A Rubric to Assess Civil Engineering Students' Grand Challenge Sustainable Entrepreneurship Projects

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A Piloted Rubric to Assess Civil Engineering Students' Grand Challenge Sustainable Entrepreneurship Projects

Abstract

To prepare the next generation of civil engineers to tackle 21st century challenges, engineering education must commit to deepening engineer's social consciousness through exposure to societal problems in addition to teaching technical competencies. The National Academy of Engineering (NAE) Grand Challenges for Engineering offers a framework for exposing students to the role of a modern engineer and the complex global challenges that require engineering intervention. In response to these challenges, many U.S. engineering schools have adopted the Grand Challenge Scholars (GCS) program to educate a new generation of engineering professionals equipped to sustainably address society's most imminent problems. This paper presents the development of a holistic rubric to assess student scholarship and inform competencies related to Grand Challenges. The rubric builds on best practices in assessment and evaluation of the five key NAE GCS program components, including 1) hands-on project/research experience, 2) interdisciplinary curriculum, 3) entrepreneurship, 4) global dimension, and 5) service-learning. The authors discuss potential applications of the rubric to evaluate course-level outcomes, including student projects from an interdisciplinary course entitled "Creatively Applying Science for Sustainability." In the course, students work to address a societal Grand Challenge in a semester-long project and in interdisciplinary student projects that tackle Grand Challenges on an international scale. This rubric fills a literature gap in assessing 21st century global engineering skills by measuring capabilities based on five key NAE GCS program components and provides a mechanism to understand and influence the quality of student education and experiences within Grand Challenge-focused courses and programs.

Introduction

The next generation of engineering professionals must be prepared to solve complex and multidisciplinary problems in a sustainable and global context. Engineering education can provide students with the tools to approach these grand challenges of the 21st century while considering aspects that are key for designing sustainable systems.[1] Despite this, engineering education faces several challenges, including, but not limited to, addressing low diversity percentages, high attrition rates, and the need to better engage and prepare students for the role of a 21st century engineer.[2]

Since the 1970s the representation of women in Science, Technology, Engineering and Mathematics (STEM) occupations has grown unevenly from 3% to 26%.[3] While the percent of women in math and science has continued to grow, growth in engineering has stagnated around 13% since 1990.[3] Also, the number of bachelor's degrees awarded in science and engineering has increased, while the percentage of women earning bachelor's degrees in computer science and engineering has decreased in the last 10 years.[4] In addition, while underrepresented minorities account for more than 30% of the total United States' workforce, only 12% are enrolled in science and engineering undergraduate degree programs and 16% are employed in some STEM occupations.[3,4] The President's Council of Advisors on Science and Technology (PCAST) and relevant research recommend that creating an educational experience where students have a connection to their degree and a connection to their technical community can contribute to increasing diversity in STEM. Sustainability is one theme that can create this connection for many students. Research indicates that students who hope to address sustainability issues related to energy, water, and the environment demonstrate increased interest in pursuing engineering degrees; increasing the connection between sustainability and engineering could broaden participation of underrepresented populations, including women.[5]

Furthermore, fewer than 40% of students enrolled in STEM majors complete their degree.[2,6] There are many reasons for a student to move from STEM to another discipline, including intellectual compatibility and institutional support.[7] However, according to a recent National Academy of Science report, *Changing the Conversation*, one of the most significant contributing factors to high attrition rates is that courses no longer appeal to our youth.[8,9]

Youth are seeking careers that can make a difference, thus strategies for engineering education need to bring exciting topics and engaging methods into the classroom to motivate students toward goals that matter to them. Sustainable engineering offers a solution to these pressing challenges by providing context for the role of a modern engineer in solving 21st century problems. Sustainability topics in engineering curricula can address many of the underlying factors facing diversity and retention of students who otherwise leave STEM majors due to lack of engagement and/or motivation.[5]

