Development of a Structured-Inquiry Module for Teaching Sustainability 'Around the Cycle'

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Abstract – Sustainable engineering has emerged as a field aimed at balancing economic, environmental, and social systems during development. For sustainable engineering to contribute to sustainability, curricula reforms are needed to train sustainability-conscious engineers. The goal of this work is to apply learning theories in development of a structured-inquiry sustainability module that can be used to integrate sustainability into existing courses. The three module components (dissemination of sustainability concepts, examination of case studies, and completion of a sustainability assessment) reflect social-constructivist-based pedagogies and the Kolb learning cycle. The final outcome is a student workbook, which is designed to aid students in navigating through the module, with the class instructor serving as a facilitator. Although intended to be integrated into capstone design courses in civil and environmental engineering, the module may be incorporated into other engineering courses with slight modifications.

Keywords: sustainability education, civil and environmental engineering education, capstone design, active pedagogies, Kolb's learning cycle

INTRODUCTION

Sustainable Development

Sustainable development has emerged as a promising strategy for combating un-sustainable patterns of population growth, resource consumption, poverty, and environmental degradation. The most widely accepted definition of sustainable development, published in *Our Common Future* in 1987, states that sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. The outcome or goal of sustainable development is to create a sustainable society, which is "one that can persist over generations, one that is far-seeing enough, flexible enough, and wise enough, not to undermine either its physical or its social systems of support" [2]. Thus, according to a sustainable development paradigm, alleviation of many global dilemmas requires that equity be promoted both within and between generations.

To provide a supporting conceptual framework, the 2002 Johannesburg Declaration proposed the three pillars of sustainable development. According to this framework, sustainable development requires economic development, social development, and environmental protection [3]. Economic sustainability requires that a development maintain or improve economic welfare, while environmental sustainability dictates conservation of natural resources [4, 5]. A project is socially sustainable if it improves social equity and provision of services [4, 5]. Many organizations and academic authors have since endorsed a sustainable development paradigm and the three-pillars framework [4, 6, 7].

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Sustainable Engineering

Although technological innovation has contributed to current unsustainable practices, engineering is important for developing and implementing sustainable development strategies. Sustainable engineering has emerged as a new field aimed at integrating and balancing economic, environmental, and social systems during global development [7-11]. To advance the area of sustainable engineering, experts gathered at a 2002 Green Engineering Conference held in Sandestin, FL and devised a set of sustainable engineering principles (Table 1) [12]. While these principles do not outline a sustainable design methodology, they can be used with existing design strategies to produce sustainable projects [12]. The need for sustainable engineering has been recognized by many organizations, including the National Research Council [13], National Science Foundation [14], National Institute of Standards and Technology [15].

Table 1. Summary of Sustainable Engineering Principles [12].

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

Sustainability and Higher Education

1. Need for Curricula Reform

For sustainable engineering to effectively contribute to global sustainability, engineering curricula must be updated to properly train sustainability-conscious engineers. Current curricula emphasize disciplinary specialization and reductionist thinking [16-18]. As a result, many engineers are "unbalanced, over-specialized, and mono-disciplinary graduates" who use their narrow skill sets to solve problems by analyzing system components in isolation [17]. In contrast, the complex nature of global and local dilemmas necessitates that sustainable engineers exercise interdisciplinary and systems thinking to understand and balance the interrelated technical, economical, environmental, and social dimensions of a problem. For instance, alleviation of global problems of resource scarcity and environmental degradation in the context of a growth population requires a broad knowledge base and the ability to analyze problems holistically [19]. Thus, significant changes in engineering education are needed to equip students to tackle complex global problems.

2. Support for Curricula Reform

Numerous international agencies and professional organizations have endorsed reforms to integrate sustainability principles into engineering curricula to guide students in developing holistic and critical-thinking skills. For instance, Agenda 21, a landmark document issued as a result of the 1992 Earth Summit in Rio de Janerio, calls for "deeper" education to provide students with the principles, skills, and desire needed to engage in sustainable development practices [20, 21]. Recognizing that practicing engineers, the principal agents responsible for designing and implementing development projects, are in a unique position to promote sustainable development, many organizations, including the Accreditation Board for Engineering and Technology (ABET), the American Association of Engineering Societies (AAES), and the American Society of Civil Engineers (ASCE) have advocated for integration of sustainability into undergraduate curricula [22, 23]. In fact, the first fundamental canon in the ASCE Code of Ethics calls for engineers to "comply with the principle of sustainable development in the performance of their professional duties" [24]. Since only a bachelor's degree is required to become a practicing engineer, it is essential that curricula reforms occur at the undergraduate level. Despite organizational support for improved sustainability education, integration of sustainability concepts and principles into engineering curricula is still considered revolutionary at many institutions [25].

