influence of project sponsors and/or course instructors on sustainable design expectations. Development of this tool, which was completed using a four-phase process, will be described only briefly, since details have been previously discussed (Watson et al. 2013).

Phase 1: Researching Existing Sustainability Evaluation Frameworks

First, existing frameworks for evaluating sustainability content of design projects were investigated (Watson et al. 2013). Leadership in Energy and Environmental Design (LEED) and Envision™, published by the Institute for Sustainable Infrastructure, were deemed inappropriate due to their narrow scope (e.g., application only to building infrastructure for LEED) and/or complexity for student-level projects). However, the Nine Principles of Sustainable Engineering (Table 1) were identified as a potential foundation for developing sustainable design criteria. In addition to being applicable to a range of CEE capstone projects, the Nine Principles are also relevant for other engineering disciplines. Second, project evaluation criteria based on expert-derived sustainability principles is advantageous because it helps promote content validity of the assessment tool. Thus, the Nine Principles were identified as a more suitable framework for evaluating student design projects than existing resources for large-scale projects.

Table 1. Nine Principles of Sustainable Engineering (from Abraham 2006).

No.	Sustainability Engineering Principle
1.	Engineer processes and products holistically using system analysis.
2.	Conserve and improve natural ecosystems while protecting human health and well-being.
3.	Use life cycle thinking in all engineering activities.
4.	Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5.	Minimize depletion of natural resources.
6.	Strive to prevent waste.
7.	Develop and apply engineering solutions, while considering local circumstances and cultures.
8.	Create engineering solutions beyond current or dominant technologies.
9.	Actively engage communities and stakeholders in development of engineering solutions.

Phase 2: Developing a Preliminary Project Evaluation Rubric

During Phase 2, a preliminary sustainable design rubric was developed based on the Nine Principles of Sustainable Engineering and the basic components of an analytical rubric, as suggested by Allen & Tanner (2006). Since many of the Nine Principles are complex and incorporate multiple ideas, each principle was decomposed into discrete design criteria for ease of rubric application. Since the economic dimension of sustainability is not explicitly represented by the Nine Principles, the set of 13 criteria was supplemented with three economic design criteria. As a result, a system of 16 sustainable design criteria was established to judge the sustainability content of student capstone projects (Table 2).

To aid judges in identifying application of criteria in project reports, a set of examples for how the 16 criteria may be met in CEE student projects was compiled (Table 3). This phase was essential for elucidating what each criterion "looks like" in student projects, as cited by Allen & Tanner (2006, pg. 198). Examples were gathered from CEE capstone projects not used in the current study, including those from Fall 2001, 2004, 2007, and 2010 semesters. As a result, a comprehensive list of sustainable design examples is available to supplement the rubric (see Watson 2013 for a comprehensive list).

Two four-point rating scales were created to aid evaluators in judging capstone reports based on the 16 sustainable design criteria (Table 4). The earned points scale captures the extent to which students consider each sustainable design criterion in their capstone projects. Evaluators assign a score of "0" to projects that show no evidence of incorporating the design criterion, while a score of "3" is assigned if the project shows extensive evidence of criterion application.

The potential points scale describes the extent to which each sustainable design criterion is applicable to a given capstone project. Evaluators assign a score of "0" if the criterion is not applicable

Table 2. Sample scoring rubric, including the 16 sustainable design criteria, used to evaluate capstone design projects.

Design Criteria	Potential Points[a]	Earned Points[a]
Environmental Design Criteria		
1. Minimizes natural resource depletion.	1-3	0-3
2. Prevents waste.	1-3	0-3
3. Protects natural ecosystems.	1-3	0-3
4. Uses renewable energy sources.	1-3	0-3
5. Uses inherently safe and benign materials (to environment).	1-3	0-3
Social Design Criteria		
6. Addresses community and stakeholder requests.	1-3	0-3
7. Considers local circumstances and cultures.	1-3	0-3
8. Protects human health and well-being.	1-3	3
9. Uses inherently safe and benign materials (to humans).	1-3	0-3
Sustainable Design Tools		
10. Incorporates life cycle analysis.	1-3	0-3
11. Incorporates environmental impact assessment tools.	1-3	0-3
12. Incorporates systems analysis.	1-3	0-3
13. Uses innovative technologies to achieve sustainability.	1-3	0-3
Economic Design Criteria		
14. Considers economic impacts of applying environmental design criteria.	1-3	0-3
15. Considers economic impacts of applying social design criteria.	1-3	0-3
16. Conducts a cost and/or cost-benefit analysis.	1-3	2

[a]See Table 4 for potential and earned points rating scales, which both range from “0” to “3”. Values shown above summarize scoring conventions used for this investigation.

to the project. A score of “3” is assigned if the criterion is applicable, as well as required by an instructor or project sponsor. Rating projects on both the extent of consideration and level of applicability allows for differentiation between sustainability application due to student motivation and external requests.

Several metrics were designated to evaluate and compare rubric scores. Raw scores for each criterion (i), including earned (E_i) and potential (P_i) points, were used to provide insights into the extent of criterion consideration and level of criterion applicability, respectively. The final sustainable design index (SD_{score}) was quantified as the difference between mean potential (M_{pot}) and mean earned (M_{earn}) scores. As a result, a sustainable design index of +3 represents a project with high sustainable design expectations and low student performance. Conversely, an index of –3 is characteristic of a project with low sustainable design requirements and high student performance. A sustainable design index near zero represents a project that largely

Table 3. Example applications of sustainable design criteria in capstone design projects.

Sustainable Design Criteria	Description/Example
Environmental	
Minimizes natural resource depletion	Promoting use of non-fossil-fuel-based transportation (e.g., providing bike racks).
Prevents waste	Providing opportunities for users of a project to recycle.
Protects natural ecosystems	Using vegetation to preserve water quality (e.g., green spaces, stream buffers, etc.).
Uses inherently safe materials (to env.)	Using certified environmentally-safe materials.
Uses renewable energy sources	Providing preferred parking for alternative fuel vehicles.
Social	
Addresses community requests	Avoiding routing traffic through residential areas.
Considers local circumstances/cultures	Designing projects to blend in with the aesthetic qualities of the community.
Protects human health/well-being	Addressing driver expectancy issues (e.g., with appropriate signs).
Uses safe materials (to humans)	Using low or non-toxic materials (e.g., non-carcinogens, non-irritants).
Sustainable Design Tools	
Incorporates life cycle analysis	Considering impacts of project over its lifecycle, rather than just its useful life.
Incorporates EIA tools	Completing preliminary steps of an assessment.
Incorporates systems analysis	Considering project impacts (econ, env, social) within/outside of system boundaries.
Uses innovative technologies	Designing for LEED certification.
Economic	
Considers economic impacts of meeting environmental design criteria	Creating a profit while enacting an environmental sustainability principle (e.g., charging extra for residential units located near green space).
Considers economic impacts of meeting social design criteria	Creating a profit from enacting a social sustainability principle (e.g., adding commercial space near residential areas to increase property values).
Conducts a cost and/or cost-benefit analysis	Using engineering economics to estimate project costs or complete a cost-benefit analysis.

