



Cross-Institution Collaborative Learning (CICL) to Connect Water Resources Design with Sustainability Analysis

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Abstract

A common challenge in teaching sustainable design is the need to incorporate knowledge and skills from multiple areas of expertise. This paper describes an approach taken to meet this challenge with a collaborative learning experience that combines students from two institutions. Students from CVEEN 6460 Sustainable Urban Water Engineering at the University of Utah were teamed with students from CIVE 6670/8670 Life Cycle Engineering at the University of Toledo in a semester project experience. The design project required the students to complete the design of a rainwater harvesting project, servicing an institutional building, based on technical, economic, environmental, and social performance criteria. The project was setup to include seven deliverables, each of which included a report submission and a team presentation update at both institutions. Each deliverable encouraged collaborative learning since student teams were required to make a presentation at each institution; therefore, teammates had to help teach across institutions to cover the content of the projects not taught in their respective courses. Student performance was assessed based on the quality of each deliverable, instructor reflection, an opinion survey, and a post-course assessment of student learning. The authors conclude the paper with a discussion of the perceived benefits of the CICL approach and provide suggestions for future implementation.

Introduction

Educators have been grappling with the challenges of integrating sustainability concepts and skills into engineering education^{1,2}. Many reasons for the lack of progress have been offered, including institutional barriers preventing interdisciplinary courses, an already full curriculum, resistance to curriculum change, and lack of knowledge of social sciences and other disciplines among engineering faculty and students. To overcome these challenges, a variety of approaches have been designed to infuse sustainability concepts and techniques into engineering courses and curricula³⁻¹⁶. These ideas include actions such as modifying learning objectives to include sustainability perspectives, incorporating sustainability knowledge and skills into learning activities, exposing students to sustainability ideas using co-curricular experiences, and creating new learning modules and even entire courses.

One general problem that has been difficult to overcome in developing new sustainability-enriched engineering education material is the need for knowledge and skills from multiple disciplines to be incorporated into learning experiences. This creates limitations to what instructors can accomplish with students lacking the necessary knowledge and skills unless there are added requirements for pre-requisite coursework, additional time taken in class to teach extra material, or extra assignments for students to learn the material independently. Each of these solutions means the course must be modified to reduce content or increase time and effort of students to enable new content to be included. In most cases this is a major impediment and one that prevents instructors from moving forward with plans for anything more than superficial coverage of sustainability concepts.

This paper presents an approach that seeks to permit the use of an array of in-depth sustainability tools and analysis methods in a project, even though the details of the tools and methods are not covered in the course. The authors accomplished this by using cross-institution collaborative learning (CICL) in the form of a semester team project. This in a way represents a type of linked learning community (LLC) created by the need for collaboration on the team project.

The concept of a learning community has existed for nearly a century, with numerous examples having been presented in the literature¹⁷. Learning communities generally take one of four forms: (1) students co-enrolled in two or more courses or students from different disciplines linked by a common theme, (2) classroom learning communities, (3) residential learning communities, and (4) student-centered learning communities (honors, under-represented groups, etc.)¹⁸. The CICL approach described here is a form of the first type of learning community: it engages students from different disciplines. However, the students are not co-enrolled in the same courses. Instead, the students are linked by a central theme (sustainable design) and are taking different courses that are linked by a common learning activity (team project). The use of the collaborative learning activity is common to learning communities, yet the use of cross-institution collaborative learning is not often used because of numerous logistical challenges. This paper describes the development and assessment of a CICL approach to teach sustainable design and the necessary actions to overcome the logistical challenges. The objectives of the paper are to describe the CICL approach, evaluate its effectiveness for student engagement and learning, and provide recommendations to improve and expand in the future.

Courses and CICL Assignment

The CICL activity described here was planned, designed, and tested by Steve Burian at the University of Utah and Defne Apul at the University of Toledo. Students from two graduate level courses, CVEEN 6460 Sustainable Urban Water Engineering students from the University of Utah and CIVE 6670/8670 Life Cycle Engineering from the University of Toledo, were partnered in the fall 2014 semester. Both courses are graduate elective courses, for their respective programs, and are regularly offered at least once every two years. The goal for the CICL was to overcome the need for specialized sustainability analysis skills (life cycle assessment (LCA) and urban watershed modeling) for a project by joining students in different courses (and at different institutions) that have the two types of specialized knowledge needed. Students at both institutions involved do not have both elements of the specialized knowledge; so it presented a perfect opportunity for the CICL application and testing.