The National Academy of Engineering (NAE) developed and issued the Grand Challenges for Engineering, with five of the fourteen directly related to sustainability (solar energy, carbon sequestration, nitrogen cycle, clean water, and infrastructure).[10] The Grand Challenges offer a framework for exposing engineering students to the role of an engineer in modern society. The White House Strategy for American Innovation and the United Nations Millennium Development Goals have identified many of the Grand Challenges as global challenges that will require diverse, innovative solutions.[11,12] Adoption of these challenges within engineering curricula has been cited to engage a diverse array of interested students by establishing contextualized linkages between course content and the contributions an engineer makes to solve global issues through systems-thinking innovation.[13]

Having acknowledged the need for graduates trained in solving 'Grand Challenge'-scale problems, a natural outcome was to develop a university program to facilitate the training. The Grand Challenge Scholars (GCS) program was created and adopted by Duke's Pratt School of Engineering, The Franklin W. Olin College of Engineering, and the University of Southern California's Viterbi School of Engineering. The program has since expanded; over the next decade 122 schools across the country have pledged to graduate at least 20 students specifically trained in solving large-scale problems like the Grand Challenges.[14]

The GCS program was developed such that each school could develop its own methods for student fulfillment of five program competencies. These five GCS program competencies are shown in Figure 1. The program competencies within the GCS program are intended to provide the foundation for graduates to tackle large-scale challenges, such as the 14 outlined in the NAE Grand Challenges for Engineering.[14]

Hands-on Project or Research Experience

- Related to a Grand Challenge

Interdisciplinary Curriculum

- A curriculum that complements engineering fundamentals with courses in other fields, preparing engineering students to work at the overlap with public policy, business, law, ethics, human behavior, risk, and the arts, as well as medicine and the sciences

Entrepreneurship

- Preparing students to translate invention to innovation; to develop market ventures that scale to global solutions in the public interest

Global Dimension

- Developing the students' global perspective necessary to address challenges that are inherently global as well as to lead innovation in a global economy

Service Learning

- Developing and deepening students' social consciousness and their motivation to bring their technical expertise to bear on societal problems through mentored experiential learning with real clients

Figure 1. Grand Challenge Scholars Program Competencies.

Since the Grand Challenge Scholars (GCS) program takes different forms at different institutions (and even different forms for students within an institution), it is critical to create a mechanism for standardizing the five program competencies within the GCS program. Rubrics can be used to promote student learning, improve instruction, and support effective programs because they make expectations and criteria explicit.[15] The proposed rubric in this paper serves as a quality control mechanism, ensuring that each student participant in the GCS program fulfills a minimum level of rigor and/or experience in each of the five program competencies.

Rubric Development

The GC Rubric was developed by mining best practices in the literature on assessment and evaluation of the five GCS program competencies, including 1) hands-on project/research experience, 2) interdisciplinary curriculum, 3) entrepreneurship, 4) global dimension, and 5) service-learning. Criteria for all five GCS program competencies were generated such that GC competencies are measured based on student project assessments (shown Table 1). The first GC competency, hands-on project/research experience, rubric components include documentation of research methods, such as problem identification, data collection, and analysis of findings.[16,17] Interdisciplinary curriculum, the second GC competency, rubric components contain demonstrating the relationship between multiple disciplines such as showing the potential conflict of the same problem viewed from two different perspectives.[18,19] Rubric criteria for the entrepreneurship GC competency considers critical thinking, customer-appropriate value propositions, effectively delivering final product and the relation of personal liberties to entrepreneurship.[20-22] The global dimension GC competency covers the temporal scale of contemporary Grand Challenges and was assessed through understanding global systems, cultures, and a student's personal role of social responsibility.[23-25] The fifth GC competency, service learning, assesses students' civic action, service to others, and understanding of differing perspectives of communities intimately affected by Grand Challenges.[26-28]

The rubric is applied using the following four metrics: "does not meet expectations" characterizes a student performance that does not display any of the desired activity, "developing" characterizes student performance that displays some of the desired target activity, "meets expectations" characterizes student performance that displays the minimal level of ability expected, and "proficient" designates student performance that exceeds "meets expectations" and evidences mastery of the target activity.[20] Students are scored by two external evaluators with expertise in Engineering Grand Challenges. The external evaluators viewed students' final presentations in which students presented a comprehensive overview of the problems, the community stakeholders they engaged, their process for addressing the problem, and their final solution. The two evaluators agreed on final scoring while applying the rubric and viewing the presentation together.