Table 4. Rating scale for extent of consideration of sustainable design criteria (earned points) and the level of applicability of sustainable design criteria (potential points).

Earned Score	Descriptor	Dimension Description
0	Unacceptable	Criterion not at all considered in project report.
1	Developing	Criterion mentioned or discussed in the project report, but not applied in design process.
2	Competent	Project report shows evidence that the criterion was adequately applied in design process (1-2 instances of criterion application).
3	Exemplary	Project report shows evidence that the criterion was extensively applied in the design process (3 or more instances of criterion application).
Potential Score	**Descriptor**	**Dimension Description**
0	Inapplicable	The criterion is not at all valid for the project.
1	Valid	Although the sponsor does not require application of the criterion, it is still applicable to the project.
2	Required	The sponsor requires some application of the criterion in the project (1-2 instances of requiring criterion application).
3	Critical	The sponsor requires extensive application of the criterion in the project (3 or more instances of requiring criterion application).

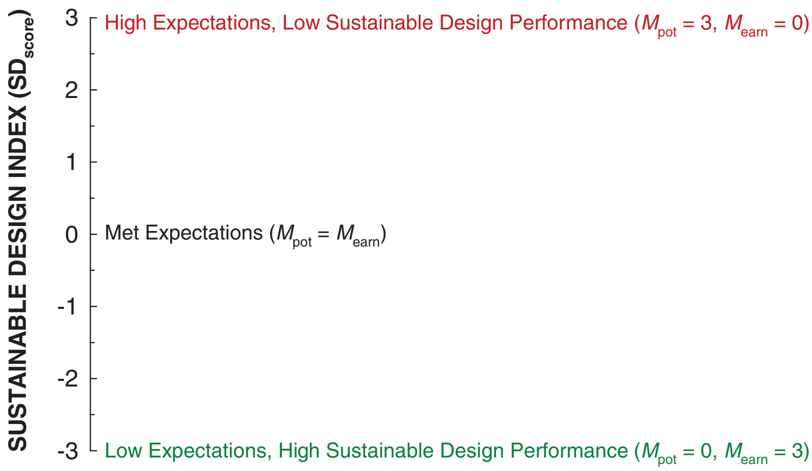


Figure 1. Scale for sustainable design index ($SD_{score} = M_{pot} - M_{earn}$).

meets sustainable design expectations (Figure 1), regardless of whether those expectations were high or low.

Phase 3: Validation of Sustainable Design Rubric

Content validity of the rubric was established through assessment by an experienced panel, which is a method that has been endorsed by other researchers (Davis 1992, Wood and Ross-Kerr 2010, Schayot 2008). Graduate student panelists included two civil engineering students and one aerospace engineering student. At the time of review, each panelist was conducting research broadly associated with sustainability. Faculty panelists consisted of two CEE faculty who had experience facilitating capstone design, as well as an educational psychologist. Each panelist reviewed the sustainable design rubric and provided qualitative feedback (see Watson et al. 2013). Suggestions, especially related to classification of sustainable design examples, were incorporated into the final rubric.

RESEARCH METHODS

The sustainable design rubric was used to examine student abilities to engage in sustainable design in CEE at Georgia Tech. A systematic process was used to train judges, score projects, and analyze the resulting data.

Case Study Context

The Georgia Tech CEE Department early recognized the importance of training students to understand and apply sustainability concepts, with efforts to incorporate sustainability into the undergraduate curriculum pre-dating the 2004-2005 mandates by the Accreditation Board for Engineering and Technology (ABET). For instance, as of 1999, all undergraduates are required to complete a civil engineering systems course, intended to introduce students to sustainability issues (Meyer and Jacobs 2000, Amekudzi and Meyer 2004). Also, an elective specifically focused on sustainable engineering is available to students particularly interested in sustainability (Watson et al. 2013). In addition to these two sustainability-focused courses, CEE faculty at Georgia Tech indicated in a 2008 Self-Study Report prepared for ABET that 15 of the 37 courses offered annually provide a "high" contribution to sustainability education (Watson et al. 2013). The findings in the Self-Study Report are based on instructors' own reflections and are not objective assessments of the breadth or depth of sustainability content. More details on the CEE curriculum at Georgia Tech are available (Watson et al. 2013).

After completing pertinent coursework, CEE seniors have an opportunity to apply their knowledge and skills, including those related to sustainability, to a real-world design project in a capstone design class. First, students form "companies" by self-organizing into groups of 4-5 students. Students may form specialized companies by joining with students from similar specializations (construction, environmental, geotechnical, structures, transportation, or water resources), or create a general civil engineering firm by including students from multiple specializations. Student companies are then allowed to select capstone projects from a variety of authentic projects provided by design firms, industries, and government agencies. Groups work closely with both instructors and external sponsors to complete their chosen design project.

Project Scoring

For this study, training of judges and scoring of capstone design reports was completed as outlined in a previous work (Watson et al. 2013). As judges practiced scoring projects, several scoring conventions were followed. For "protects human health and well-being," judges gave a default potential score of "3," due to ethical requirements set by the American Society for Civil Engineers (ASCE 2015b). Similarly, judges awarded a standard potential score of "2" for "conducts a cost and/or cost-benefit analysis," since student groups were required to complete an economic analysis as part of a course requirement. In the event that no evidence was found to suggest that the group was required to meet a criterion and no special scoring consideration was applied, judges were directed to give potential scores of "1" for all criteria, since they are broadly applicable to all CEE projects (Watson et al. 2013).

The trained judges scored a sample of 40 CEE capstone design projects using the sustainable design rubric. All projects (of various types) completed during the Fall 2002 (n = 7), 2006 (n = 9), and 2011 (n = 14) semesters were analyzed. In addition, all multi-use trail projects completed between 2004 and 2011 were examined as a unique case (n = 11). The project type and sponsor remained constant over time for multi-use trail projects, which provided an opportunity to evaluate changes in sustainable design scores due to improved student abilities or motivation, rather than changes in the sustainable design potential or expectations.

Since projects were being analyzed retrospectively, potential scores were assigned by the judges based only on content in the final design reports, including the required project scope and design requirements. While consensus building with the external project sponsors would have provided a more complete evaluation of sustainable design expectations, this was not possible for a historical analysis of projects completed up to twelve years prior to this investigation.

The lead judge scored each project, while remaining judges each scored half of the projects. As a result, each project was reviewed by two different judges. Individual scores were recorded and any discrepancies were discussed to reach a set of consensus scores, as per Besterfield-Sacre et al. (2004). Thus, for each project, data included judges' individual potential and earned points scores for each criterion, as well as consensus scores for each criterion.

Statistical Analysis of Project Scores

Interrater reliability was quantified using Krippendorff's alpha based on judges' individual scores. Krippendorff's alpha was selected because it can be applied to all levels of measurement and any number of judges. For potential and earned scores, Krippendorff's alpha values were 0.80 and 0.73, respectively. Krippendorff's alpha values were within ranges either deemed acceptable ($\alpha \geq 0.80$) or acceptable for exploratory research ($\alpha \geq 0.67$) (Krippendorff 2003).