3. Curricula Reform Strategies

Two common methods for effective incorporation of sustainability concepts into curricula include horizontal and vertical integration. Horizontal integration is a strategy where concepts are incorporated into several courses across a curriculum, while vertical integration involves the addition of new sustainability courses into an existing curriculum [26]. Dissemination of a new course with sustainability content is essential for teaching students about fundamental concepts and principles related to sustainability [27]. However, vertical integration alone may be insufficient because only teaching students about sustainability separate from core engineering concepts does not encourage them to incorporate sustainability into their professional designs and practices [27]. Rather, integration of sustainability into existing courses may aid students in viewing sustainability in a systemic and holistic manner by demonstrating how sustainability and technical content can be blended to create sustainable designs [26, 27].

Whether courses are modified or created to include sustainability concepts, they may be classified as sustainability-related or sustainability-focused courses. Sustainability-related courses include emphasis on one of the three sustainability pillars, while sustainability-focused courses concentrate on the interrelationships between the three sustainability pillars or analyze a topic using a sustainability framework [28]. Sustainability-focused courses may be characteristic of vertically-integrated courses, since content is dedicated to teaching students about fundamental sustainability concepts. However, horizontally-integrated courses may be sustainability-related or sustainability-focused, depending on the extent to which the economic, environmental, and social dimensions can be intertwined with traditional content. Nevertheless, several strategies and course types are available for incorporation of sustainability into engineering curricula.

4. Examples of Curricula Reform

Several initiatives to integrate sustainability into engineering curricula have been undertaken in the United States and abroad. Vertical integration was employed at Iowa State University through creation of a multi-disciplinary sustainable engineering course [29]. Similarly, the University of Missouri piloted a sustainable design course in its civil engineering curricula [30]. Horizontal integration was used at Washington State University by piloting a capstone design course that encouraged multi-disciplinary teams to consider sustainability while designing an on-campus sustainable farm [31]. Delft University of Technology integrated sustainability into its curricula using both vertical and horizontal integration through initiation of the Education in Sustainable Development (ESD) project in 1998. The ESD project included creation of the Technology in Sustainable Development course, incorporation of sustainability concepts into nearly all courses, and creation of a graduate specialization in sustainable development [32]. Thus, a variety of initiatives are being conducted to improve the quality of sustainability education.

Project Scope

The goal of this project is to develop a pedagogically-sound module that can be used to facilitate horizontal integration by transforming an existing undergraduate capstone design course into a sustainability-focused course. The project objectives are to: (1) outline the theoretical framework for module development, (2) develop and disseminate a guided-inquiry module that allows students to actively learn about and engage in sustainability analysis, and (3) provide suggestions for module implementation.

THEORETICAL FRAMEWORK

The sustainability module employs several theoretically-grounded pedagogies to promote student learning and application of sustainability. Specifically, constructivist- and experiential-learning-theory-based pedagogies of inquiry teaching and learning-cycle-based instruction are applied to encourage student engagement in learning.

Constructivist Theories and Related Pedagogies

1. Constructivist Theories

Constructivist theory proposes that knowledge is constructed by the learner. In contrast to the positivist viewpoint that objective knowledge can simply be transferred from teacher to learner, constructivists postulate that students construct knowledge as they process their own experiences. If experiences align with a student's view of reality, then the new information is assimilated into his or her knowledge framework. However, if an experience contradicts a student's understanding of reality, then the new information may either be accommodated by altering his or her

view of reality or ignored. Either through assimilation or accommodation, learning requires that students engage in experiences. Thus, constructivist theory holds that learning is an active, experience-driven process [33, 34].