CVEEN 6460 at the University of Utah is a project-based course introducing students to concepts and tools for sustainable planning and design of urban water infrastructure systems, including water supply, stormwater, and sanitation. Topics include sustainability principles, low-impact development, green infrastructure, decentralized water supply, water conservation, secondary water systems, greywater reuse, sanitation and onsite wastewater management, water reuse, ecological wastewater treatment, water-energy nexus, climate vulnerabilities and adaptation strategies, life-cycle cost, and sustainable building and infrastructure rating systems (e.g., LEED® and Envision™). The goal of the course is to increase knowledge and competency in the practice of sustainable urban water infrastructure engineering. After completing this course students are expected to be able to:

1. Describe sustainability concepts and tools related to urban water infrastructure.

2. Plan, assess feasibility, design, estimate costs, and consider the societal and policy implications of green infrastructure systems including permeable pavement, green roofs, bioretention, and rainwater harvesting.
3. Estimate urban water demand and specify conservation measures.
4. Specify decentralized wastewater management methods including greywater reuse, dry toilets, ecological treatment, and water reuse.
5. Estimate energy requirements for urban water sector, specify energy recovery techniques, and reduce greenhouse gas emissions.
6. Determine life-cycle cost and complete life-cycle assessments for urban water infrastructure systems.
7. Compare resiliency and vulnerability of water infrastructure alternatives.
8. Complete an ISI Envision Rating for a water infrastructure project.
9. Recommend a vision for sustainable urban water infrastructure systems.

Students are assessed with individual homework assignments, a midterm examination, and a team project. The team project was modified to implement the CICL activity. In the fall 2014 semester, the course had 17 civil and environmental engineering graduate students.

CIVE 6670/8670 at the University of Toledo is a course developed based on Fink's taxonomy of significant learning¹⁹. The course focuses on life-cycle assessment (LCA) with topics introducing LCA, describing LCA steps, different LCA types, computational LCA approaches, and applications. Students are required to complete written assignments, make oral presentations, and undertake a team project. In the fall 2014 semester, the course had five civil engineering students, two chemical engineering students, and one industrial engineering student. Therefore, it is a multidisciplinary class across engineering disciplines. The learning objectives for this course were written using Fink's taxonomy and included both technical and soft skills (Table 1). Content specific skills were then elaborated as quantitative and qualitative skills as below:

Qualitative learning objectives:

1. Explain what constitutes weak (and strong) technical writing style in a journal paper
2. List the phases of an LCA and explain what is done in each phase
3. Discuss the similarities and differences between EIOLCA and process based LCA
4. Discuss the advantages and disadvantages of process based and EIOLCA
5. Discuss the similarities and differences between ReCiPe and TRACI impact assessment methods
6. Determine the appropriate functional unit for an LCA
7. List online resources for following LCA literature
8. List names and regions (where they were developed) of major life cycle inventory databases
9. List names of common LCA software
10. Explain the following terminology to an intelligent high school student:
 - a. Primary data
 - b. Secondary data
 - c. Elementary flows
 - d. Allocation
 - e. Cut-off data

- f. Consequential LCA (prospective, change oriented)
- g. Attributional LCA (retrospective, accounting style, descriptive)
- h. Gate to gate, cradle to gate, cradle to grave
- i. Technosphere

Quantitative learning objectives:

1. Given the inputs and outputs for multiple processes,
 - a. Draw a flow chart representing the system
 - b. Normalize the data for unit product output from each process
 - c. Normalize the data for the functional unit
 - d. Calculate the energy, emissions, and impact from the system based on the functional unit
 - e. Use completed LCIA results to determine where one should focus for process improvement
2. Use EIOLCA to perform a simple LCA
3. Use EIOLCA to determine how a sector can reduce impacts by working with the direct suppliers. In this analysis, the student should be able to determine the direct and indirect impacts from a sector.
4. Use matrix calculations to determine the life cycle inventory for a system
5. Given inputs, output, and functional unit of a system, determine impacts using economic allocation, mass based allocation and system expansion methods
6. Calculate the global warming potential (GWP) of using electricity using eGRID database and IPCC GWP characterization factors
7. Calculate a TRACI or a ReCiPe impact given a life cycle inventory for a system and the TRACI or ReCiPe characterization factors
8. Use GaBi software to perform simple LCAs, analyze linearity of LCA results, and compare different impact assessment methods (e.g. TRACI or ReCiPe)

Table 1: Fink's taxonomy based course objectives for the CIVE 6670/8760 course

Course Objectives:

This course will improve your **foundational knowledge** on (understanding and remembering ideas, information):

1. life cycle assessment steps and methods
 - a. goal and scope, functional unit, inventory, impact assessment, interpretation
2. computational structure of life cycle assessment problems (matrix calculations)
3. global warming potential / characterization factors
4. carbon footprint analysis

This course will improve your **application** skills such as:

5. Performing simple life cycle assessment studies for a given process using EIO/LCA and GaBi software
6. Critically reviewing articles and websites related to life cycle engineering
7. Communicating technical information (in writing and orally)
8. Managing your time
9. Managing projects
10. Creative, critical, and practical thinking and solutions