Judge's consensus scores were used for all subsequent statistical analyses. To provide insight into areas of student design proficiency and deficiency, IBM SPSS 22 was employed to conduct paired-samples t-tests to compare mean potential and earned points for each of the 16 sustainable design criteria. Differences in scores over time were detected using regression analyses. A level of significance of 0.05 was used for all hypothesis testing.

RESULTS

Trends in sustainable design scores over time were investigated, as well as relationships between project sponsor requirements (potential scores) and student application of design criteria (earned scores).

Historical Trends in Sustainable Design Scores

Capstone design projects completed by students during Fall 2002, 2006, and 2011 were examined to identify any significant changes in sustainable design application over time. In addition, student projects focused on different sections of a multi-use trail were examined as a unique case. Students working on multi-use trail projects were subject to many of the same project specifications and constraints, since the sponsor and project location remained relatively constant. As a result, any changes in rubric scores could possibly be tied to increases in student abilities to engage in sustainable design.

Overall Sustainable Design Indexes

Trends in overall sustainable design indexes remained fairly constant over time (Figure 2A). Although the sustainable design indexes for projects completed between 2002 and 2011 ranged between –0.1 and 0.9, the year in which projects were completed did not account for a significant amount of the variance in scores [$R^2 = 0.002$, $F(1, 28) = 0.06$, $p = 0.803$]. Similarly, sustainable

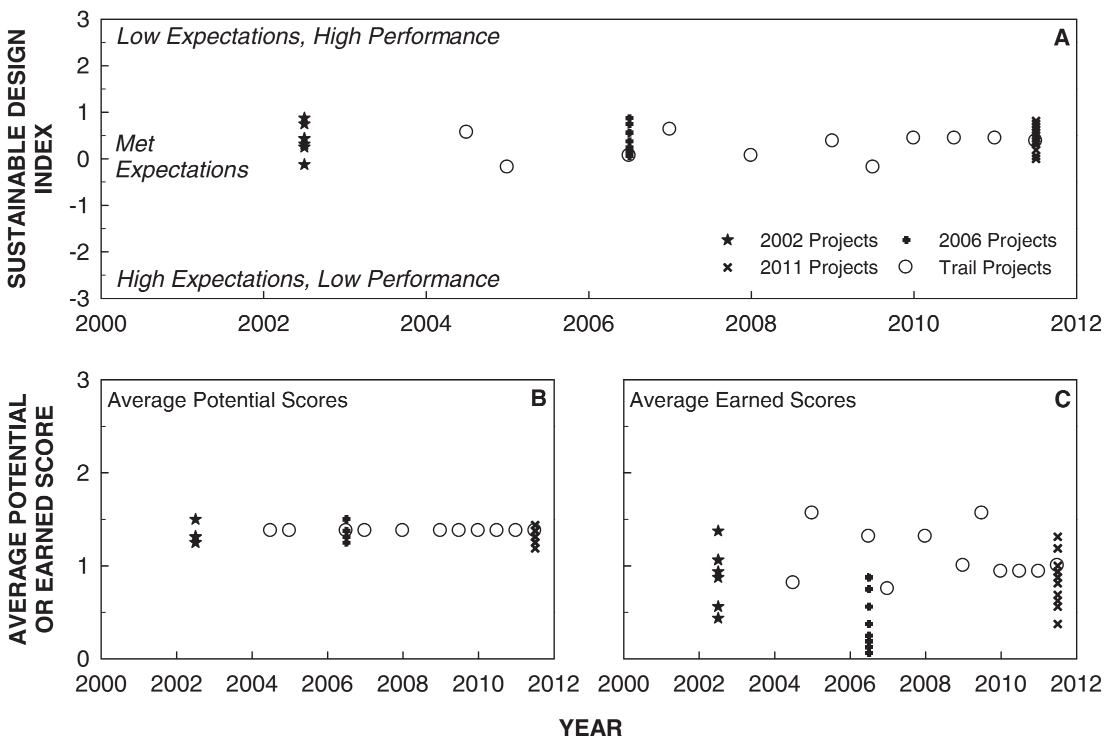


Figure 2. (A) Sustainable design indexes, (B) average potential scores, and (C) average earned scores for multi-use trail and general projects.

design indexes for multi-use trail projects ranged between –0.2 and 0.6, although the year in which projects were completed did not account for a significant amount of the variance in scores [R^2 = 0.04, $F(1, 9) = 0.36$, $p = 0.562$].

Potential Scores

Trends in potential scores remained fairly constant over time (Figure 2B). Although potential scores for projects completed between 2002 and 2011 ranged between 1.2 and 1.5, the year in which projects were completed did not account for a significant amount of the variance in scores ($p > 0.05$). Upon evaluating several multi-use trail project reports, judges agreed that the expectations of the common project sponsor did not change significantly over time. Due to this scoring convention, average potential scores for multi-use trail projects also remained constant between 2004 and 2011.

Earned Scores

Unlike potential scores, some differences in average earned scores, which capture the extent of student engagement in sustainable design, were observed over time (Figure 2C). In fact, earned scores for the criterion "considers economic impacts of environmental criteria" significantly decreased over time for all projects [$\beta = -0.400$, $t = -2.311$, $p = 0.028$], as well as for multi-use trail projects [$\beta = -0.682$, $t = -2.795$, $p = 0.021$]. However, earned scores for "conducting a cost and/or cost-benefit analysis" substantially increased with time for all projects [$\beta = 0.450$, $t = 2.669$, $p = 0.013$], while there was no significant change for multi-use trail projects ($p > 0.05$).

Overall Trends in Sustainable Design Scores (Fall 2002, 2006, 2011 Projects)

Given the few changes in scores over time, data for all years was compiled to study overall sustainable design expectations and student performance.

Sustainable Design Expectations (Potential Points)

Potential points were analyzed to capture the extent to which sustainable design criteria could reasonably have been applied in student projects, given instructor/sponsor requests (Table 2). The mean potential score for all 16 sustainable design criteria was 1.3, with 75, 18, and 7% of all potential points classified as "valid," "required," or "critical" for the projects, respectively (Table 4). Several trends were also noted for each of the four rubric dimensions.

Students were required to consider social aspects of sustainable design as defined by the rubric, at least more extensively than other dimensions (Figure 3B). The mean potential score for all social criteria was 1.8 out of a possible 3.0 points. More specifically, as designated by the scoring convention, all projects required students to "protect human health and well-being" ($M = 3.0$). In addition, 83% of project sponsors required students to "address community and stakeholder requests"

($M = 1.9$) at least to some extent during the design process. Despite the emphasis on safety and incorporating stakeholders, no sponsors explicitly requested students to "use inherently safe materials."

