Life Cycle Thinking and Engineering in Developing Communities: Addressing International Sustainability Challenges in the Classroom

Dr. Pablo K. Cornejo, California State University, Chico

Dr. Pablo K. Cornejo is an Assistant Professor in the Department of Civil Engineering at California State University, Chico. Dr. Cornejo received his Ph.D. and Master's degree in Environmental Engineering from the University of South Florida (USF) and B.S. in Civil Engineering from the University of Colorado at Boulder. His research focused on the sustainability of water, wastewater, and integrated resource recovery systems; water and sanitation issues in the developing world; and sustainability in engineering education. Pablo is passionate about teaching and increasing the participation of underrepresented students in STEM.

Mr. Kevin Orner, University of South Florida

Kevin Orner is a Ph.D. Candidate in Environmental Engineering at the University of South Florida, where he studies nutrient management of wastewater. Kevin was a Teaching Assistant and course instructor for the Sustainable Development Engineering course in Fall 2014. After obtaining a B.S. in Civil and Environmental Engineering with a certificate in Technical Communication from the University of Wisconsin-Madison, Kevin served for two years as a Peace Corps Volunteer in Panama. In December 2011, he completed his M.S. in Civil and Environmental Engineering at the University of South Florida. Kevin is an E.I.T. with engineering consulting experience.

Life cycle thinking and engineering in developing communities: Addressing international sustainability challenges in the classroom

Abstract

Integrating sustainability issues into engineering curriculum can be used to expose undergraduates to complex global challenges related to the food-water-energy nexus. This paper explores the integration of engineering in developing communities and life cycle thinking for civil, mechanical, and mechatronic engineering students (n=79) at a Hispanic-Serving Institution (HSI) through a semester-long group project. Life cycle assessment (LCA) and life cycle cost analysis (LCCA) were used to analyze the environmental and economic impacts of energy recovery, water reuse, and nutrient recycling processes from a small-scale agricultural wastewater treatment system in rural Costa Rica. Students' ability to solve problems and produce solutions that accounted for environmental, economic, and social factors were evaluated using direct measures of student performance on specific assignments (e.g., final report, final video presentation) and indirect measures using a self-efficacy questionnaire. Direct measures were graded by the instructor of the course and an in-country partner using rubrics to assess: (1) problem definition in a global context, (2) life cycle assessment skills, (3) life cycle cost analysis skills, (4) ability to integrate social and cultural implications of proposed solutions, (5) written communication, and (6) oral communication. Students performed well in defining problems in a global context, conducting an economic analysis, and communicating via oral presentations. Improvements could be made in assessing environmental impacts, accounting for social implications of proposed solutions, and written communication via written reports. The self-efficacy questionnaire highlighted that increased communication between students and stakeholders in Costa Rica could improve understandings of social and cultural implications of proposed solutions. Additionally, restructuring the course to increase exposure to life cycle assessment could be used to improve student performance in assessing environmental impacts of engineering alternatives. This research provides insight on ways to address new ABET student outcomes 2-4 while exposing students to important global issues in environmental engineering. Additionally, this paper provides a model for future courses interested in conducting project-based learning on sustainability issues in a global context, especially for cases when international travel for large groups of students is cost-prohibitive.

1 Introduction

The United Nations Sustainable Development Goals, the National Academy of Engineering Grand Challenges of Engineering, and the recently published Grand Challenges in Environmental Engineering elucidate a direction towards a healthy, sustainable future for people and the planet. Two prominent themes in these documents are the importance of (1) sustainability to address climate change and (2) the food-water-energy nexus. These two themes are integrated into multiple Sustainable Development Goals (SDGs), including SDG 13 (climate action), SDG 2 (zero hunger), SDG 7 (affordable and clean energy), and SDG 6 (clean water and sanitation) [1]. Similarly, several of the National Academy of Engineering (NAE) Grand Challenges seek to develop carbon sequestration methods, manage the nitrogen cycle, make solar energy economical, and provide access to clean water [2]. Additionally, the Environmental Engineering Grand Challenges seek to sustainably supply food, water and energy, while curbing climate change and adapting to its impacts [3].

The Environmental Engineering Grand Challenges also give direction on how to enhance environmental engineering curriculum to address these grand challenges. In addition to depth of environmental engineering knowledge, the environmental engineer should also develop breadth in areas such as systems analysis, data science, social sciences, policy, law, humanities, health, global cultures and engagement [3]. This breadth can be achieved through extracurricular student contests and projects, such as EPA's P3 student design competition or Engineers Without Borders. While international projects driven by student organizations are beneficial to the smaller groups that actively participate in these organizations, they often do not expose larger group of students to the importance of global, cultural, and social implications of engineering problems and solutions. As a result, many engineering programs are now developing engineering curriculum that allow students to develop global competencies through coursework and/or travel [4]. Additionally, new ABET criteria for the 2019-2020 cycle call for the integration of global, cultural, social, environmental, and economic factors in engineering decision-making and design [5].