This course will improve your ability to **integrate and connect** ideas, people, realms of life such as:

11. Connecting the engineering, environmental, social, and economic factors that make engineering analysis, design or solutions sustainable or not

This course will teach you about yourself and others (**human dimension of learning**). You will:

12. Learn how you can use life cycle assessment to make more informed personal decisions in your life
13. Learn how to effectively contribute to project goals in a team effort
14. Develop your own work ethic towards submitting deliverables on time
15. Learn about how you communicate with others

This course will teach you new feelings, values, interests (**caring dimension of learning**). At the end of the class you might:

16. Get more interested in sustainability assessment tools and claims
17. Be more interested in incorporating LCA into your MS or PhD research
18. Feel overwhelmed but satisfied to have completed a meaningful project

This course will give you opportunities to **be a better student and a self-directed learner** by:

19. By using a flipped class format where the reading is done outside of class and class time is used mainly for discussions.

The team project assigned to students in both classes is included in Appendix I of this paper. The project had seven deliverables as summarized in Figure 1. The objective of the collaborative project was to design a rainwater harvesting system for an institutional building on the University of Utah campus. Thus, the case study location is local to one institution and can be subject to site visits, actual data, and coordination with facilities personnel. Deliverable 1 focused on introducing students to the concept of rainwater harvesting and provided the students the opportunity to establish methods for cross institutional collaboration using online tools (e.g. Skype, email, Dropbox). Deliverables 2 and 3 focused on infrastructure design and were led by students in CVEEN 6460. Deliverable 4 encompassed concepts discussed in both classes and were equally led by students in both institutions. Deliverables 5 and 6 focused on sustainability analysis and were led by students in CIVE 6670/8670. For each deliverable, all teams in both institutions had to do a short progress presentation in class which ensured that even if a lead institution did most of the work, the students in the other institution still needed to understand the work well enough to intelligently present it in their classes. These progress presentations also encouraged students to teach each other the concepts not discussed in their own classes. For example, students from University of Toledo had to teach some basic concepts of LCA to students at University of Utah, which overcame the lack of instruction on LCA at University of Utah. Similarly, the students at University of Utah had to teach the basic concepts of urban watershed modeling and water budget analysis to students at University of Toledo. Deliverable 7 was equally led by each institution and the students were asked to identify who wrote which section of the report. Skype was used during oral presentations of the final project where each team member presented the slides related to their own specific work. As such, some slides were presented by students in Utah and others by students in Toledo.

A unique aspect of this project assignment design was to require students to plan their online collaboration approach, to comment on it in the deliverable reports and presentations, and to continuously seek to improve the collaboration through online interaction. It is important to note that there is no organized cross-institution instruction or student-instructor interaction. The cross-institution interaction is entirely among students. Students were permitted to ask questions to the instructor at the other institution whenever they needed help, but formal instruction was not provided. Semi-formal instruction among the students was permitted and was noted to have occurred.

Teams were selected based on general student characteristics (gender, duration in program, degree level) using instructor discretion. The teams were designed to include representation from both institutions and to include at least one PhD student per team. Teams were monitored throughout the semester to ensure team dynamics remained positive and constructive. No on course corrections were needed, the teams operated effectively.