Economic ($M = 1.3$), environmental ($M = 1.2$), and sustainable design tools ($M = 1.1$) considerations were under-emphasized by project sponsors (Figure 3). Related to economic sustainability, all students were required to "conduct a cost and/or cost-benefit analysis" ($M = 2.0$) as part of the course requirement. In the environmental dimension, 50% of sponsors made requests that required students to "protect natural ecosystems" ($M = 1.5$), while 20% required students to "minimize natural resource depletion" ($M = 1.2$). For sustainable design tools, 23% of sponsors suggested that students "incorporate systems analysis" ($M = 1.2$).

Student Application of Sustainable Design Criteria (Earned Points)

Earned points were analyzed to describe the extent to which students actually addressed sustainable design criteria, regardless of instructor/sponsor expectations (Figure 3). The mean earned score was 1.0 out of a maximum of 3.0 points. Overall, students considered criteria across all four rubric dimensions, with 51, 17, 21, and 11% of sustainable design attempts being "unacceptable", "developing", "competent", or "exemplary", respectively (Table 4).

Although still room for improvement, students emphasized social criteria more than other dimensions (Figure 3B). Specifically, the mean earned score for all social criteria was 1.5 out of a maximum of 3.0 points. Nearly all groups "considered human health and well-being" ($M = 2.7$), while 87% also "addressed community and stakeholder requests" ($M = 2.2$). Only 33% of groups "considered local circumstances and cultures" ($M = 0.9$). Thus, social sustainability was considered, at least to some extent, in student projects.

Economic ($M = 1.0$), environmental ($M = 0.6$), and sustainable design tools ($M = 0.7$) considerations were under-emphasized by students (Figure 3). Related to economic sustainability, 87% of teams "conducted a cost and/or cost benefit analysis" ($M = 1.4$). In the environmental dimension, 77% of groups showed evidence of "protecting natural ecosystems" ($M = 1.7$), while 47% of teams "minimized natural resource depletion" ($M = 0.7$). For sustainable design tools, 80% of groups "incorporated systems analysis" ($M = 1.3$).

Comparing Project Potential and Student Actions (Potential versus Earned Points)

Sustainable design scores indicated that students fell just short of meeting overall sustainable design expectations and could have further incorporated sustainability into their projects (Figure 3). Specifically, the mean sustainable design index ($SD_{score} = M_{pot} - M_{earn}$) was 0.41 on a scale from –3.0 to 3.0, which suggests that student performance (earned scores) were just below design expectations (potential scores) (Figure 1). Indeed, when comparing the averages for all design criteria, the mean earned score ($M = 0.9$) was significantly lower ($p \leq 0.001$) than

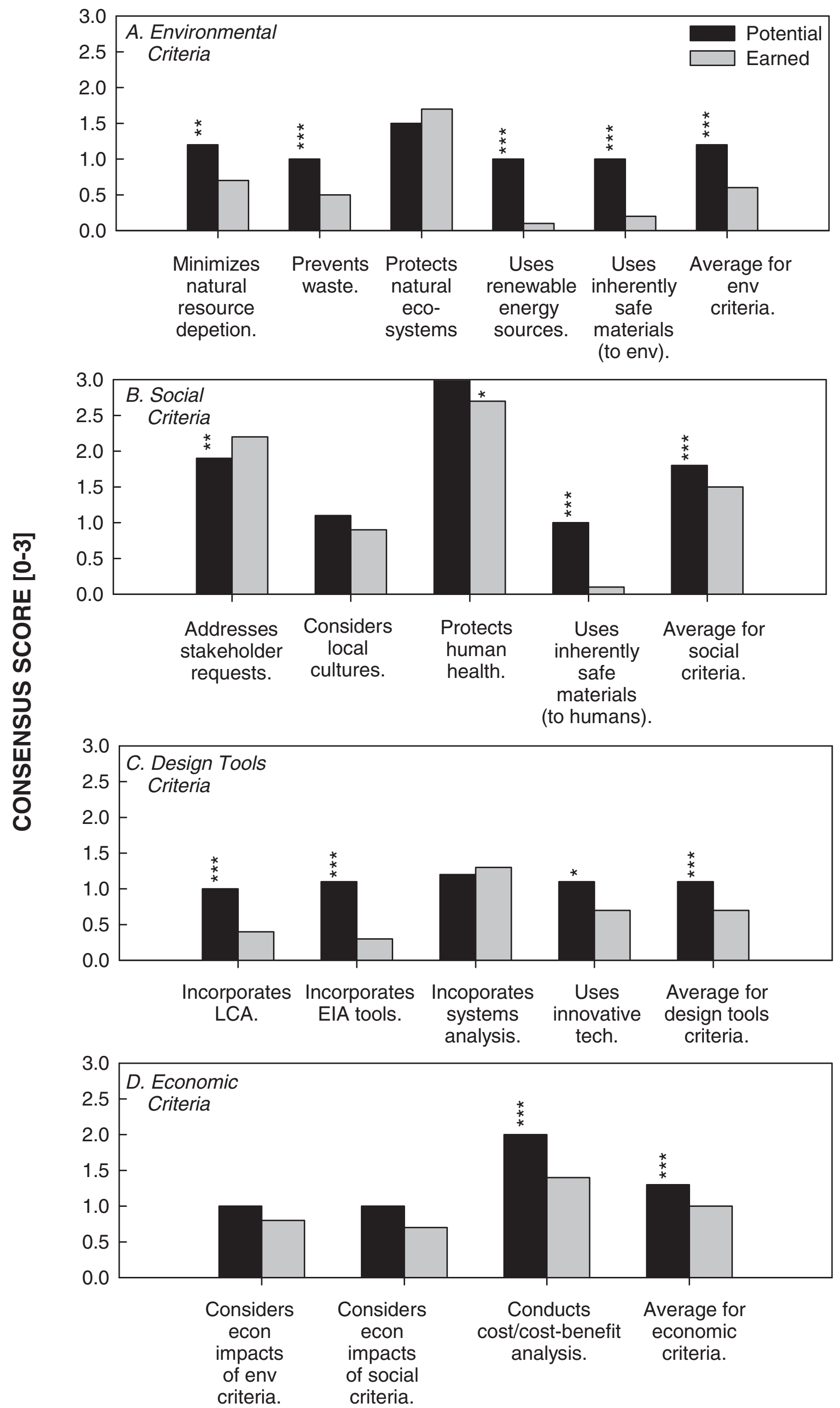


Figure 3. Mean consensus potential and earned scores for (A) environmental, (B) social, (C) design tools, and (D) economic design criteria (*p < 0.05; **p < 0.01, ***p < 0.001).

the mean potential score (M = 1.3). This indicates that students could have further improved the sustainability of their designs.

Earned means were statistically ($p < 0.05$) lower than potential means for 11 of the 16 criteria across all four of the rubric categories (Figure 3). Among those criteria with the greatest deficiencies in the environmental category were “uses renewable energy sources” and “uses inherently safe materials (for environment).” Similarly, a large difference between potential and earned scores for “uses inherently safe materials (for humans)” was shown in the social dimension. Related to use of sustainable design tools and economic sustainability, deficiencies for “incorporates environmental impact assessment tools” and “conducts a cost and/or cost-benefit analysis” were also observed, respectively.