Social constructivist theory suggests that learning is fundamentally dependent on social interactions. While there are differing branches of social constructivism, the emergent or pragmatic perspective describes learning as occurring as students internally construct knowledge through their social interactions within a community [35, 36]. As a result, pragmatic social constructivism posits that learning occurs both individually and in the context of group interactions [37]. Thus, application of social constructivist theory requires that students engage in active learning through collaboration with peers.

2. Inquiry-Based Teaching and Learning

Inquiry-based teaching is an inductive method based on constructivist theories. In contrast to traditional teaching methods, inductive teaching requires that a context for learning be presented before introducing fundamental theories and concepts. For instance, examining a case study on sanitation in a developing country may encourage students to engage in a lecture on drinking water treatment. A key feature of inductive teaching strategies is that they promote a student-centered learning environment by encouraging active, collaborative learning. Active learning requires that students assume responsibility for the learning process, while collaborative learning occurs when students learn from their peers. One example of active, collaborative learning is learning-by-teaching where students prepare and deliver concepts to group members. Inductive teaching strategies comply with constructivist theories by providing students with opportunities to engage in experience-driven learning [33, 38].

Inquiry teaching uses problems to provide a context for learning. Several types of inquiry teaching can be employed, each of which varies in the level of instruction provided by the teacher. In structured inquiry, students are given a problem and guidelines for how to solve the problem. Alternatively, in guided inquiry, students are provided with a problem but they are required to solve the problem without instructor directions. Open inquiry requires that students both select and solve the problem. Regardless of the inquiry teaching strategy chosen, students are encouraged to actively learn by engaging in experiences [33].

Experiential Learning Theory and Related Pedagogies

1. Experiential Learning Theory

Originally proposed by Kolb and based on constructivist theory, experiential learning theory (ELT) is a model for adult development which asserts that experiences play a key role in the learning process. ELT postulates that learning is "the process whereby knowledge is created through the transformation of experience" [39]. Thus, learning occurs as students process educational experiences and integrate resulting conclusions into their existing knowledge bases. Furthermore, the ELT model proposes that student learning occurs in two stages: grasping experiences and transforming experiences. Students may grasp or perceive experiences through concrete experience (CE) or abstract conceptualization (AC). Concrete experiences may occur by perceiving information by using one's senses, while AC can include perceiving information through concepts or symbols [40]. Once experiences have been grasped, they are transformed or processed through reflective observation (RO) or active experimentation (AE). Those that reflectively process experiences may do so by contemplating the actions of themselves or others, while active processers may begin to immediately experiment with their new-found conclusions. Depending on a student's learning style, he or she will often used a preferred method for grasping experiences (CE or AC) and transforming experiences (RO or AE) [39, 41].

2. Learning Cycle-Based Instruction

Based on experiential learning theory, Kolb postulates that complete learning occurs when students engage in all phases of the learning cycle (Figure 1). Based on the methods for concept grasping and transformation, Kolb's learning cycle consists of four parts: CE, RO, AC, and AE. Learning begins when a student engages in a given experience (CE) and continues as he or she reflects on that experience (RO). Student reflection leads to development of logical conclusions, to which theoretical or expert ideas can be added (AC). Finally, students apply new concepts and skills are tested (AE) to serve as templates for new experiences (CE) [39, 41]. Often referred to as "teaching around the cycle," [33] Kolb's ELT suggests that an instructor can promote complete learning by designing course materials [40] to encourage students to complete all learning cycle phases (Figure 1). For instance, CE may be facilitated through laboratories or primary text reading, while RO is promoted through journals and

brainstorming [42]. Next, AC can occur during lectures or model building, while AE is encouraged through projects and case studies [42]. When teaching around the cycle, students are encouraged to learn as they are taught using their preferred styles. However, teaching students using less-preferred styles may help them to develop new ways of thinking about problems or ideas [33, 41, 42].

Sustainability Education Research

Discipline-independent theories and pedagogies are important for facilitating effective teaching and learning related to sustainability. For instance, Segalàs et al. [43] conducted a study analyzing sustainability concept map scores from ten classes administered with different pedagogies in the United Kingdom (UK). Active pedagogies included project-based learning, case study, problem-based learning, backcasting, and role playing. Results indicated that student learning about sustainability was improved when experiential and active learning pedagogies were used in the classroom [43]. Thus, student learning about sustainability can be encouraged by providing opportunities for collaborative, student-driven experiences.