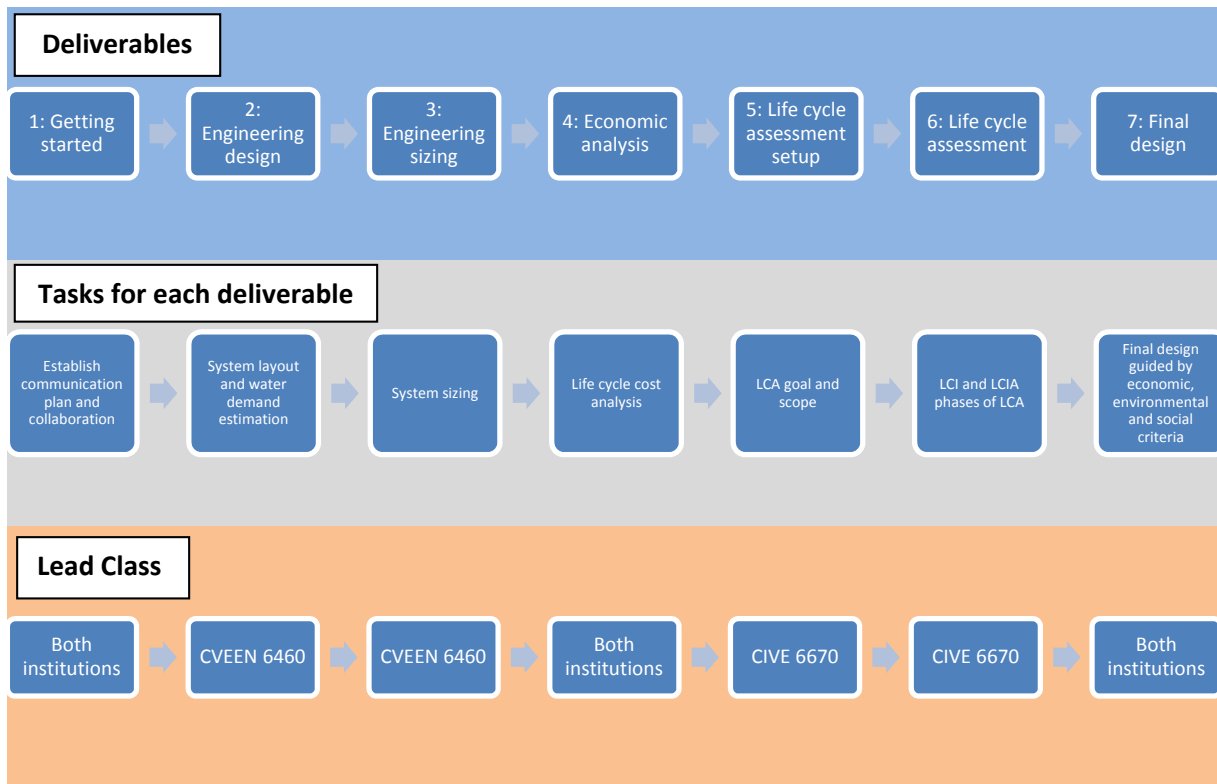


Figure 1. Schematic illustrating key phases, elements, and lead institution of the CICL project assignment.

Assessment

The authors assessed the effectiveness of the CICL approach for improving (1) student engagement, (2) accountability, and (3) learning. It was believed that the key to improving the success of this cross-institution project was the requirement that teams deliver presentations at both institutions for each collaborative assignment (see Appendix I). The teams would divide by institution to deliver each presentation because the courses did not meet at the same time. Therefore, team members were responsible to deliver presentations on content they were not taught in their home institution course, but were expected to know through interaction with team members at the other institution. Students were guided by the expectation that they should be able to explain the concepts and tasks that were the primary responsibility of students at the other institution. Students were expected to achieve the comprehension level in Bloom's taxonomy, and this was used to help guide how much cross-institution peer teaching was required.

To conduct the assessment, feedback was collected using a survey administered at the end of the semester. Five statements were provided and students ranked their relative agreement to the answers according to a Likert scale (Strongly Agree to Strongly Disagree). The five questions were:

1. The collaborative project helped me learn the content of my institution's course better.
2. The collaborative project helped me learn the content of the other institution's course.
3. The outcome of the project was negatively impacted because we could not meet as an

entire team in person.

4. As a result of the cross-institution interaction, I learned enough about the other institution's subject matter to effectively explain it.
5. I found the cross-institution interaction valuable to help me improve my social network and professional socializing skills.

Students were also asked to provide a list of the communication skills and tools used, the most valuable part of the project, the least valuable part of the project, the most frustrating part, and the most important concept or skill learned. A final question asked the students to suggest something to do differently the next time the cross-institution project was conducted.

A post-course questionnaire (see Appendix II) was administered one month after the course concluded to determine student learning of LCA basics. LCA basics were chosen because they were an integral part of the project and they were only taught in the class at the University of Toledo. Therefore, only students at the University of Utah were given the questionnaire.

To add to the assessment, the authors (instructors) reviewed the team project deliverables, and especially monitored the oral presentation deliverables. The authors noted the general quality of the deliverables and achievement of the learning outcomes associated with the project. The instructors also recorded observations of student engagement and interaction during the project and considered feedback from the students acquired through informal discussions about the project. And because the teams had to deliver content not included in their course in their presentations, the instructors could monitor cross institution student learning driven by the CICL activity.

Results

The survey and post-course questionnaire were administered one month after the end of the course to permit students to reflect on the entirety of the CICL activity and to better assess the deeper learning of the concepts. Twelve of the 16 students at the University of Utah provided responses.

Figure 2 displays the average of the results of the student responses to the survey's five statements listed at the top of this page. The student response to the first statement indicates students generally agreed that the collaborative project helped them learn the content of their institution better. Student comments indicated that they comprehended the concepts better from helping other institution's students with the same concepts. Students in general agreed or were neutral that the collaborative project helped them learn the content of the other institution's course. Although not directly compared, the student responses on the first two questions suggest their feeling was that they learned their material better by explaining it to the other institution's students than they learned the other institution's materials from having it explained to them. The responses to question 3 indicate that students did not find the lack of meeting in person as a team to have affected the outcome of the project. This is an interesting outcome of this project that shows that the students were effective in using online tools to collaborate across campuses. The responses to the fourth statement corroborated the responses to statement 2, indicating that students generally found the cross institution interaction to be helpful to learn the material.