Students met or exceeded sustainable design expectations for some criteria. Notably, no statistical differences between potential and earned scores were demonstrated for “protects natural ecosystems,” “considers local circumstances and cultures,” “incorporates systems analysis,” and “considers economic impacts of environmental/social criteria” ($p > 0.05$). In addition, students exceeded expectations for “addresses community and stakeholder requests,” since mean earned scores were significantly higher than mean potential scores ($p \leq 0.01$). Despite the many deficiencies in student reports, evidence of exceptional work related to some sustainable design criteria was demonstrated.

DISCUSSION

Based on the outlined results, several key research questions were addressed. Importance of findings, both to Georgia Tech and the broader engineering education community are discussed below.

Which Aspects of Sustainable Design are Encouraged by Instructors and Project Sponsors?

Expectations for students to engage in sustainable design during capstone design were somewhat limited. In fact, 5 out of 16 design criteria from across all four rubric categories were neither directly nor indirectly requested by any project sponsor. However, instructor and/or sponsor requirements did prompt students to consider some sustainable design criteria, most commonly to “protect human health and well-being,” “conduct a cost and/or cost-benefit analysis,” “address community and stakeholder requests,” and “protect natural ecosystems.” Consequently, the highest scoring criteria were balanced, with at least one criterion from each the economic, environmental, and social rubric categories being represented. This is in accordance with Lozano (2008) that supports a holistic perspective of sustainability with balance among relevant dimensions.

Although there is still room for improvement, potential scores were the highest for criteria from the social dimension, as compared to other dimensions. In part, the potential score for the social dimension was elevated by the judges' decision to award a potential score of 3.0 for "protects human health and well-being," due to the ethical requirement for civil and environmental engineers to ensure safety during the design process (ASCE 2015b). Even so, "addresses community and stakeholder requests" also received a relatively high potential score and was specified by 83% of sponsors, even though it was not classified as fundamental to all CEE projects. This contradicts numerous reports that stakeholders, including professionals (Wright and Wilton 2012), over-emphasize the environmental aspects of sustainability. Perhaps civil and environmental engineers, because of their duties to develop infrastructure on behalf of society, are inherently more likely to address some aspects of social sustainability than other professionals.

Which Aspects of Sustainable Design are Evident in Student Capstone Projects?

Five sustainable design criteria were substantially addressed across many student projects. Specifically, "protect human health and well-being," " address community and stakeholder requests," "conduct a cost and/or cost-benefit analysis," "incorporate systems analysis," and "protect natural ecosystems" received the highest earned scores. Demonstration of systems thinking, in particular, may have been prevalent in student projects due to earlier completion of a mandatory civil engineering systems course (Amekudzi and Meyer 2004, Meyer and Jacobs 2000). Student incorporation of sustainability into their projects was also balanced, with at least one criterion from each of the four rubric categories being represented among the five criteria with the highest earned scores.

When further examining earned scores, it became evident that students had more deficiencies in applying the economic and environmental dimensions than the social dimension. Students frequently "protected human health and well-being" and "addressed community and stakeholder requests," while almost half of groups "considered local circumstances and cultures," at least to some extent. It is important to note, however, that students could have received points for "addressing community and stakeholder requests" if they accounted for the sponsor's needs that were presumably, but not necessarily, representative of the larger community's needs. Future implementations of the rubric may seek to differentiate between meeting sponsor needs and broader community needs, although it may be difficult for a student group to fully assess the latter over the course of a one- or two-semester class.

Nevertheless, somewhat high earned scores for social criteria may contradict reports by previous authors. Specifically, social sustainability is considered to be the least emphasized dimension (Salzmann, Ionescu-Somers, and Steger 2005), especially within civil engineering education (Velazquez, Munguia, and Sanchez 2005). When examining the conceptual understanding of sustainability among undergraduates, using tools such as surveys and concept maps, social sustainability is usually the least understood for undergraduates world-wide (e.g.,Segalàs, Ferrer-Balas, and Mulder 2010, Kagawa 2007), including CEE students at Georgia Tech (Watson, Noyes, and Rodgers 2013b, Barrella and Watson 2015). However, when examining student designs in the current study, social sustainability was most evident in design reports, as compared to economic and environmental sustainability. The discrepancy between students' conceptual knowledge and their design performance may stem from the fact that they do not closely associate social topics with sustainability (Watson, Noyes, and Rodgers 2013b). In a sense, they do know something about social sustainability (as evidenced in their projects), but they do not know that they know about the topic (as evidenced by knowledge surveys). In addition, student designs likely reflected several aspects of social sustainability due to the explicit requirements set forth by instructors and project sponsors. As previously stated, many sponsor requirements may have been socially-oriented due to the ethical responsibility (ASCE 2015b) of civil engineers to protect the public.

To What Extent do Student Teams Meet Sustainable Design Expectations?

While sustainable design indexes for Fall 2002, 2006, and 2011 projects suggest that overall sustainable design expectations were nearly met (scores close to zero), examining criteria individually reveals that students performed better in some aspects of sustainable design than others. For instance, mean earned scores were higher than average potential scores for "addresses community and stakeholder requests." Thus, student performance may have been acceptable, especially for select criteria, given the sustainable design expectations posed by sponsors/instructors.

Interestingly, student performance was largely aligned with instructor and/or sponsor requests. First, many of the criteria with the highest potential scores were also awarded the most earned points. In fact, "protects human health and well-being," "addresses community and stakeholder requests," and "protects natural ecosystems," which were among the few to have potential scores of over 1.5, were perhaps not coincidentally the only criteria with earned scores of at least 1.5. Conversely, those criteria with potential scores of 1.0 also received earned scores of less than 1.0. Given the alignment of potential and earned scores, it is possible that increasing sustainable design expectations would prompt students to further incorporate sustainability into the design process.

To What Extent have Sustainable Design Expectations and Student Performance Changed Over Time?

Few trends in sustainable design scores over time were observed, regardless of project type. Although potential scores for multi-use trail projects were not expected to change due to influence from the same sponsor for each project, potential scores for general capstone projects completed during Fall 2002, 2006, and 2011 did not change significantly over time either. Similarly, almost no changes in sustainable design scores were detected over time, with the exception for some of the economic design criteria. Most promising was evidence showing the tendency for students to more holistically consider the costs and benefits (monetary and non-monetary) of the projects, rather than completing simple cost analyses. Given that potential scores did not change for this criterion, it is likely that the increase in earned scores is attributed to actual increases in student abilities.

Implications for Sustainability Education in CEE at Georgia Tech

Based on evaluation of student projects using the sustainable design rubric, it is evident that efforts are needed to better equip and encourage students to more extensively incorporate sustainability into the design process. In fact, scoring of student reports indicated that application of only about 13% of all sustainable design criteria were rated as at least "competent" with earned scores of 2.0 or higher (Figure 3).