Table 1. Grand Challenge Scholars (GCS) Rubric for Evaluating Student Work

GCS Program Competency	Rubric Criteria	Ref
1. Hands-on Project/ Research Experience	a. Identify the problem	16,17
	b. Collect data with supporting methodology	
	c. Analyze data and generate results	
	d. Present conclusions and applications of project/research findings	
2. Interdisciplinary Curriculum	a. Discuss problem from multiple perspectives	18,19
	b. Show connections between two or more disciplines	
	c. Integrate conflicting insights from two or more disciplines	
	d. Demonstrate interdisciplinary understanding of the problem	
3. Entrepreneurship	a. Collaborate as a team	20-22
	b. Apply critical and creative thinking to ambiguous problem	
	c. Construct customer-appropriate value proposition	
	d. Persist and learn through failure	
	e. Effectively manage projects through final delivery process	
	f. Demonstrate social responsibility	
	g. Relate personal liberties to entrepreneurship	
4. Global Dimension	a. Demonstrate global and cultural self-awareness and curiosity	23-25
	b. Engage and learn from global cultures	
	c. Develop intercultural sensitivity and empathy	
	d. Recognize personal and social responsibility	
	e. Understand global systems	
5. Service Learning	a. Define civic action and reflect on personal role	26-28
	b. Connect and extend knowledge to civic engagement and serve others	
	c. Communicate differing perspectives of communities and cultures	
	d. Collaboratively work across and within a community to provide a service	

The rubric was created by the authors for this study and for use at Clemson University to evaluate GCS projects based on the 5 GCS program competencies. The rubric criteria were mined and adapted from best practices in the literature.

Rubric Application

To demonstrate the use of the proposed rubric, the following section describes two real-world, Grand Challenge-themed student projects, which have been evaluated by the rubric to assess whether they fulfill any, or multiple, GCS program components based on the GCS rubric.

Authors applied the rubric to select students' semester projects from the Fall 2015 Clemson University course entitled "Creatively Applying Science for Sustainability." The course combines sustainability concepts with applications in students' design ventures in an interdisciplinary, flipped-course setting. Students chose a wide variety of challenges to address within the design venture, including local and international issues, with topics ranging from addressing infrastructure to human health to sustainability education. Students work through the six milestones project assignments in tandem with the six course themes: Our Grand Challenges;

Systems and Sustainability; Evaluating Sustainability; Creating- Sustainable Design Process; Creating- Sustainable Design Principles; and Creating- Finding Deep Simplicity. For the semester project, students first identify their Grand Challenge and, optionally, form teams. Each unit is required to perform background research to understand the Grand Challenge, its impact on society and stakeholders, inherent cultural or ethical considerations, and relevant cause-and-effect relationships. Students then define minimum requirements for success and constraints, create a best-case scenario, and develop criteria for which they can evaluate solutions. After which, students brainstorm and define a possible solution and they begin to design and solicit feedback from stakeholders, peers, and experts. Students then refine their prototype, consider operations and maintenance, generate a basic business model, and continue improving their solution. At the end of the semester students present their solution, reflect on their experience, and develop a path forward. The authors piloted the rubric by assessing two student group projects. The first one, entitled "Economic Use of CMU Blocks," explored the recycle of waste materials into concrete masonry units (CMU), the impact on material quality, and the potential use of these units to support Haiti's infrastructure. The second, entitled "Banana Bags", explored the use of banana fibers to create bags in Cameroon and address the plastic bag black market.