Interestingly, the most strongly agreed statement was the one that indicated social networking and professional socializing skills improved through the cross-institution interaction. This was unexpected because no team building activities were programmed into the course.

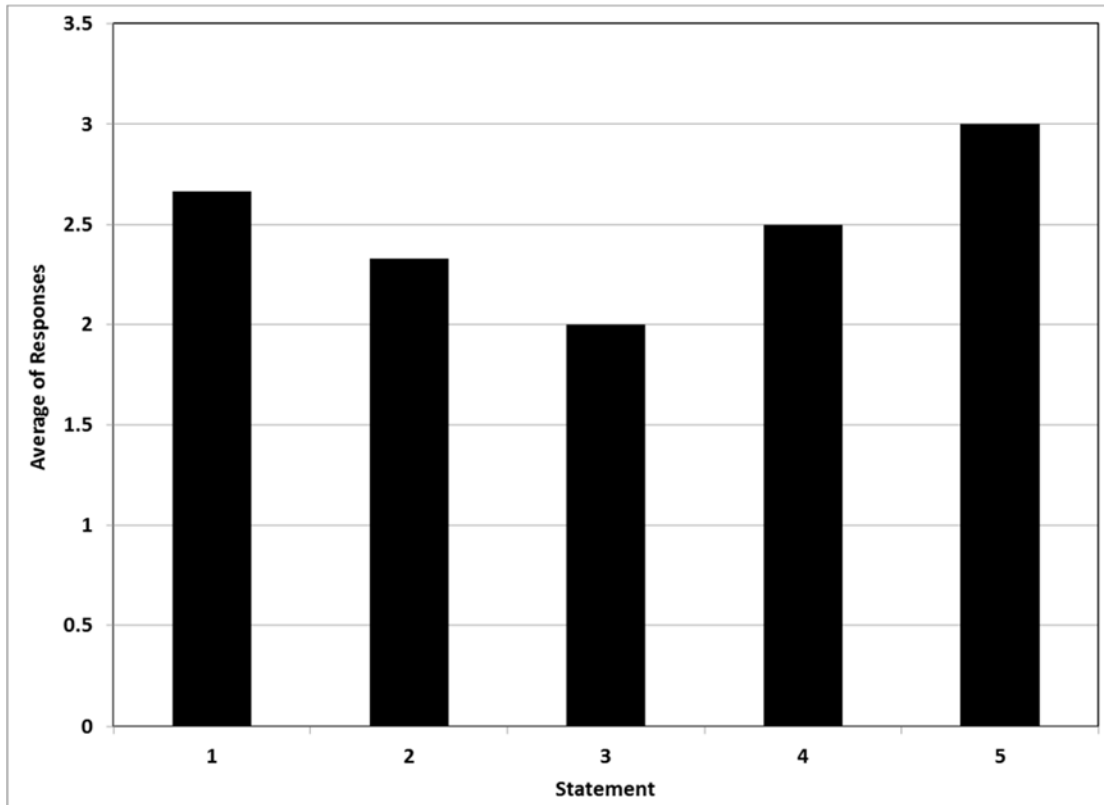


Figure 2. Summary of the student responses to five opinion statements (n = 12). The magnitude of the response was based on setting Strongly Agree = 4, Agree = 3, Neither Agree or Disagree = 2, Disagree = 1, and Strongly Disagree = 0.

The survey also acquired student feedback about the collaborative tools used to conduct the project. The authors expected students to have experience with online communication and collaboration tools. The survey responses indicated this was the case. No instruction or guidance was provided, other than the requirement that teams provide a communication plan at the onset of the project. In the survey, students reported using GoogleDrive, Skype, Email, Dropbox, Conference Calls, and Text Messaging to communicate during the project coordination and tasks.

Important feedback from the survey instrument regarded the value of the project from the students' perspective. The following list highlights the important benefits noted by the students in their comments:

- Students were positive on the long-distance collaboration because the experience will help as it is becoming more prevalent in professional practice

- Students valued the experience to operate similar to a project manager with specialized tasks being completed by members of the team
- Students enjoyed working across disciplines in graduate school, since typically they do not get exposed to students in other engineering disciplines at the graduate level

It is interesting to note that the least useful aspects of the cross-institution collaboration match the usual feedback about class projects – disappointed in quality of work submitted by team members, inability to meet consistently, and disagreement over value of written and oral reporting.

The teams submitted a final project report and presented their results in a final webinar using a Skype video call that was established between University of Utah and University of Toledo classes. The teams coordinated the presentation such that they could each present the parts of the project that they were responsible for completing. The quality of the final document and presentations were excellent. Following a rubric for the reports and presentations, each team was rated as receiving above 90% of the possible points on each of the deliverables. The quality of the presentation was noteworthy because of the cross-institution delivery. It was clear that the teams had practiced and were familiar with the content of the students from the other institution. The presentation practices are assumed to have helped further reinforce the cross-institution learning facilitated by the team project.