While CEE instructors at Georgia Tech have sought to incorporate sustainability into their classes (2008, Watson, Noyes, and Rodgers 2013), efforts did not translate into improved student design capabilities, given that mean earned scores positively increased over time for only 1 of the 12 sustainable design criteria. It is possible that faculty perceive their courses as covering content that relates to sustainability, but they may not explicitly make those connections for their students. In addition, instructor efforts to address sustainability were not coordinated over the time period investigated. As a result, it is possible that courses were addressing the same aspects of sustainability (e.g., the three pillars), which would not serve to improve the breadth or depth of student knowledge. Even still, efforts in previous classes may have improved students' conceptual understanding of sustainability, while not improving sustainable design skills and application to real projects.

As a result, new and innovative approaches to teaching sustainability are needed. For instance, Segalàs et al. (2010) demonstrated that collaborative and experiential pedagogies are especially effective at encouraging student learning about sustainability concepts. In addition, one mechanism for encouraging students to incorporate sustainability into the capstone design process may be to explicitly increase sustainable design expectations, since criteria receiving high earned scores also showed high potential scores. The rubric could even be used to evaluate candidate capstone projects (i.e., determine potential points) to ultimately communicate to students the sustainable design expectations. Overall, ensuring that students develop sustainable capstone designs requires more innovative and intentional efforts from instructors and/or sponsors.

Broad Application of Sustainable Design Rubric

While the sustainable design rubric was applied to CEE capstone design projects at one institution, it can also be applied by other departments and institutions to benchmark student capabilities to engage in sustainable design. If utilized by other CEE departments, the rubric, including the 16 design criteria (Table 2), two rating scales (Table 4), and numerous examples (Table 3), may be directly applicable. While specific sustainable design examples may not be relevant for engineering programs beyond CEE, the design criteria and accompanying rating scales are still applicable to many engineering disciplines, since they are based on general sustainable design principles and related criteria (Table 2). In addition, the rubric is applicable for any design course, not solely capstone design. In fact, using the sustainable design rubric to weave sustainability into multiple existing undergraduate courses (design or engineering science) may facilitate horizontal integration, and further prepare students to incorporate sustainability into their professional designs and practices (Peet, Mulder, and Bijma 2004).

LIMITATIONS AND FUTURE WORK

Several limitations to these research methods are acknowledged. First, when assigning potential and earned scores for each criterion, judges only had access to final student reports. As a result, an accurate evaluation of sponsor and/or instructor requests was only achieved if students made these requirements explicit in the report. Indeed, students were often very clear, especially when defining their project objectives and special instructions from sponsors. Similarly, when awarding earned points, judges could only give credit for consideration or application of those design criteria that were evident in the final report. However, just because a sustainable design element did not make it in the report, does not mean that the group did not consider it. Nevertheless, it was assumed that the elements of research and analysis that the group deemed most important and spent the most time on were evident in the final report.

An additional limitation is related to the repeatability of judges' scores, due to the somewhat subjective nature of rubrics. For instance, depending on the context presented in the final report, some design activities could be classified as meeting different design criteria. As a result, a different set of judges evaluating the same set of projects may yield different results. However, efforts were made to ensure the generation of reliable data, including training of judges and reporting of inter-rater reliability statistics. In addition, the extensive database of design examples for each criterion (see Watson 2013) was developed to help aid in reproducibility of rubric application.

Presented in this work is the first version of the sustainable design rubric; subsequently, future work will include revision of criteria. Specifically, criteria may be added and reinterpreted to distinguish between required elements of design that benefit stakeholders and truly innovative practices that go beyond the norm to achieve social sustainability. For instance, in the future, consideration of safety during design may not be interpreted as "promoting human health and well-being," as was done in the current study. Rather, actions to ensure the safety of the public, which are required for most civil infrastructure projects, may be captured in a new "ensures safety during the design process" criterion. Creation of this new criterion would allow the "promotes human health and well-being category" to capture non-safety related actions that are often not required of engineers. Second, the "addresses community and stakeholder requests" criterion may also be re-interpreted. As discussed previously, students received credit for meeting the needs of their project sponsors, as well as those of broader stakeholders. While it was not possible for students to receive the maximum earned score by only addressing technical stakeholders' needs, they were given credit for such efforts. Perhaps a re-interpretation of the earned points scale for this criterion, or a creation of a new sponsor-specific criterion, would more clearly capture students' efforts to ensure inclusiveness during the design process. Changes to social design criteria, while making the rubric more transparent, would not significantly impact the outcomes of this project, since reclassification of student activities would still result in emphasis of the social dimension overall (at least compared to other dimensions).

SUMMARY AND CONCLUSIONS

A sustainable design rubric was applied to examine sustainable design expectations and performance in a CEE capstone design course between 2002 and 2011. Expert judges examined a wide variety of projects (e.g., roadways, bridges, etc.), including a unique set of multi-use project trails that were directed by the same project sponsor. The following conclusions were made based on the results.

1. While the 16 sustainable design criteria are fundamentally applicable to almost all CEE projects, instructor and/or sponsor requirements dictated that students primarily "protect human health and well-being" and "conduct a cost and/or cost-benefit analysis," at least to some extent.
2. Although student incorporation of sustainable design criteria was limited (12 criteria received earned scores of less than 1.0), students most frequently "protected human health and well-being" and "addressed community and stakeholder requests."
3. Both sponsor requirements and student design activities incorporated the social design criteria into their projects more than those related to other dimensions, although consideration of social sustainability was still incomplete.
4. Sustainable design scores have largely remained unchanged since 2002, which indicates the need for more innovative and intentional efforts to encourage students to practice sustainable design skills throughout the curriculum.

Results from the evaluation of student projects suggest that efforts are needed to compel students to incorporate a wider variety of sustainable design criteria into their capstone projects. Due to the influence of sponsor and instructor requests on student performance, it is suggested that sustainable design requirements be made explicit in the capstone design course and project requirements. Broadly, the sustainable design rubric can be used by CEE and other engineering departments to quantify student design abilities in any design course. Given that engineers will be increasingly called upon to develop and implement innovative solutions that serve a growing population, while simultaneously exploiting fewer resources and minimizing environmental impacts, it is essential that undergraduate engineering education guide students in developing sustainable design skills. After all, the design decisions made by engineers have the potential to impact both current and future generations.

ACKNOWLEDGMENTS

The authors would like to thank Kari Watkins, Alexandra Coso, and Joshua Pelkey for their thoughtful critiques of the sustainable design rubric. Their feedback greatly improved the final product. Financial support was provided through a National Science Foundation Graduate Research Fellowship awarded to M.K. Watson (DGE/0946809).

SUPPLEMENTARY INFORMATION

To demonstrate application of the sustainable design rubric, a sample project with corresponding consensus scores and supporting evidence is provided online (http://advances.asee.org/wp-content/uploads/vol05/issue04/Media/Watson_et_al_multimedia.pdf).

REFERENCES

Abraham, M.A. 2006. "Principles of Sustainable Engineering." In *Sustainability Science and Engineering: Defining Principles*, 3-10. Amsterdam, The Netherlands: Elsevier, B.V. doi: 10.1016/s1871-2711(06)80008-5.