Previous studies have discussed effectiveness of international experiences [6][7] or offered assessment tools of such experiences [8]. This paper is unique in that it discusses how new ABET criteria can be evaluated through a project-based engineering course at a Hispanic-Serving Institution (HSI). As the Hispanic population grows in the United States, traditionally underrepresented Hispanic students can benefit from culturally-relevant projects focused on environmental engineering issues in Latin America. Additionally, shared language and cultural experiences between students and community members can facilitate knowledge transfer and effective communication. To the authors' knowledge, limited studies have investigated the ways in which exposure to engineering in developing communities can impact student learning objectives at an HSI. Additionally, the use of life cycle assessment allowed for a large groups of junior level students (n=79) to work on a real project of global significance with international partners that sought to address key environmental engineering goals and challenges, without the expenses of international travel. This paper provides an economically affordable model to build global competency in the classroom.

To address global sustainability challenges, climate change, and the food-water-energy nexus, an international collaboration was established to facilitate research and education. The collaboration sought to improve agricultural waste management practices for small farmers in rural Costa Rica. This site location was of particular interest due to its location in Central America and potential for enhanced relevance to underrepresented students attending a Hispanic-Serving Institution (HSI). This collaboration was established through a partnership between California State University, Chico (CSU-Chico), University of South Florida (USF), and University of Georgia, Costa Rica (UGA-CR). Kevin Orner, a recipient of a Fulbright Research Grant and a Ph.D. Candidate in Environmental Engineering at the USF, was investigating nutrient and energy recovery from agricultural waste at UGA-CR in Monteverde, Costa Rica for ten months in 2018.

In coordination with UGA-CR staff, Kevin Orner established a partnership with Pablo K. Cornejo, an Assistant Professor of Civil Engineering at CSU-Chico to aid assessment of the economic and environmental sustainability of an agricultural waste system in Costa Rica. As a result, CSU-Chico students were tasked with assessing the life cycle environmental and economic impacts of an agricultural waste system in an interdisciplinary junior level civil engineering course called "Engineering Sustainability and Economic Analysis". This paper describes the international project in Costa Rica, assessment of student performance on the project to inform new ABET student outcomes, highlights from a student self-efficacy questionnaire, and instructor insights for future improvements relevant to universities seeking to explore the food-water-energy nexus in a global context.

2 Site Location

Costa Rica has made tremendous strides towards green energy, biodiversity preservation, and carbon neutrality. Costa Rica desires to become carbon neutral by 2021 and has over 25% of its territory categorized as nature reserves, national parks, and protected forests [9]. The country's desire to protect the environment and strong in-country partners make it a great location for international collaborations in research and education. Despite Costa Rica's efforts to move towards sustainability, further work is needed to address wastewater and agricultural waste management practices. Approximately 5% of human wastewater in Costa Rica is treated, and 79,000 of 93,000 farms do not have any form of treatment for agricultural waste [10]. Therefore, an agricultural waste management investigation was carried out in San Luis, Costa Rica at UGA-CR campus and surrounding areas, where the first tubular digester was installed in 1999. Fabricio Camacho, a Ph.D. Candidate in Agricultural Engineering at the UGA-CR and General

Manager and Associate Director of UGA-CR, expanded the use of digesters to several farms in the region that previously did not treat their agricultural waste. Local farmers implemented nine tubular digesters to varying levels of success. UGA-CR is a valuable in-country partner because it hosts approximately 800 students a year, mostly from Costa Rica and the United States, for classroom, laboratory, and field education and research.

3 Agricultural Treatment System Analyzed

An agricultural waste treatment system in Costa Rica was analyzed in a civil engineering course at CSU-Chico due to its ability to recover water, nutrient, and energy, thereby addressing multiple global environmental goals and challenges. The 1,500 liter per day treatment system is located on the UGA-CR campus to treat waste from several swine and cows, which are used to provide a local source of pork and milk for visiting tourists and local staff (Figure 1). The system includes two tubular anaerobic digesters, one struvite precipitation reactor, and four lagoons (Figure 2). The digesters produce a biogas that is transferred to the cafeteria and used as a cooking fuel. The digesters also produce a sludge that can be applied to compost to increase nutrient composition. The digester effluent, which still contains nitrogen and phosphorus, is the influent to a struvite precipitation reactor. Struvite ($MgNH_4PO_4$), a slow-release fertilizer, can replace synthetic fertilizer. The liquid effluent leaving the struvite precipitation reactor enters the four lagoons for additional treatment. Tilapia are grown and harvested from the fourth (last) lagoon. Figure 3 displays the several opportunities to recover resources.