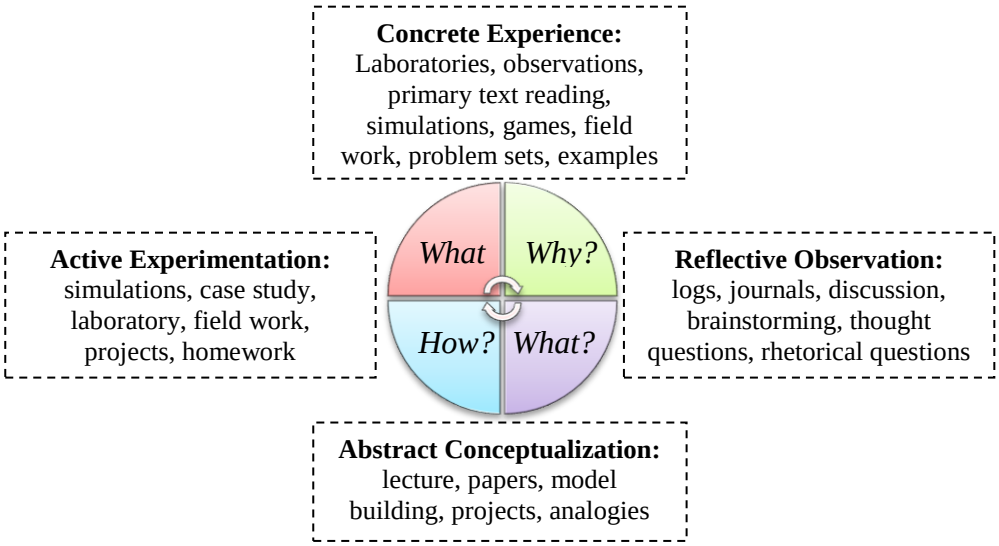

Figure 1. Kolb's learning cycle and corresponding classroom activities [39, 42].

MODULE DEVELOPMENT

For this project, a module was developed to encourage students to actively engage in learning and application of sustainability concepts and principles by teaching "around the cycle" using active and collaborative pedagogies. First, a survey of literature on sustainability was completed to identify areas in which a sustainability-conscious engineer should be proficient. After an extensive literature review, it was determined that students should have a fundamental understanding of sustainability and sustainable development, as well as five sustainability themes: economic sustainability, environmental sustainability, social sustainability, sustainable engineering, and sustainability assessment. For each theme, a detailed 5-8 page tutorial and corresponding reflection question was developed. Next, a series of activities were developed in accordance with the Kolb learning cycle to encourage students to learn about and apply each theme. Finally, a module workbook was compiled to include all materials necessary for student-led module completion. The module workbook was reviewed by faculty and graduate students in environmental engineering, computer engineering, aerospace engineering, and educational psychology to evaluate relevance and comprehensiveness of sustainability content, as well as suitability of module structure and pedagogies for undergraduate students. Reviewer comments, such as requiring students to submit key activities and shortening required readings, were addressed during final workbook compilation.

MODULE DISSEMINATION

Module Description

The developed sustainability module is intended to be integrated into undergraduate civil and environmental engineering (CEE) capstone design courses. Students will complete a series of assignments and activities, both individually and in their capstone groups, to learn about sustainable development and design. Completion of the module should aid students in incorporating sustainability concepts into their final capstone design projects.

Module Components

1. Overview

The module is composed of three components that include material to promote student understanding of both sustainable development and design. In Part 1, students learn about fundamental sustainability concepts, while they identify application of those concepts in case studies in Part 2. During Part 3, students apply sustainability concepts to their own capstone project by completing a preliminary sustainability assessment (Figure 2).