A general questionnaire was administered to the students at the University of Toledo asking them to provide a rating and feedback on all learning activities and aspects of CIVE 6670/8670. Highlighting a few responses, the students mentioned multiple times that the best part of the class was the team project, with comments indicating it was because they learned the most from the activity and it improved their communication and collaboration skills. The student feedback was unanimous to keep the project as part of the course, and the majority requested to increase its role.

The post-course questionnaire was the second instrument used in the assessment (see Appendix II). The results of University of Utah student knowledge gained and retained for one month after the course was fairly impressive. Unfortunately, the results cannot be compared to a pre-class questionnaire since at the time of the start of the course a study of effectiveness of the CICL activity was not anticipated; therefore, a pre-course questionnaire was not administered. The average student score on the questionnaire was 83% (approximately 9 out of 11 questions answered correctly). The most commonly missed question was number 8 (see Appendix II), which was a detailed question about LCA. Recall that LCA was not covered in the University of Utah course. The poor performance on this question is not surprising since it requires greater depth of detail of LCA to be comprehended and recalled.

Instructors' Reflections

Both instructors have been very satisfied with the CICL approach tested in their respective classes. In general, assigning projects in classes add considerable amount of planning and time management skills to both the students and the instructors. The instructors spent considerable amount of time designing the project assignment upfront which minimized the planning and other interactions between the instructors throughout the semester. From students' perspective,

the cross institution collaboration increased student time commitment. Many students informally noted that the project took a lot of time to coordinate across institutions. This time invested from students' perspective seemed valuable by some but not by others who noted that a smaller less involved project would have served them better in learning more content. In future implementations, instructors plan to spend more time explaining the nature of the project and the skills they learn from working on it that go beyond learning content.

Another challenge from the instructors' perspective is to make sure that the project is equally weighted and valued in both courses. The weight assigned to the project and the grading of the project was the same in both courses. However, in some cases, one course would have another project going on which suggested to students in the other class that the common project was not a priority. One way to resolve such issues is to create a system that allows the student in one course to more transparently see what is happening in the other course. One challenging way to facilitate this would be to allow students to use the other institution's online learning system (e.g. Blackboard course site). The instructors initially considered this approach and quickly realized the logistical challenges with it. The instructors will be considering other ways for students to more effectively see what is happening in the other course so as to help them maximize their learning and perhaps extend it to beyond the project focus.

Conclusion

This paper presented a new cross-institution collaborative learning project developed between the University of Utah and the University of Toledo. The CICL learning activity was designed to require students to complete a team design project that included design and analysis steps, with some elements being taught only at one institution. In this way, students were encouraged to interact and help each other achieve Remember and Comprehend levels of Bloom's Taxonomy for the information they learned from the students at the other institution. The courses linked by the CICL were offered in the fall 2014 semester and had 25 total graduate students enrolled.

The assessment indicated that in general, students were positive about the cross-institution interaction, but they did note it to be a source of frustration and lost time. Students displayed on a post-course questionnaire knowledge and comprehension of key concepts associated with the project and not covered in their course. This suggested that the cross-institution peer teaching and independent learning facilitated by the project was effective.

Upon reflection, the instructors concluded the first trial of the CICL team project to be a success. The most important lesson learned was the need to be highly coordinated as instructors and be ahead of schedule to make sure on course corrections could be executed. Reflections also noted students to have been enthusiastic about the project and interested in the topics being covered at the other institution that they were not learning. Genuine friendships across institutions also developed through the course interactions. Several areas were noted to be in need of improvement. Recommendations for future offerings included coordinating time so synchronous interaction during class can be scheduled. The assignment will still stress institutional updates to encourage cross-institution training, but having a fraction (2 or 3 of the 7 deliverables) of the presentations be made by the entire cross-institution team would lead to more practice with cross-institution presentation and use of online collaboration tools. Other recommendations include (1) providing training on collaborative tools and collaboration across distances, (2)

having substantive objectives and rubric elements associated with collaboration, and (3) having cross-institution instruction from the instructors to provide foundational content.

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Appendix I. Cross-Institution Team Project Assignment

Learning Objectives:

At the end of this learning module students will be able to:

- List components of rainwater harvesting systems for urban applications
- Calculate storage capacity for rainwater harvesting systems
- Apply water balance to size and analyze performance of a rainwater harvesting system
- Use life-cycle assessment tools to quantify environmental impacts of rainwater harvesting systems
- Design a water management system for a building based on technical, economical, social, environmental performance criteria
- Use online collaboration tools to perform design tasks, produce reports, and deliver presentations

Project Description

You will work in a team to design the most sustainable rainwater harvesting (RWH) system for the CME building based on technical, environmental, economic and social criteria. Teams will have members from University of Utah and University of Toledo. This project involves multiple deliverables.