Figure 1: Photo of swine and cows. The agricultural waste from these animals is washed into two tubular anaerobic digesters.

Figure 2: Photo of the agricultural waste treatment system that includes two tubular anaerobic digesters, one struvite precipitation reactor, and four lagoons.

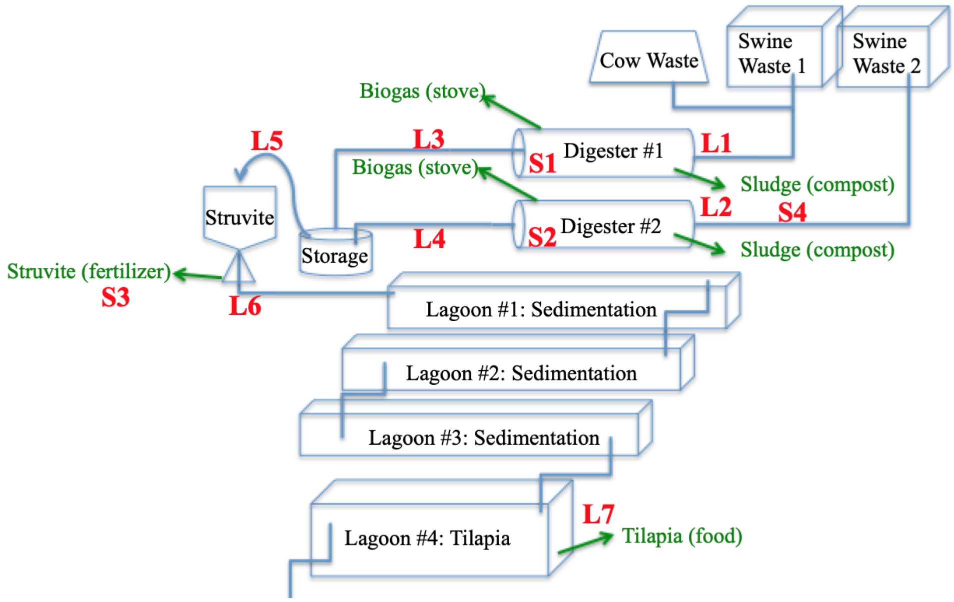

Figure 3: The agricultural waste treatment system treats waste from cows and swine using two tubular anaerobic digesters, a struvite precipitation reactor, and four lagoons. Testing locations for water quality are shown in red text for liquids (L) and solids (S). Opportunities for resource recovery are shown in green text.

Student groups worked on three sub-projects focused on varying resource recovery strategies related to the food-water-energy nexus:

- **Water Reuse**: system boundary includes infrastructure and O&M phases of the four lagoons and reutilization of the reclaimed water for fish production.
- **Nutrient Recycling**: system boundary includes infrastructure and O&M phases of the struvite reactor and subsequent utilization of the struvite fertilizer for crop production.
- **Energy Recovery**: system boundary includes infrastructure and O&M phases of the two digesters with subsequent recovery of biogas utilized as a cooking fuel.

4 Engineering Sustainability and Economic Analysis Course

Undergraduate students at CSU-Chico were tasked with conducting a life cycle environmental and economic assessment of the agricultural waste treatment system at the UGA-CR campus. The semester-long project utilized life cycle inventory data collected on-site through communication with UGA-CR staff that manage the agricultural waste treatment system. The life cycle inventory (LCI) compiled information on wastes, emissions, materials, and costs associated with the construction and operation and maintenance (O&M) phases of the system.

Interdisciplinary teams of students (n=79) in civil engineering, mechanical engineering, mechatronic engineering, and electrical engineering worked in groups to analyze: (1) life cycle environmental impacts using LCA software (SimaPro 8) and (2) life cycle economic impacts using engineering economics to evaluate net present worth. Students must have junior standing and second semester calculus as prerequisites to take this course, entitled CIVL 302 - Environmental Sustainability and Economic Analysis. Students are currently not required to take an introductory design course earlier in the curriculum, such as a first-year projects course.

A total of 17 groups worked on varying aspects of the project to address key learning objectives for the course. Direct measures were used to evaluate student performance on specific assignments. This paper aims to explore the effectiveness of this course in addressing three of the new ABET student outcomes. Learning objectives for the course and corresponding ABET 2-4 student outcomes are summarized in Table 1.

Table 1. Student Learning Objectives and Corresponding ABET Student Outcomes.