"Economic Use of CMU Blocks" student group attempted to find a solution for Haiti's poor infrastructure and waste management issues. They explored the possibility of using waste products in building CMUs, a common construction material in Haiti. By working with Clemson Engineers for Developing Countries (a student organization actively working in Haiti), they defined a problem and connected students with Haitian stakeholders. Faculty members from the Glenn Department of Civil Engineering gave advice concerning materials and feasibility. Students determined waste availability, obtained an understanding of potential additives to strengthen or serve as substitutes in concrete, and developed plans to test certain prevalent waste products in CMUs. At the end of their project, students anticipated obstacles that could prevent the project from continuing, including the possibility that Haitians may use the higher strength block due to higher costs and lack of central waste management system or even basic incentives for collecting waste.

The "Banana Bags" project attempted to find a solution for Cameroon's plastic bag black market. The student leading the project, a native of Cameroon, explored the unintended consequences of a national banning of plastic bags in 2014. Plastic bags are primarily used in the transport of groceries and goods. When the Cameroon government banned plastics bags, without any alternative object to substitute for the bags, a black market was created. This student identified a potential industrial symbiotic relationship between the plastic bag black market and Cameroon's chief export of bananas. Banana fibers remaining from the production of bananas exhibit properties excellent for weaving into baskets and bags. This student proposed to use the waste output of one export as the input to the black market plastic bag import as a solution that not only addressed the issue but also provided jobs and monetary flows for locals.

The GCS rubric application of the Creatively Applying Science for Sustainability Fall 2015 project, “Economic Use of CMU Blocks,” revealed that students perform ‘proficiently’ by going above minimal expectations in seven assessment criteria; students ‘meet expectations’ for twelve and reach ‘developing’ for four assessment criteria and “does not meet expectations” for one out of twenty-four assessment criteria (Table 2). It is anticipated that students perform at the ‘meets expectation’ level for each GC program competency at minimum. The GC rubric application of the “Banana Bags” project revealed that the student perform ‘proficiently’ by going above minimal expectations in nine assessment criteria; students ‘meet expectations’ for nine and reach ‘developing’ for four assessment criteria, and “does not meet expectations” for two out of twenty-four assessment criteria (Table 3). The rubric assessment of both student project reveals areas in which students excel, by a function of their own effort, by the nature of the problem they are attempting to solve, or both. It also reveals the areas where weakness may lead to the inability of the project to address a Grand Challenge holistically.

Table 2. Rubric Assessment of Creatively Applying for Sustainability Fall 2015 student project "Economic Use of CMU Blocks" in Haiti.

GC Rubric	Student Project Assessment Criteria	Student Performance			
		Does Not Meet Expectations	Developing	Meets Expectations	Proficient
1. Hands-on Project/ Research Experience	a. Identify the problem				■
	b. Collect data with supporting methodology			■	
	c. Analyze data and generate results			■	
	d. Present conclusions and applications of project/research findings			■	
2. Interdisciplinary Curriculum	a. Discuss problem from multiple perspectives			■	
	b. Show connections between two or more disciplines			■	
	c. Integrate conflicting insights from two or more disciplines		■		
	d. Demonstrate interdisciplinary understanding of the problem			■	
3. Entrepreneurship	a. Collaborate as a team				■
	b. Apply critical and creative thinking to ambiguous problem			■	
	c. Construct customer-appropriate value proposition		■		
	d. Persist and learn through failure			■	
	e. Effectively manage projects through final delivery process	■			
	f. Demonstrate social responsibility			■	
	g. Relate personal liberties to entrepreneurship		■		
4. Global Dimension	a. Demonstrate global and cultural self-awareness and curiosity				■
	b. Engage and learn from global cultures				■
	c. Develop intercultural sensitivity and empathy				■
	d. Recognize personal and social responsibility				■
	e. Understand global systems			■	
5. Service Learning	a. Define civic action and reflect on personal role				■
	b. Connect and extend knowledge to civic engagement and serve others			■	
	c. Communicate differing perspectives of communities and cultures			■	
	d. Collaboratively work across and within a community to provide a service		■		

Table 3. Rubric Assessment of Creatively Applying for Sustainability Fall 2015 student project "Banana Bags" in Cameroon.