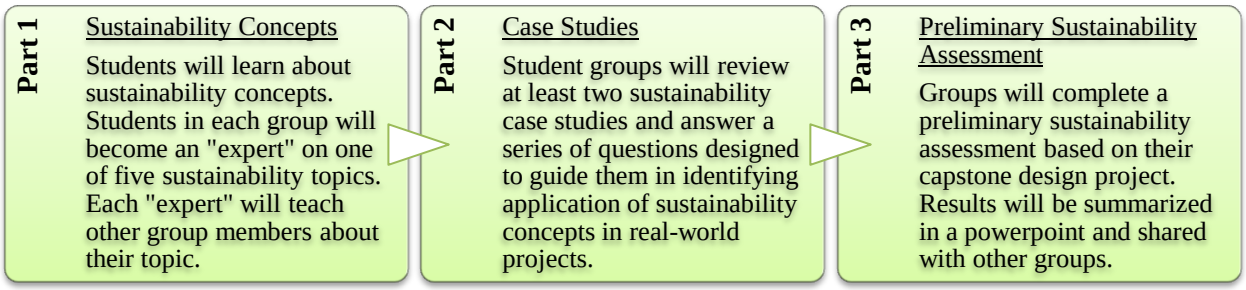

Figure 2. Three sustainability module components.

1. Part 1: Sustainability Concepts

The purpose of Part 1 is for students to collaboratively learn about sustainability concepts that can later be applied in their design projects. Before class, students will familiarize themselves with sustainable development by completing a series of activities independently: reading primary literature, responding to a reflection question, and reviewing a tutorial (Tables 2-3). Next, students in each group will select a unique sustainability theme on which to become an "expert". The themes include economic sustainability, environmental sustainability, social sustainability, sustainability assessment, and sustainable engineering (Table 3). Before class, students will repeat the aforementioned independent activities for their sustainability topic (Tables 2-3). Using provided lecture outlines, students will then prepare mini-lectures to teach group members about their topics. Students will also review the tutorials for other sustainability themes. In class, students will deliver mini-lectures to group members and record key concepts from other lectures using provided outlines. While each student becomes an "expert" on only one theme, in-class lectures should ensure that group members learn about all five sustainability themes.

Table 2. Required readings and reflection questions for sustainable development and five sustainability themes.

Theme	Required Reading[1]	Reflection Question
Sustainable Development	[44]	Can humans escape the Tragedy of the Commons?
Economic Sustainability	[45]	Why is economic development an important component of sustainable development?
Environmental Sustainability	[46]	Why is environmental protection an important component of sustainable development?
Social Sustainability	[47]	Why is social development an important component of sustainable development?
Sustainable Engineering	[8]	Why is it important for engineers to promote sustainable development?
Sustainability Assessment	[48]	Why is sustainability assessment important to engineers?

[1]Supplementary readings provided in tutorials.

2. Part 2: Sustainability Case Studies

The purpose of Part 2 is for students to identify sustainability concepts learned during Part 1 in case studies. Students will first review an extensive case study on the Beddington Zero Energy Development (BedZED) [49], a housing development in London that was designed to include numerous sustainability initiatives, such as use of only renewable energy, incorporation of low-impact materials, and promotion of waste recycling [49]. Next, students will select a shorter case study from a provided database that relates to their capstone project. The database includes case studies on wastewater treatment, buildings, transportation, hydrology, and construction provided by *GreenSource* magazine [50], the National Center for Appropriate Technology (NCAT) Smart Communities Network [51], the National Resources Defense Council (NRDC) [52], and the Royal Academy of Engineering (RAE) [53]. After reviewing case studies, groups will answer a series of questions (Table 4) to aid them in identification of sustainability concepts in real-world examples.

Table 3. Topics covered in tutorials[1] on sustainable development and five sustainability themes.

Sustainable Development	Social Sustainability
• Global trend in population, resource consumption, and environmental degradation • Tragedy of the Commons • Definition of sustainable development • Triple-Bottom-Line Model • Nested Dependencies Model • Hierarchy of unsustainable actions	• Socially sustainable communities • Methods to promote social sustainability • Stakeholder engagement • Stakeholder identification • Stakeholder mapping • Engineering ethics • Project social sustainability
Environmental Sustainability	**Sustainable Engineering**
• Fundamentals of ecosystems • Definition of environmental sustainability • Precautionary principle • Daly Principles • Natural Step Framework • IPAT equation • Environmental impact assessments • Lifecycle analysis • Project environmental sustainability	• Green engineering and systems engineering • Sustainable design methodologies • Nine Principles of Sustainability Engineering • Hannover Principles for Design • Sustainability indicator frameworks • Environmental assessment tools (LCA, MET matrix, Eco-Indicator 99) • Strategic design tools (Ecodesign Web, Design Abacus)
Economic Sustainability	**Sustainability Assessment**
• Economic growth and development • Neoclassical and ecological economics • Five Capitals Model for economic sustainability • Neoclassical economical view of sustainability • Ecological economical view of sustainability • Project economic sustainability	• Origin of sustainability assessments • EIA-driven sustainability assessment • Objectives-led sustainability assessment • Sustainability indicators • DPSIR indicator framework • UNCSD indicator framework