<table>
<tr><th>Student Learning Objectives</th><th>Corresponding ABET Student Outcomes</th></tr>
<tr><td>Communicate technical information to technical and/or non-technical audiences using different techniques (e.g., video, presentations, reports)</td><td>Student Outcome 3. “an ability to communicate effectively with a range of audiences.” [4]</td></tr>
<tr><td>Apply social, environmental and economic evaluation techniques to assess the sustainability of engineering alternatives</td><td rowspan="3">Student Outcome 2. “an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors” [4]</td></tr>
<tr><td>Understand systems thinking, triple bottom line design, and the application of sustainability to design given current local and global challenges</td></tr>
<tr><td>Conduct an evaluation of alternatives to evaluate economic and environmental tradeoffs and select the best design</td></tr>
<tr><td>Discuss definitions, challenges, and principles of sustainability, the evolution of engineering design, and green engineering</td><td rowspan="4">Student Outcome 4. “an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.” [4]</td></tr>
<tr><td>Comprehend the multifaceted complexity of engineering problems</td></tr>
<tr><td>Recognize that engineering and scientific knowledge is not static and therefore requires continuous life-long learning</td></tr>
<tr><td>Apply professional engineering judgment, decision-making process, statistical tools, life cycle assessment, and life cycle cost analysis to a contemporary issue</td></tr>
</table>

Student groups worked on the economic and environmental analysis of one of the resource recovery strategies and were required to produce a group video and final report as their culminating deliverables at the end of the semester. In addition to the economic and environmental evaluation, students were tasked with clearly defining the problems, needs, and significance of their project in a global context, while discussing the social and cultural implications of the proposed solutions. Using both a video and a final written report allowed for an evaluation of both oral and written communication skills, respectively. These two assignments were graded by the authors of this manuscript to assess the following criteria that relate to new ABET student outcomes (Table 2).

Table 2. Key Criteria Assessed and Description of Criteria.

Key Criteria	**Description of Criteria**
Problem Definition	Students' ability to define problems, needs, and significance of issues in a global context
Life Cycle Assessment	Students' ability to produce solutions accounting for environmental impacts
Life Cycle Cost Analysis	Students' ability to produce solutions accounting for economic impacts
Social Implications	Students' ability to discuss social and cultural implications of their proposed solutions
Oral or Written Communication	Students' ability to communicate effectively via written and oral communication

It is important to note that this course is a 300-level course designed for junior undergraduates that have not been exposed to upper division design courses. Consequently, it does not contain the same level of complexity of engineering design associated with a culminating capstone course and could be considered a formative assessment of those outcomes. At the same time, the economic and environmental evaluation tools used to address problems related to the food-water-energy nexus provide a means to better prepare students with skills that can be applied to a senior capstone. Additionally, this course provides oral and written communication practice for students to better prepare them for future courses.

Student performance was evaluated based on: (1) technical content and (2) preparation and organization using the rubrics shown in Table 3 and Table 4. Technical content included: problem definition in a global context, goal and scope, life cycle inventory, life cycle assessment, life cycle cost analysis, social implications of proposed design, and conclusions. These criteria allowed for an evaluation on the student outcomes 2 and 4 from the new ABET criteria.

Preparation and organization criteria included: effort and organization, legible and appropriate information, variety of visual aids, and oral or written communication/professionalism. These criteria allowed evaluation of ABET student outcome 3 focused on effective oral and written communication.

Table 3. Rubric used to evaluate student performance based on technical content.

Criteria	Unsatisfactory	Developing	Satisfactory	Exemplary
Problem Definition	**0-2.5** *Unsatisfactory development of problem, need, and significance to sustainability in a global context*	**2.5-5.0** *Developing development of problem, need, and significance to sustainability in global context*	**5.0-7.5** *Satisfactory development of problem, need, significance to sustainability in a global context*	**7.5-10** *Clearly defines problem, need, significance to sustainability in a global context*
Goal and Scope	**0-2.5** *Unsatisfactory presentation of goal, scope, and study design parameters*	**2.5-5.0** *Developing presentation of goal, scope, and study design parameters*	**5.0-7.5** *Satisfactory presentation of goal, scope, and study design parameters*	**7.5-10** *Exceptional presentation of goal, scope, and study design parameters*
Life Cycle Inventory	**0-2.5** *Unsatisfactory application of life cycle inventory*	**2.5-5.0** *Developing somewhat clear application of life cycle inventory*	**5.0-7.5** *Somewhat clear application of life cycle inventory*	**7.5-10** *Exceptional application of life cycle inventory*
Life Cycle Assessment	**0-2.5** *Demonstrates unsatisfactory ability to explain solutions accounting for environmental impacts*	**2.5-5.0** *Demonstrates developing ability to produce solutions accounting for environmental impacts*	**5.0-7.5** *Demonstrates satisfactory ability to produce solutions accounting for environmental impacts*	**7.5-10** *Demonstrates exceptional ability to produce solutions accounting for environmental impacts*
Life Cycle Cost Analysis	**0-2.5** *Demonstrates unsatisfactory ability to produce solutions accounting for economic impacts*	**2.5-5.0** *Demonstrates developing ability to produce solutions accounting for economic impacts*	**5.0-7.5** *Demonstrates satisfactory ability to produce solutions accounting for economic impacts*	**7.5-10** *Demonstrates exceptional ability to produce solutions accounting for economic impacts*
Social Implications of Proposed Solution	**0-2.5** *Demonstrates unsatisfactory ability to discuss social and cultural implications of proposed solution*	**2.5-5.0** *Demonstrates developing ability to discuss social and cultural implications of proposed solution*	**5.0-7.5** *Demonstrates satisfactory ability to discuss social and cultural implications of proposed solution*	**7.5-10** *Demonstrates exceptional ability to discuss social and cultural implications of proposed solution*
Conclusions	**0-2.5** *Demonstrates unsatisfactory ability to recommend solutions accounting for problem in global context*	**2.5-5.0** *Demonstrates developing ability to recommend solutions accounting for problem in global context*	**5.0-7.5** *Demonstrates satisfactory ability to recommend solutions accounting for problem in global context*	**7.5-10** *Demonstrates exceptional ability to recommend solutions accounting for problem in global context*