Summary of Deliverables

	Deliverable	Points assigned	Due date
CA1 Getting Started	1 Oral presentation	3	9/24 (for U); 9/25 (for U)
CA2 System Layout and Estimating Water Demand	2a: report/relevant files	10	10/1 (for U), 10/2 (for U)
	2b: Oral update	3	10/1 (for U), 10/2 (for U)
CA3 System Sizing	3a: report	10	10/9 (for U), 10/15 (for U)
	3b: Oral update	3	10/9 (for U), 10/15 (for U)
CA4 Life cycle cost	4a: report	10	10/22 (for U); 10/23 (for U)
	4b: oral update	3	10/22 (for U); 10/23 (for U)
CA5 LCA Part 1	5a: report	10	11/5 (for U); 11/6 (for U)
	5b: oral update	3	11/5 (for U); 11/6 (for U)
CA6 LCA Part 2	6a: report	10	11/19 (for U); 11/20 (for U)
	6b: oral update	3	11/19 (for U); 11/20 (for U)
CA7: Final design	7a: report	22	12/4 (for U); 12/5 (for U)
	7b: Presentation	10	Finals week
	Total	100	

Collaborative Assignment 1: Getting Started

Deliverable 1: Team update presentation. Each team prepares one combined presentation. University of Utah students present this file in class to the Utah classroom and University of Toledo students present the same file to the Toledo classroom.

Grading rubric: A presentation addressing all six items below receives full points. Points are taken off if each item is not addressed well.

As a team, start collaborating and do some research towards producing a presentation that will have the following components:

1. Introduce each team member
2. A screenshot of you collaborating using online tools (e.g., Skype, Google Hangout)
3. Your plans for collaboration including weekly meeting times and online collaboration tools you plan to use
4. presentation materials explaining which parts of the US may most benefit from urban RWH implementation and why
5. Three neat examples of RWH that you found online or in your area.
6. Examples of technical, social, economic and environmental performance metrics you plan to use in your final deliverable. In other words, which specific metrics you think should be considered to evaluate the design you will be doing in this class

Collaborative Assignment 2: System Layout and Estimating Water Demand

Deliverable 2a: a mini report – including 5 sections listed below compiled into a single PDF document

Deliverable 2b: Team update

Estimate the toilet flushing and irrigation water demand at University of Utah CME building. Discuss which demand is higher and how the demand might change for different climates and buildings types.

Utah students should do the work and Toledo students should review it prior to deliverable being submitted. Each team will do a 1-2 minute update on results in their respective classes. Toledo students will need to present the work that Utah students did. So, they need to understand to a certain level what was done.

Report should include:

- i. Description of the system. Use sketches, pictures, text, graphics, etc. to describe the components of your system from the point of rainfall collection to the point of use.
- ii. Plan view “engineering” drawing of drainage areas contributing to cistern
- iii. Brief explanation of drainage details: catchment connection to cistern, water quality control, pumps, etc. should be designed and details included (preferably write details on the plan view drawing)
- iv. Estimates/calculations of water demand from irrigation, indoor uses, etc. depending on what you identify as your end uses (you are required to complete and submit your water demand estimation tool – one for both team members – and show it can provide water demand estimates for at least one year)
- v. Other pertinent details relevant for the preliminary design

Collaborative Assignment 3: System Sizing

Deliverables: 3a: Team report submitted as single PDF including elements listed below

Deliverable 3b: Team update

Size the system for toilet flushing end use using three different methods. Discuss the results from the three different methods. Utah students will do the work. Toledo students need to review the work prior to submission of the deliverable. Each team will present their results in respective classes in 1-2 minutes (i.e., team update).

Your report should include:

- vi. Summary analysis of a monthly water balance analysis showing the “optimized” cistern size
- vii. Summary of analysis of long-term (20 years+ at daily or smaller time increment) using a spreadsheet tool, the Rainwater Harvester 2.0 tool, or another tool of your choosing based on the water balance; the objective of the analysis must be to “optimize” the storage to maximize benefits
- viii. Summary of long-term analysis using SWMM; again seek to “optimize” the benefits of the system
- ix. Discuss comparison of monthly, daily with Rainwater Harvester, and SWMM analyses – how did the cistern size change?

Collaborative Assignment 4: Life Cycle Cost

Deliverable: Team report; progress update

Estimate the life cycle cost of the system. Utah and Toledo students should work organically on this assignment. One student can create the excel file and others can review/improve and type up the results.