Allen, D., and K. Tanner. 2006. "Rubrics: Tools for Making Learning Goals and Evaluation Criteria Explicit for Both Teachers and Learners." *CBE-Life Sciences Education* 5 (3):197-203. doi: 10.1187/cbe.06-06-0168.

Amekudzi, A., and M. Meyer. 2004. "The Civil Engineering Systems Course at Georgia Institute of Technology." Engineering Systems Symposium, Cambridge, MA. https://esd.mit.edu/symposium/pdfs/papers/amekudzi.pdf.

ASCE. 2015a. "Sustainability." American Society of Civil Engineers Accessed July 24. http://www.asce.org/sustainability/.

ASCE. 2015b. "Code of Ethics." The American Society of Civil Engineers Accessed July 24. http://www.asce.org/code-of-ethics/.

Barrella, Elise, and Mary Katherine Watson. 2015. "Comparing the Outcomes of Horizontal and Vertical Integration of Sustainability Content into Engineering Curricula using Concept Maps." Paper Presented at The Seventh International Conference on Engineering Education for Sustainable Development, Vancouver, B.C., June 9 – 12, 2015. http://hdl.handle.net/2429/53692.

Bauer, S.K., A.R. McFarland, M.M. Staehle, and K. Jahan. 2012. "Weaving Sustainability into Undergraduate Engineering Education Through Innovative Pedagogical Methods: A Student's Perspective." Paper Presented at the American Society for Engineering Education Annual Conference and Exposition, San Antonio, TX, June 10 – 13, 2012. https://peer.asee.org/22224.

Besterfield-Sacre, M., J. Gerchak, M.R. Lyons, L.J. Shuman, and H. Wolfe. 2004. "Scoring Concept Maps: An Integrated Rubric for Assessing Engineering Education." *Journal of Engineering Education* 93 (2):105-115. doi: 10.1002/j.2168-9830.2004.tb00795.x.

Bhamra, T., and V. Lofthouse. 2007. *Design for Sustainability: A Practical Approach*. Hampshire, England: Gower Publishing Ltd. doi: 10.1007/s10668-015-9644-z.

Clough, G.W. 2004. The Engineer of 2020: Visions of Engineering in the New Century. Washington, DC: National Academy of Engineering. http://www.nap.edu/openbook.php?record_id=10999.

Cortese, A.D. 2003. "The Critical Role of Higher Education in Creating a Sustainable Future." *Planning for Higher Education* 31 (3):15-22. http://www.aashe.org/resources/pdf/Cortese_PHE.pdf.

Crismond, D.P., and R.S. Adams. 2012. "The Informed Design Teaching and Learning Matrix." *Journal of Engineering Education* 101 (4):738-797. doi: 10.1002/j.2168-9830.2012.tb01127.x.

Davidson, Cliff I., H. Scott Matthews, Chris T. Hendrickson, Michael W. Bridges, Braden R. Allenby, John C. Crittenden, Yongsheng Chen, Eric Williams, David T. Allen, Cynthia F. Murphy, and Sharon Austin. 2007. "Viewpoint: Adding Sustainability To The Engineer's Toolbox: A Challenge for Engineering Educators." *Environmental Science & Technology* 41 (14):4847-4849. doi: 10.1021/es072578f.

Davis, Linda Lindsey. 1992. "Instrument Review: Getting The Most From A Panel of Experts." *Applied Nursing Research* 5 (4):194-197. doi: 10.1016/S0897-1897(05)80008-4.

Dym, C.L., A.M. Agogino, O. Eris, D.D. Frey, and L.J. Leifer. 2005. "Engineering Design Thinking, Teaching, and Learning." *Journal of Engineering Education* 94 (1):103-120. doi: 10.1109/emr.2006.1679078.

Kagawa, F. 2007. "Dissonance in Students' Perceptions of Sustainable Development and Austainability: Implications for Curriculum Change." *International Journal of Sustainability in Higher Education* 9 (3):317-338. doi: 10.1108/14676370710817174.

Kelly, B. 2008. "Sustainability in Engineering Education and Ethics." *Connexions*. http://cnx.org/content/m19062/latest/.

Krippendorff, K. 2003. *Content Analysis: An Introduction to its Methodology*. 2nd ed. Thousand Oaks, CA: Sage Publications Inc.

Lozano, R. 2008. "Envisioning Sustainability Three-Dimensionally." *Journal of Cleaner Production* 16 (17):1838-1846. doi: 10.1016/j.jclepro.2008.02.008.

Lozano, R. 2010. "Diffusion of Sustainable Development in Universities' Curricula: An Empirical Example from Cardiff University." *Journal of Cleaner Production* 18 (7):637-644. doi: 10.1016/j.jclepro.2009.07.005.

Lozano, R., F. Lozano, K. Mulder, D. Huisingh, and T. Waas. 2013. "Advancing Higher Education for Sustainable Development: International Insights and Critical Reflections." *Journal of Cleaner Production* 48:3-9. doi: 10.1016/j.jclepro.2013.03.034.

MacRae, J.D. 2011. "Introducing Elements of Sustainability into Formal and Informal Environmental Engineering Education." Paper Presented at the American Society for Engineering Education Annual Conference and Exposition, Vancouver, British Columbia, June 26 – 29. https://peer.asee.org/18165.

McLennan, J.F. 2004. *The Philosophy of Sustainable Design: The Future of Architecture*. Bainbridge Island, WA: Ecotone Publishing Company LLC.

Meyer, M., and L. Jacobs. 2000. "A Civil Engineering Curriculum for the Future: The Georgia Tech Case." *Journal of Professional Issues in Engineering Education and Practice* 126 (2). doi: 10.1061/(asce)1052-3928(2000)126:2(74).

Mihelcic, J.R., J.C. Crittenden, M.J. Small, D.R. Shonnard, D.R. Hokanson, and Q. Zhang. 2003. "Sustainability Science and Engineering: The Emergence of a New Metadiscipline." *Environmental Science & Technology* 37 (23):5314-5324. doi: 10.1021/es034605h.

Mueller Price, J., CM. Taylor, P. Brackin, R.A. House, K. Toohey, M. DeVasher, R.B. DeVasher, and M.H. Minster. 2012. "Integrating Sustainability Principles in Undergraduate Engineering Curriculum: A Home for Environmentally Responsible Engineering." American Society for Engineering Education Annual Conference and Exposition, San Antonio, TX. https://peer.asee.org/21568.

Peet, D.J., K.F. Mulder, and A. Bijma. 2004. "Integrating SD into Engineering Courses at the Delft University of Technology. The Individual Interaction Method." *International Journal of Sustainability in Higher Education* 5 (3):278-288. doi: 10.1108/14676370410546420.

Salzmann, O., A. Ionescu-Somers, and U. Steger. 2005. "The Business Case for Corporate Sustainability: Literature Review and Research Options." *European Management Journal* 23 (1):27-36. http://f2.washington.edu/fm/sites/default/files/Business%20Case%20for%20CSR%20Literature%20Review.pdf.