Table 4. Rubric used to evaluate student performance based on preparation and organization.

Criteria	Unsatisfactory	Developing	Satisfactory	Exemplary
Effort & Organization	**0-1** *Unsatisfactory evidence of effort and organization*	**1-2.5** *Developing evidence of effort and organization*	**3-4** *Satisfactory evidence of effort and organization*	**4-5** *Exceptional evidence of effort and organization*
Legible and Appropriate Information	**0-1** *Unsatisfactory presentation of legible and appropriate information*	**1-2.5** *Developing presentation of legible and appropriate information*	**2.5-4** *Satisfactory presentation of legible and appropriate information*	**4-5** *Exceptional presentation of legible and appropriate information*
Variety of Visual Aids (graphics, tables)	**0-2.5** *Unsatisfactory use of visual aids (graphic, figures, tables)*	**2.5-5.0** *Developing use of visual aids (graphic, figures, tables)*	**5.0-7.5** *Satisfactory use of visual aids (graphic, figures, tables)*	**7.5-10** *Exceptional use of visual aids (graphic, figures, tables)*
Oral or Written communication	**0-2.5** *Developing written communication, professionalism*	**2.5-5.0** *Developing written communication, professionalism*	**5.0-7.5** *Satisfactory written communication, professionalism*	**7.5-10** *Exceptional written communication, professionalism*

5 Assessment Results

Instructor Evaluation - Direct Measures

Performance of key criteria were assessed for the final report and video presentations (see Figures 4 and 5). Average scores and standard deviations for both assignments are expressed as percentages of points out of the total possible points (Figure 4). The number of groups that received exemplary, satisfactory, developing, or unsatisfactory scores is shown as a percentage in Figure 5. For both assignments, average student performance was highest for problem definition (85% for report, 87% for video) and assessing economic impacts (84% for report, 90% for video). This highlights that most students were able to (1) define problems, needs, and significance of issues in a global context and (2) produce solutions accounting for economic impacts using engineering economics. 94% of the student groups achieved a score in the exemplary range for these two criteria based on instructor evaluation.