Your report should include:

- x. Estimate of whole life cost based on three different tank sizing methods
- xi. Calculation of cost savings and payback period; include a summary assessment and recommendation

Collaborative Assignment 5: Life Cycle Assessment - Part 1

Deliverable: Team report and progress update

In this deliverable you will submitting the goal and scope stage of the LCA that should include the following discussion points:

- Goal of the LCA study
- Functional unit
- System boundary
- Time boundary
- Geographical boundary
- Cut-off
- Allocation
- Life cycle impact categories and methods
- Assumptions
- Limitations

Collaborative Assignment 6: Life Cycle Assessment - Part 2

Deliverable: Team report and progress update

University of Toledo students use GaBi software to estimate the life cycle impact using ReCiPe impact assessment method. They also use EIOLCA software to estimate the impacts. In this deliverable, you add the LCI approach and the results to what you submitted in Assignment 5

- Life cycle inventory
 1. Detailed flow chart
 2. Explanation of activities in the life cycle
 3. Data collection
 4. Data quality management
 5. Calculations
- Results
 - xii. ReCiPe process based life cycle impact results and associated discussion
 - xiii. EIOLCA life cycle impact results and associated discussion
 - xiv. Discussion comparing the results from ReCiPe and EIOLCA

Collaborative Assignment 7: Final Design

Deliverable: Team report and a final virtual party where teams present their design

Compile and synthesize assignments 1-6 into a brief and coherent final design report. Perform “value” engineering on your system to create a more sustainable design according to technical, economic, social, and environmental performance criteria.

Final report should include:

- All relevant pieces from prior reports (copy pasted/modified as needed)
- Justification of your design
- One paragraph explanation of water rights issues and how it relates to your design – recommendation to client
- Person in charge of writing each section should be indicated in the report.
- Final report outline:
 - Executive Summary (< 1 page)
 - Introduction, Background and Basis of Design
 - Objectives and Alternatives considered
 - Methods
 - System Layout and Description
 - Goal and Scope of the LCA study
 - Goal of the LCA study
 - Functional unit
 - System boundary
 - Time boundary
 - Geographical boundary
 - Cut-off
 - Allocation
 - Life cycle impact categories and methods
 - Assumptions
 - Limitations
 - Estimation of Water Demand
 - System Sizing
 - Life cycle inventory
 - Detailed flow chart
 - Explanation of activities in the life cycle
 - Data collection
 - Data quality management
 - Calculations
 - LCC

- Results
 - LCA Results
 - LCC Results
 - Other discussion
- Final Design to Maximize Sustainability
 - Includes consideration of multiple metrics and approach to weight metrics in your design iteration
 - Indicates the design changes considered during optimization process
- Conclusions and Recommendations
- References
- Appendices

Appendix II. Post-Course Questionnaire

1. A technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (resource extraction through usage and disposal), is called:
 - a. an annual review
 - b. life cycle assessment
 - c. an energy audit
 - d. a thermal system analysis
 - e. do not know

Answer: B

2. List 3 LCA impact categories.

Answer: numerous

3. What is the possible objective of life-cycle assessment of infrastructure?
 - a. monitor life-cycle of infrastructure
 - b. guide experiments of infrastructure life-cycle environmental performance
 - c. quantify infrastructure life-cycle environmental impacts
 - d. determine infrastructure user attitudes

Answer: C

4. List two life-cycle environmental impact models used to conduct LCA.

Answer: ReCiPe and TRACI

5. Which design elements would help achieve a Cradle to Cradle™ outcome of a civil engineering project? (circle all that apply)
 - a. providing child care and universal living considerations
 - b. specifying reuse of materials used in the project
 - c. locating a nearby landfill to dispose of recyclable material used in the project
 - d. seeking to ensure the protection of the safety of children and elderly

Answer: B

6. The steps of an LCA applied to civil engineering infrastructure are
 - a. install sensors, collect data for life cycle, identify needs, improve design
 - b. set scope and boundaries, inventory, produce output, interpret results
 - c. create user survey, administer survey, analyze data, make recommendation
 - d. setup experiment, simulate life-cycle, collect failure data, make recommendation

Answer: B

7. Describe briefly the SWMM model, specifically any 3 processes it can model.

Answer: varied

8. Which one of the following is true regarding: ReCiPe and TRACI

- a. They are exactly the same models; one is the newer version of the other
- b. TRACI uses characterization factors for the US whereas ReCiPe was developed for Europe
- c. One of them is an impact assessment model, the other is a life cycle inventory model
- d. One of the models global warming potential whereas the other one doesn't

Answer: B

9. List and briefly (1 sentence) describe the steps of a water budget calculation.

Answer: varied

10. The project life duration provides which of the following used to calculate the life cycle cost?
- a. A service factor used in an econometric equation to calculate cost
 - b. Project life duration is not needed in the LCC calculation
 - c. A multiplier to scale the construction costs
 - d. Number of years of future costs to include

Answer: D

11. List the three pillars of sustainability needed to evaluate an infrastructure project

Answer: economic, environmental, social