Expert Evaluation of a Sustainable Design Rubric

Elise Barrella[1], Mary Katherine Watson[2], and Charles Cowan[1]
[1]James Madison University/[2]The Citadel

Abstract

Sustainable development poses a challenge for all engineers, regardless of discipline, to improve the design of infrastructure, products, and processes by balancing technical, environmental, social, and economic objectives. Prior work developed and applied a sustainable design rubric based on the Nine Principles of Sustainable Engineering to civil engineering student design projects. Subsequently, the rubric was updated based on insights from the pilot application phase and a subsequent systematic literature review. This paper presents preliminary expert evaluations of the cross-disciplinary sustainable design rubric. Paper and web-based forms were used to gather perspectives from engineering education professionals from the United States and abroad. Participants, with different disciplinary perspectives, ranked the importance of 34 criteria related to sustainable design. Quantitative and qualitative analysis of feedback will be used to validate and update the sustainable design rubric for use across various engineering disciplines.

Keywords

Sustainable design, rubric, assessment

Introduction

Sustainable development poses a challenge for all engineers, regardless of discipline, to improve the design of infrastructure, products, and processes by balancing technical, environmental, social, and economic objectives. Addressing the challenge begins with educating future engineers and citizens who embrace and apply sustainability as a framework for design and decision-making. The motivation for this research is to foster a learning environment in which students apply appropriate concepts of sustainable design to different types of complex engineering problems, such as a capstone design project. One approach to stimulating both student learning and assessment is the use of rubrics. Rubrics can be used to evaluate the quality of student work products like homework, reports, presentations, prototypes, etc.

The purpose of this study is to present expert evaluations of the cross-disciplinary sustainable design rubric. A sustainable design rubric was previously developed based on the Nine Principles of Sustainable Engineering for application in civil and environmental engineering (CEE) courses[1], and used to score a set of forty CEE capstone design projects from a mid-sized research-intensive university. After the pilot project, several improvements to the rubric were noted. For example, it was determined that criteria should 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. The rubric was recently updated through systematic literature review to improve upon the piloted version and to reflect a broader set of evaluation criteria that apply to engineering design projects from multiple disciplines or originating from interdisciplinary teams[2]. The new rubric's constructs of sustainable design and their measures are being validated in three phases consistent with the Benson model of construct validity[3]. This paper will focus on efforts to validate the new rubric's content using expert feedback on and prioritization of the design criteria.

Use of Rubrics in Engineering Education

Rubrics are used to judge the quality of constructs (e.g. reports, presentations, etc.) made by students during performance tests, which require students to exhibit high-level skills to complete an authentic (i.e. real-world) challenge[4]. As a result, rubrics are commonly used in the classroom as both assessment and teaching tools to enhance student learning. For instance, an instructor may provide students with a rubric to guide them in completion of a task. Reflecting on the rubric helps students self-assess their own work and provides the instructor with a tool for grading the assignment and providing feedback to the students[5]. Alternatively, rubrics may be used for evaluation purposes to track changes in educational programs over time due to reform efforts[6,7]. In engineering education, rubrics have been used widely to assess and evaluate many complex skills, including critical thinking[5,8].

Cross-Disciplinary Sustainable Design Rubric

The current version of the sustainable design rubric reflects the original sixteen criteria derived from the Nine Principles of Sustainable Engineering plus additional criteria resulting from a systematic review of recent literature on sustainability/sustainable design instruction and evaluation in engineering departments. The set of thirty-four criteria can be loosely grouped into four categories as shown in Table 1.

Table 1. Draft criteria for cross-disciplinary sustainable design rubric.

Category	Criterion
Environmental	Minimizes natural resource depletion
	Prevents waste
	Protects natural ecosystems
	Uses renewable energy sources
	Provides for low-energy production
	Provides for technological adaptability
	Uses inherently safe and benign materials (to environment)
	Uses footprint analysis to estimate impact
	Analyzes embedded energy of alternatives
Social	Addresses stakeholder or client requests
	Considers local circumstances and cultures
	Incorporates public/stakeholder participation
	Incorporates user experience
	Protects human health and well-being
	Uses inherently safe and benign materials (to humans)
	Demonstrates ethics/ethical reasoning
	Reflects social responsibility
	Manufacturing complies with safety regulations

Economic	Considers economic impacts of environmental design criterion
	Considers economic impacts of a social design criterion
	Conducts a cost and/or cost-benefit analysis
	Demonstrates cost competitiveness or cost reduction
	Stimulates labor/jobs
	Considers affordability
	Promotes low-carbon economy
Other including Tools	Incorporates life cycle analysis
	Uses DfX in design process (indicate "X")
	Reflects cradle-to-cradle design
	Uses industrial ecology principles
	Incorporates environmental impact assessment tools
	Incorporates systems analysis
	Incorporates uncertainty analysis
	Uses innovative technologies to achieve sustainability
	Reflects leadership

Methods

Participants were sixteen academic professionals within engineering, however they were not required to be teaching at the time of taking the survey. Participants' specific sub-disciplines within engineering included construction engineering, civil engineering, electronic engineering, product design, aerospace engineering design, mechanical engineering, chemical engineering, mining engineering, and industrial engineering; non-engineering academic professionals also completed the survey.