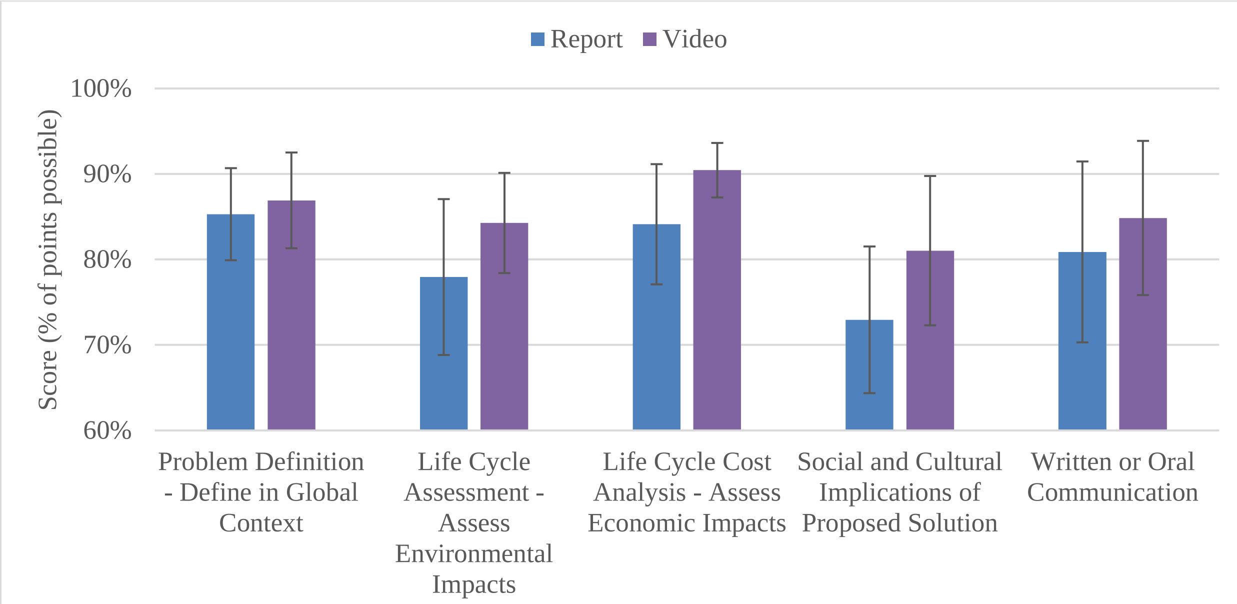

Figure 4. Student performance on final report and video for key learning outcomes, expressed as percentage of possible points.

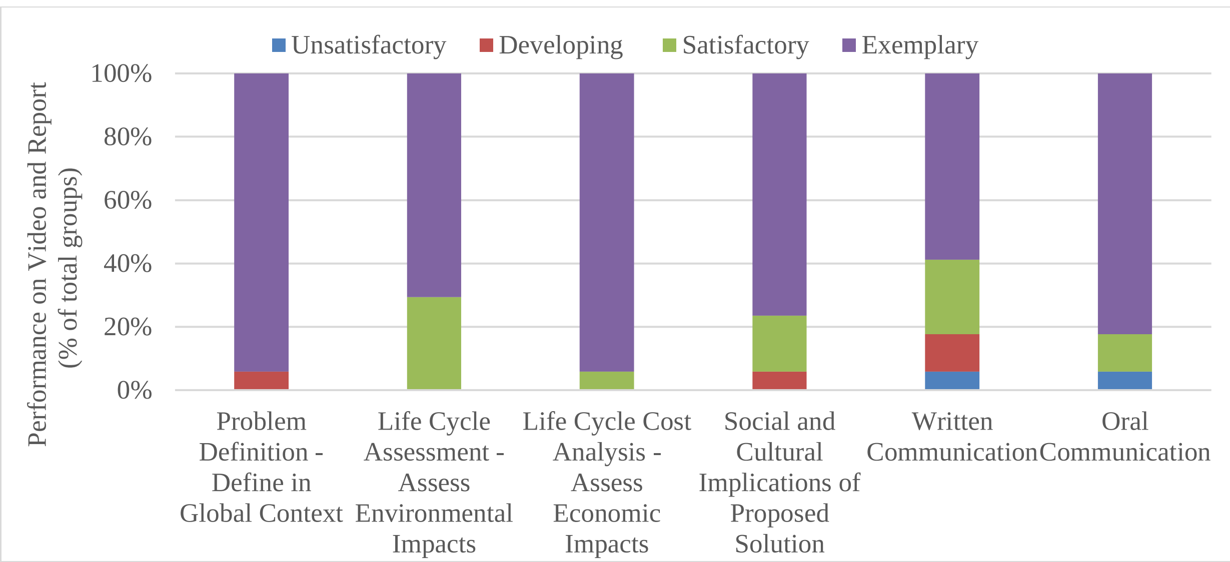

Figure 5. Performance (exemplary, satisfactory, developing, and unsatisfactory) for the video and report, expressed as percentage of total groups.

Average scores were lowest for assessing environmental impacts (78% for report, 84% for video) and discussing social and cultural implications of proposed solutions (73% for report, 81% for video). The low scores for assessing environmental impacts were often due to a lack of critical interpretation of life cycle assessment results or incorrect application of life cycle assessment. Lower scores for social and cultural implications of proposed solutions were associated with lack of in-depth discussion on context-specific issues related to social sustainability of recovering resources from animal waste (e.g., potential health risks, public perception, operation and maintenance concerns, importance of appropriate technology in developing world). 71% of the groups achieved an exemplary score for assessing environmental impacts and 76% of the groups achieved an exemplary score for discussing social and cultural implications. Additionally, 29% of the groups achieved a satisfactory score for assessing environmental impacts and 18% of the groups achieved a satisfactory score for discussing social and cultural implications.

Generally, the students' average oral communication scores (85%) were higher than their written communication scores (81%). This was primarily due to better performance in explaining results through the group video, compared to explaining the results in the final written report. For all criteria assessed, students performed better in the video assignment than the report. In this case, 59% of the groups achieved an exemplary score for written communication, whereas 82% of the groups received an exemplary score for oral communication, highlighting a large difference in performance and need for improvement in written communication skills.