GC Rubric	Student Project Assessment Criteria	Student Performance: Does Not Meet Expectations	Developing	Meets Expectations	Proficient
1. Hands-on Project/ Research Experience	a. Identify the problem				X
	b. Collect data with supporting methodology		X		
	c. Analyze data and generate results		X		
	d. Present conclusions and applications of project/research findings			X	
2. Interdisciplinary Curriculum	a. Discuss problem from multiple perspectives			X	
	b. Show connections between two or more disciplines			X	
	c. Integrate conflicting insights from two or more disciplines		X		
	d. Demonstrate interdisciplinary understanding of the problem			X	
3. Entrepreneurship	a. Collaborate as a team	X			
	b. Apply critical and creative thinking to ambiguous problem			X	
	c. Construct customer-appropriate value proposition				X
	d. Persist and learn through failure			X	
	e. Effectively manage projects through final delivery process	X			
	f. Demonstrate social responsibility				X
	g. Relate personal liberties to entrepreneurship		X		
4. Global Dimension	a. Demonstrate global and cultural self-awareness and curiosity				X
	b. Engage and learn from global cultures				X
	c. Develop intercultural sensitivity and empathy				X
	d. Recognize personal and social responsibility				X
	e. Understand global systems				X
5. Service Learning	a. Define civic action and reflect on personal role			X	
	b. Connect and extend knowledge to civic engagement and serve others			X	
	c. Communicate differing perspectives of communities and cultures			X	
	d. Collaboratively work across and within a community to provide a service				X

Future Direction

Though this rubric is still in the development phase, authors intend to include the rubric as an assessment piece of a new Grand Challenge minor at Clemson University, as well as to integrate it into our existing GCS program. This will help to ensure that students in the GCS program and/or Grand Challenge minor fulfill each of the program competencies, serving as a quality control mechanism to provide consistency among student experiences.

In addition to analyzing the fulfillment of program objectives on an individual student basis, authors plan to develop a similarly structured rubric to assess entire existing programs, courses, and organizations on campus that are interested in whether their student experiences fulfill a program competency (or multiple program competencies) of the GCS program. These rubrics will have the ability to work in tandem; to qualify an entire program, course, or organization, it is necessary to review the requirements of each student, as well as to assess a representative sample of final deliverables within the rubric to determine if all deliverables are expected to meet program competencies. Authors expect to garner interest from Clemson's Engineers Without Borders chapter, Clemson Engineers for Developing Countries, the proposed Grand Challenge minor offering, and Grand Challenge Scholars program at Clemson University, among others.

In the future the evaluators will utilize Inter-Rater Reliability (IRR) best practices to understand the impact of the evaluators on rubric results as additional evaluators are engage with the rubric. IRR is defined as the process through which two or more raters classify subjects or objects independent of one another.[29] High IRR verifies that the raters can be used interchangeably, thereby establishing the rater as an abstract entity to the main focus of study, the subjects.[29,30] Furthermore, the evaluators plan to examine the impact of the rubric on student learning by establishing a control course without introduction to the rubric and experimental course that introduces and integrates the rubric throughout the semester.

Beyond Clemson, the rubric can be used by any institution interested in assessing any or all of the five program competencies of the GCS program, whether or not they currently have a GCS program. This application could be useful for institutions that already have a GCS program to create a cross-institutional minimum standard to ensure that NAE program competencies are fulfilled. For institutions that are considering starting a GCS program, this rubric could assess their potentially appropriate programs to determine the institutional readiness for a GCS program and highlight any deficiencies or gaps that may need to be filled, as well as potential institutional strengths. Finally, the rubric could be used in institutions that have no desire to become an official part of the GCS program but would like an indication of how well their programs are preparing students to address the Grand Challenges of the 21st century.

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