Participants completed the feedback form either electronically or in person, without imposed time limitations. The form requested background information including: (1) "Which discipline(s) do you identify with professionally?" (2) "For which engineering discipline(s) do you teach?" and (3) "What types of courses have/do you teach?" The survey then contained four activities for each participant to complete. Activity 1 asked the participant to define "sustainable design." Activity 2 asked the participant to "brainstorm sustainable design criteria." Activity 3 asked the participants to "refine and rank evaluation criteria" as either "always important," "sometimes important," "not important," or "not sure." Activity 3 contained four subsets of categories including: Environmental Design Criteria, Social Design Criteria, Use of Sustainable Design Tools, and Economic Design Criteria, with a total of 34 items across all categories. Every category gave the participant the option to define and rank their own item(s) within the category. Activity 4 asked the participants to "provide examples that satisfy criteria" and was left to open response. The survey came in both paper and online form, with very minor differences between the two formats.

Data was initially recorded using either the Qualtrics survey system or paper surveys. The Qualtrics data was then automatically exported into a .sav file for use in SPSS (Statistical Package for the Social Sciences). The paper surveys were entered into a separate SPSS data file, and then eventually merged with the Qualtrics data. The researchers created new variables for each of the Activity 3 items, in order to analyze whether the item was included in a participants' "always important" or "sometimes important" categories.

Preliminary Results

Participant responses were reviewed using both quantitative and qualitative methods in order to identify trends in how criteria were prioritized or gaps in one or more categories. Preliminary survey results from the numerical rankings show that participants consistently identified three criteria as being more important than the others. Specifically, the criteria "incorporate user experience," "consider economic impacts of an environmental design criterion," and "consider economic impacts of a social design criterion" were highly-ranked by 62% of respondents. Additionally, two criteria were never ranked among participants' most important criteria, including "manufacturing complies with safety regulations" and "incorporates environmental impact assessment tools."

With respect to free response questions, participants consistently mentioned either energy efficiency, environmental impact, minimizing waste, consideration of environmental impact of design, and general environmental health in their response to Activity 1: "Define sustainable design." This is surprising considering the relatively moderate amount of times that Environmental Design Criteria appeared in participants' top criteria from Activity 3. Additionally, when participants' defined their own sustainability criteria, very few seemed unique from previously-established criteria, and there were no other noticeable trends among these responses.

Based on the preliminary results, a Cross-Disciplinary Sustainable Design rubric should contain the following ten criteria, which includes six social criteria, three economic criteria, and one environmental criterion. Further survey of experts is expected to lead to inclusion of additional criteria.

1. Incorporates user experience
2. Considers economic impacts of a social design criterion
3. Considers economic impacts of environmental design criterion
4. Reflects social responsibility
5. Considers local circumstances and cultures
6. Conducts a cost and/or cost-benefit analysis
7. Protects human health and well-being
8. Minimizes natural resource depletion
9. Incorporates public/stakeholder participation
10. Addresses stakeholder or client requests

Future Work

Feedback from academic professionals continues to be collected through snowball recruitment with the electronic form and in-person workshops. For example, in early Spring 2017, workshops will be used to gather perspectives of civil, electrical, and mechanical engineering faculty at a small, teaching-focused college in the southeastern United States. Once a broad distribution of respondents from across engineering disciplines have provided feedback, the rubric criteria will be prioritized and sorted to reflect core sustainability criteria and disciplinary differences.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. 1463865 *Developing and Assessing Engineering Students' Cognitive Flexibility in the Domain of Sustainable Design*. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

1 Watson, Mary Katherine, Elise Barrella, Thomas Wall, Caroline Noyes, and Michael O. Rodgers. "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, 2013.

2 Barrella, E. and M.K. Watson. "Developing a Cross-Disciplinary Sustainable Design Rubric for Engineering Projects". Proceedings of and Presentation at the 8th International Conference on Engineering Education for Sustainable Development, Brugges, Belgium, 4-6 September 2016.

3 Benson, Jeri. "Developing a strong program of construct validation: A test anxiety example". Educational Measurement: Issues and Practice, 17(1), 1998, pp. 10-17.

4 Popham, W. J. What's wrong-and what's right-with rubrics. Educational Leadership, 55, 1997, pp. 72-75.

5 Andrade, H. G. Using rubrics to promote thinking and learning. Educational Leadership, 57(5), 2000, pp. 13-19.

6 Blumberg, P. Developing Learner-Centered Teaching: A Practical Guide for Faculty. San Francisco, CA: Jossey-Bass, 2008.

7 Cook, D. "Using Qualitative Methods in Action Research". In D. Cook & L. S. Farmer (Eds.), Performance-Based Self-Assessment of a Library Liaison Program Using a Rubric. Chicago, IL: American Library Association, 2011.

8 Ralston, P., & Bays, C. Refining a critical thinking rubric for engineering. Paper presented at the American Society for Engineering Education, Vancouver, BC, 2010.

Mary Katherine Watson

Dr. 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 the Georgia Institute of Technology 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. Dr. Watson also has research experience related to sustainable biotechnology, including biological treatment of wastes to form useful products.

Elise Barrella

Dr. Elise Barrella is an Assistant Professor of Engineering at James Madison University and was recently recognized with the university's Junior Scholar Award. Prior to joining the Madison

Engineering faculty, Dr. Barrella completed her Ph.D. at the Georgia Institute of Technology as part of the Infrastructure Research Group. Her scholarly interests focus on two areas: community-based design and urban planning, including the use of sustainability rating systems, and engineering education for sustainability. In addition to teaching and student mentoring, Dr. Barrella is engaged in research projects sponsored by National Science Foundation investigating engineering students' application of sustainability concepts across courses and project contexts.

Charles Cowan

Mr. Charles Cowan is currently a graduate student in Experimental Psychology at James Madison University. He has previous experience with psycho-physiological assessment tools in both human and animal models. His other areas of interest include cognitive and behavioral assessment tools, sleep, and behavioral pharmacology.