Student Perception - Indirect Measures

Student perceptions of their group project performance were gathered through a self-efficacy questionnaire. The questionnaire allowed student to rate their group's performance on key criteria (refer back to Table 2). In addition to rating their group's performance, students were asked to justify their response to provide qualitative data to contextualize their answers.
Given the low performance for discussing social and cultural implications of proposed solutions, this outcome was analyzed to identify common themes in student responses. For other criteria with low performance (written communication and life cycle assessment), student responses lacked sufficient detail and were often vague. Consequently, examples of student responses for these categories were not analyzed to identify common themes.

Three common themes emerged in student responses to assessing social and cultural implications of proposed solutions (Table 5): (1) Limited detail provided - students provided limited details or lacked specific examples to justify exemplary performance, (2) Focus on positive attributes only - students focused on their ability to identify positive social and cultural implications of the proposed solutions to justify exemplary performance, ignoring potential negative consequences, (3) Further improvement acknowledged - students acknowledged that further improvements were needed to improve discussions on social and cultural implications to justify satisfactory or developing self-evaluated performance scores.

Table 5. Examples of responses and common themes from a student self-efficacy questionnaire.

Common Themes	**Examples of student responses**
Limited Detail Provided	"Social and cultural implications were discussed well in the essay. I felt like it was our strong point in the essay" "We provided good alternatives to our main solution that take into account social and cultural implications."
Focus on Positive Attributes Only	"Discussed how preventing nutrients from entering ocean has social implications that effect both fishing and ecotourism" "We were able to discuss the social aspect of using methane vs propose using our knowledge about Costa Rica's agriculture. We discussed improvements of methane to their society."
Further Improvement Acknowledged	"Social Implications were not clearly mentioned" "Could have gone more in-depth"

6 Challenges in the Classroom and Future Recommendations

Based on student performance and the self-efficacy questionnaire, improvements could be made in three key areas: (1) life cycle assessment - assessing environmental impacts, (2) social and cultural implications of proposed solution, and (3) written communication. Increasing exposure to these areas would strengthen students' ability to solve problems considering social, economic, and environmental factors in a global context.

Life Cycle Assessment – Assessing Environmental Impacts

Students' performance could be improved in the assessment of environmental impacts.
During the class, increased exposure to an open access life cycle assessment (LCA) software would be beneficial for student learning. In this case, students were using a proprietary software was only accessible in a university laboratory. This may have limited student exposure to life cycle assessment software. Additionally, increased exposure to introductory environmental engineering courses could improve performance for assessing life cycle environmental impact in upper-division courses. This could be done through a first-year projects course (currently not offered) or a new second-year 'Introduction to Environmental Engineering', a new course currently offered at CSU-Chico. The Civil Engineering Department at CSU-Chico is in the process of expanding its environmental engineering curriculum due to two new environmental engineering faculty hires. A future study could be conducted to assess the potential benefits of introductory environmental engineering course in improving the performance of upper-division courses covering complex issues, such as life cycle assessment modeling.

Social and cultural implications of proposed solution

Based on the comparatively lower performance of 'understanding social and cultural implications of proposed solutions', the data suggests that students would benefit from increased exposure to social and cultural aspects of sustainability that impact environmental engineering decisions in the developing world. The three pillars of sustainability encompass social, environmental, and economic elements; however, there is often a lack of exposure to social aspects of sustainability in engineering courses. An option to address this issue would be to introduce a freshman-level projects course that includes triple-bottom line decision making (environmental, economic, social) strategies, while emphasizing the importance of public health, safety, and welfare in engineering design. At CSU-Chico, students could then further develop these skills as juniors in the course discussed in this paper. After that, students would go on to gain a more thorough understanding of ABET student learning outcomes 2 and 4 in a senior capstone course.

In order to integrate engineering education in an international setting, a strong in-country partner is needed, as well as good communication with local stakeholders. Increased interactions with local partners via remote meetings could have increased students understanding of social and cultural context. For this course, limited remote meetings were held between students and in-country partners. Although site visits are ideal when assessing global issues, that was not feasible for a semester-long project with 79 students in two sections. Student performance could be improved by enhancing teaching related to societal factors that impact the success or failure of engineering in developing communities. Examples of societal factors of importance include: (1) appropriate technologies that utilize locally available replacement parts, (2) ease of operation of waste management technologies, (3) potential benefits of revenue generated from recovered resources, (4) the importance of public perceptions for resource recovery from waste, and (5) the importance of protection of human health and the environment.

Written Communication

An increased focus on technical writing within the course and during introductory courses would also be beneficial. Efforts are underway to better integrate technical writing early on in the Civil Engineering curriculum. Currently, students take introductory writing courses; however, the courses offered aren't specific to engineering or technical writing. Consequently, the university is exploring efforts to increase exposure to technical writing courses, specifically for STEM majors early in the curriculum. These efforts aim to improve student performance related to written communication in STEM. For the group project, efforts could also be made to improve iterative feedback, include student peer review of writing, and emphasize technical writing skills.