Schayot, L.A. 2008. "School Councelors' Perceptions of their Academic Preparation in their Rolses as Professional School Counselors " PhD Dissertation, University of New Orleans. http://scholarworks.uno.edu/cgi/viewcontent.cgi?article=1862&context=td.

Seager, T., E. Selinger, and A. Wiek. 2012. "Sustainable Engineering Science for Resolving Wicked Problems." *Journal of Agricultural and Environmental Ethics* 25 (4):467-484. doi: 10.1007/s10806-011-9342-2.

Segalàs, J., D. Ferrer-Balas, and K. F. Mulder. 2010. "What Do Engineering Students Learn in Sustainability Courses? The Effect of the Pedagogical Approach." *Journal of Cleaner Production* 18 (3):275-284. doi: 10.1016/j.jclepro.2009.09.012.

Skerlos, S.J., W.R. Morrow, and J.J. Michalek. 2006. "Sustainable Design Engineering and Science: Selected Challenges and Case Studies." In *Sustainability Science and Engineering: Defining Principles*, edited by M.A. Abraham, 467-515. Amsterdam, The Netherlands: Elsevier, B.V. doi: 10.1016/s1871-2711(06)80030-9.

Stasinopoulos, P. 2009. *Whole System Design: An Integrated Approach to Sustainable Engineering*. London, UK: Earthscan. doi: 10.1177/097340820900300225.

Thomas, J. 2012. "Engineering Education: The Key to a Sustainable Future." *Technology and Engineering Teacher* 72 (3):18-23.

Thompson, G. 2002. "Status and Prospects of Sustainable Engineering Education in Some American Universities." Engineering Education in Sustainable Development, Delft University of Technology, Netherlands, October 24-25, 2002. http://www.researchgate.net/profile/Gordon_Thompson/publication/242160153_Status_and_Prospects_of_Sustainable_Engineering_Education_in/links/00b4953513a2b980ab000000.pdf

Velazquez, L., Nora Munguia, and Margarita Sanchez. 2005. "Deterring Sustainability in Higher Education Institutions: An Appraisal of the Factors Which Influence Sustainability in Higher Education Institutions." *International Journal of Sustainability in Higher Education* 6 (4):383-391. doi: 10.1108/14676370510623865.

Wallace, B. 2005. *Becoming Part of the Solution: The Engineer's Guide to Sustainable Development*. Washington, DC: American Council of Engineering Companies.

Watson, M.K. 2013. "Assessment and Improvement of Sustainability Education in Civil and Environmental Engineering." Dissertation, Georgia Institute of Technology.

Watson, M.K., E. Barrella, T. Wall, C. Noyes, and M. Rodgers. 2013. "Development and application of a sustainable design rubric to evaluate student abilities to incorporate sustainability into capstone design projects." Paper Presented at the American Society for Engineering Education Annual Conference and Exposition, Atlanta, GA. https://peer.asee.org/19422.

Watson, M.K., C. Noyes, and M. Rodgers. 2013. "Student Perceptions of Sustainability Education in Civil and Environmental Engineering at the Georgia Institute of Technology." *Journal of Professional Issues in Engineering Education and Practice*.doi: 10.1061/(ASCE)EI.1943-5541.0000156.

Watson, M.K., J.G. Pelkey, C. Noyes, and M.O. Rodgers. 2014. "Use of Concept Maps to Assess Student Sustainability Knowledge." American Society for Engineering Education, Indianapolis, IN. doi: https://peer.asee.org/23238

Wood, M., and J. Ross-Kerr. 2010. *Basic Steps in Planning Nursing Research: From Question to Proposal*. Sudbury, MA: Jones and Bartlett Publishers, LLC. doi: 10.1097/00006199-197901000-00004.

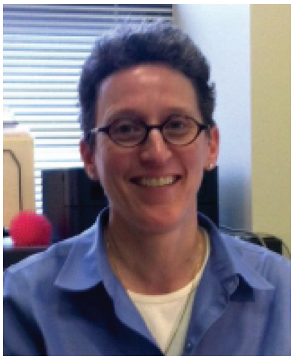
Wright, T.S.A., and H. Wilton. 2012. "Facilities Management Directors' Conceptualizations of Sustainability in Higher Education." *Journal of Cleaner Production* 31:118-125. doi: 10.1016/j.jclepro.2012.02.030.

AUTHORS

Mary Katherine Watson is currently an assistant professor in the Department of Civil and Environmental Engineering at The Citadel. Previously, she completed her doctoral work at Georgia Tech where she worked to develop, implement, and assess a variety of instructional materials to integrate sustainability into undergraduate civil engineering courses. Dr. Watson is also an active member of the American Society for Engineering Education where she has received Best Paper Awards in both the Civil Engineering and New Engineering Educators Divisions. In addition to her interests in engineering education, Dr. Watson also has research experience related to sustainable biotechnology, including biological treatment of wastes to form useful products.

Elise Barrella is an Assistant Professor of Engineering at James Madison University (JMU), focusing on design, sustainability, and transportation systems. Prior to joining the JMU Engineering faculty, Dr. Barrella was at Georgia Tech completing her Ph.D. research as part of the Infrastructure Research Group (IRG). Her academic interests focus on two primary areas: (1) community-based design and urban planning, including the use of sustainability rating systems, and (2) engineering education for sustainability. Dr. Barrella is engaged in research projects sponsored by National Science Foundation to investigate how engineering students learn and apply sustainability concepts across courses and project contexts.

Thomas A. Wall is currently an infrastructure analyst in the Risk and Infrastructure Science Center at Argonne National Lab. Previously, he was an affiliate researcher with the School of Civil & Environmental Engineering at Georgia Tech. His research has been focused on climate change adaptation planning and policy in infrastructure management, transportation system health, and the applications of social networking and social media in transportation planning. Dr. Wall currently works for the Risk and Infrastructure Science Center (RISC) at Argonne National Laboratory in Lemont, Illinois.



Caroline Noyes is trained as an educational psychologist, and her education and work have focused on assessing student learning both in and outside of the classroom. Experiences in both academic affairs and student affairs provide her with a holistic understanding of the modern university and a broad collection of assessment methodologies suitable to a variety of situations. As her intellectual pursuits turned increasingly towards broader applications of educational assessment and evaluation, she left the classroom and moved to an administrative position focusing on both academic assessment of student learning and program evaluation. This administrative move has allowed her to increase use of qualitative assessment methods and to enhance her skills in survey design.

Michael Rodgers is a research professor in the Georgia Tech School of Civil and Environmental Engineering and a principal research scientist and distinguished technical fellow with the Georgia Tech Research Institute. Over the last thirty plus years, Dr. Rodgers has held various academic, research and administrative positions including serving as director of the Georgia Tech Air Quality laboratory from 1988 to 2008. He currently serves as deputy director for Research and Technology Transfer for National Center for Transportation Productivity and Management at Georgia Tech.