Instructor Insights and Future Recommendations

Future studies are needed to understand the importance of culturally-relevant pedagogy for local and international experiences in environmental engineering education. This could be done by exploring differences in student performance between groups that conduct in-country visits and groups that do not. Alternatively, comparisons could be made to assess student performance while addressing local versus international environmental issues to better understand the importance of global engagement. Local issues could focus on environmental problems impacting marginalized communities (e.g., water contamination issues in rural agricultural communities where Hispanic populations' live and work or air quality issues that impact urban communities of color). These topics are of particular interest at Hispanic-Serving Institutions (HSI) or other institutions seeking to improve student learning outcomes for underrepresented groups through exposure to culturally-relevant projects.

7 Conclusions

Engineers of the 21st century will require global competencies to address worldwide challenges associated with the food-water-energy nexus. This paper describes how engineering students can gain global competencies through a course that utilized life cycle assessment and life cycle cost analysis to analyze an operating small-scale agricultural wastewater treatment system implementing resource recovery strategies (water reuse, energy recovery, and nutrient recycling) in rural Costa Rica. Student performance data from two sections of a junior level course (n=79) suggests that highlighting environmental engineering issues in the developing world can benefit student learning outcomes at a Hispanic-Serving Institution (HSI), while addressing new ABET student learning outcomes 2- 4. ABET student learning outcomes 2 and 4 focus on producing solutions and making informed decisions accounting for global, cultural, social, environmental and economic factors, while outcome 3 focus on effective communication. Students performed well in identifying problems in a global context, economic analysis, and oral communication, while improvements could be made in assessing environmental impacts, understandings of social and cultural implications, and written communication.

This paper provides a unique framework for the integration an international project-based learning that can expose students to environmental engineering education and life cycle thinking. Knowledge creation and intercultural collaboration can facilitate a positive learning experience for students. Simultaneously, communities can benefit from environmental engineering education focused climate change mitigation strategies and the food-water-energy nexus in a rural Latin American setting. This case study provides an example of developing mutually beneficial collaborations with international partners that meet the needs of students, faculty, host institutions, and the environment.

References

[1] United Nations (UN). “Transforming Our World: The 2030 Agenda for Sustainable Development.” <https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf> [accessed July 13, 2018].

[2] National Academy of Engineering (NAE). “NAE Grand Challenges for Engineering.” <http://www.engineeringchallenges.org/File.aspx?id=11574&v=34765dff> [accessed January 16, 2019].

[3] National Academy of Sciences, Engineering, and Medicine (NASEM). “Environmental Engineering for the 21st Century: Addressing Grand Challenges.” <https://www.nap.edu/catalog/25121/environmental-engineering-for-the-21st-century-addressing-grand-challenges> [accessed January 16, 2019].

[4] N.D. Manser, C.C. Naughton, M.E. Verbyla, C. Prouty, K.D. Orner, and J.R. Mihelcic. “Improving the Global Competency of Graduate Engineers Throught Peace Corps Partnership and Long-Term International Service,” presented at 2015 ASEE Annual Conference & Exposition, Seattle, WA.

[5] ABET. “Changes in Criterion 3 – Student Outcomes” <https://www.abet.org/wp-content/uploads/2018/03/C3_C5_mapping_SEC_1-13-2018.pdf> [accessed January 16, 2019].

[6] B.K. Jesiek, Y. Chang, Y. Shen, J.J. Lin, D. Hirleman and A.E. Groll. “International Research and Education in Engineering (IREE) 2010 China: Developing Globally Competent Engineering Researchers,” presented at *2011 ASEE Annual Conference & Exposition, Vancouver, BC.*

[7] D. Budny. “International Service Learning Design Projects: Educating Tomorrow’s Engineers, Serving the Global Community, and Helping to Meet ABET Criterion,” *International Journal of Service Learning in Engineering*, vol. 6, 2011.

[8] I. Esparragoza, A. Friess, and M.M.L. Petrie. “Developing Assessment Tools for International Experiences in Engineering Education,” in *ASEE Annual Conference and Exposition*, Conference Proceedings, 2008.

[9] Climate Action. “Costa Rica pledges carbon neutrality by 2021.” <http://www.climateaction.org/news/costa_rica_pledges_carbon_neutrality_by_2021> [accessed January 16, 2019].

[10] Costa Rica Ministerio de Ambiente y Energia. “Compendio de Estadisticas Ambientales: Costa Rica 2015” < http://www.inec.go.cr/sites/default/files/documetos-biblioteca-virtual/puambientalcompendioisticas-2015-01.pdf> [accessed July 13, 2018].