[1]Tutorials are 5-8 page documents that explain fundamental topics for sustainable development and the five sustainability themes. Tutorials were developed as part of the module workbook and are available upon request.

Table 4. Questions used to guide students in identifying sustainability concepts in case studies.

BedZED Case Study Questions
1. What was the overall project goal?
2. What were the environmental, economic, and social objectives? What strategies were used to meet objectives?
3. Are the principles of sustainable design addressed in the BedZED project?
4. Explain why or why not the sustainability objectives outlined for the BedZED project were fulfilled.
Group-Selected Case Study Questions
1. What economic, environmental, and social issues were addressed in your case study?
2. How could the strategies for addressing sustainability issues used in the case study be applied to your project?

3. Part 3: Preliminary Sustainability Assessment

The purpose of Part 3 is for students to apply sustainability concepts to their own capstone design projects (Table 5). Students will complete a brief system outline and provide an overview of their project. Next, students will consider the sustainability of their projects by outlining potential project impacts (economic, environmental, social), completing a stakeholder analysis using a power interest matrix [54-56], proposing sustainability objectives and related indicators, and discussing possible applications of the Sustainable Design Principles (Table 1). The final product will be a powerpoint presentation that will be shared with other groups.

Table 5. Requirements for preliminary sustainability assessment to be presented in powerpoint format.

System Description	Project Overview
• Provide a visual depiction of the system. • State the purpose of the system. • Define the boundary of the system. • List the components within the system. • Describe relationships between system components.	• State the main project goal. • Outline technical objectives. • State any constraints.
Sustainability Considerations	
• Potential Impacts: Outline potential positive and negative economic, environmental, and/or social impacts that could result from your project. • Stakeholder Analysis: Conduct a stakeholder analysis and display your results in a power/interest matrix. Identify any groups whose interests may need to be protected (high interest, low power). What methods would you use to promote stakeholder participation? • Sustainability Objectives: Based on the possible impacts previously outlined, propose objectives for each sustainability dimension. Provide at least one sustainability metric for each objective. • Sustainable Design Principles: Describe how three Principles can be applied to your project.	

Module Theoretical Basis

1. Pedagogies Founded in Constructivist Theory

Several instructional methods based on constructivist and social constructivist theories will be applied during module implementation (Table 6). First, the module will be designed to promote structured inquiry learning by requiring that students produce a sustainability assessment using information in the tutorials (Table 3), case studies (Table 4), and assessment instructions (Table 5). Second, collaborative learning will be encouraged by requiring that students complete most activities and assignments in groups. Learning-by-teaching, a collaborative learning method, will be employed as students prepare and deliver mini-lectures on assigned topics for their group members. Both inquiry-based and collaborative teaching methods promote active learning, which requires students to be responsible for their own learning processes.

2. Pedagogies Founded in Experiential Learning Theory

Individual and group learning will be facilitated by encouraging students to engage in Kolb's learning cycle (Table 6). Module content was developed to ensure that students complete each of the four phases of learning (Figure 3). Throughout the three-part module, students will be introduced to primary literature, encouraged to reflect on a sustainability topic, provided with tutorials, and challenged to apply the new concepts to case studies and their capstone design projects.

Module Workbook

The final outcome of this project is a student workbook that can be used to implement the designed sustainability module into existing capstone design courses. Since the module is completed primarily by students with the instructor serving as only a facilitator, the workbook is essential for effective module delivery. Workbook contents for Part 1 include required readings, reflection questions, detailed tutorials, lecture outlines, and notes pages for all sustainability topics. Directed case study questions and a final project description are included for Parts 2 and 3, respectively. In addition, directions for completing before- and in-class assignments for each module component are

included to ensure that students understand all requirements. Electronic copies of this workbook are available from the primary author upon request.

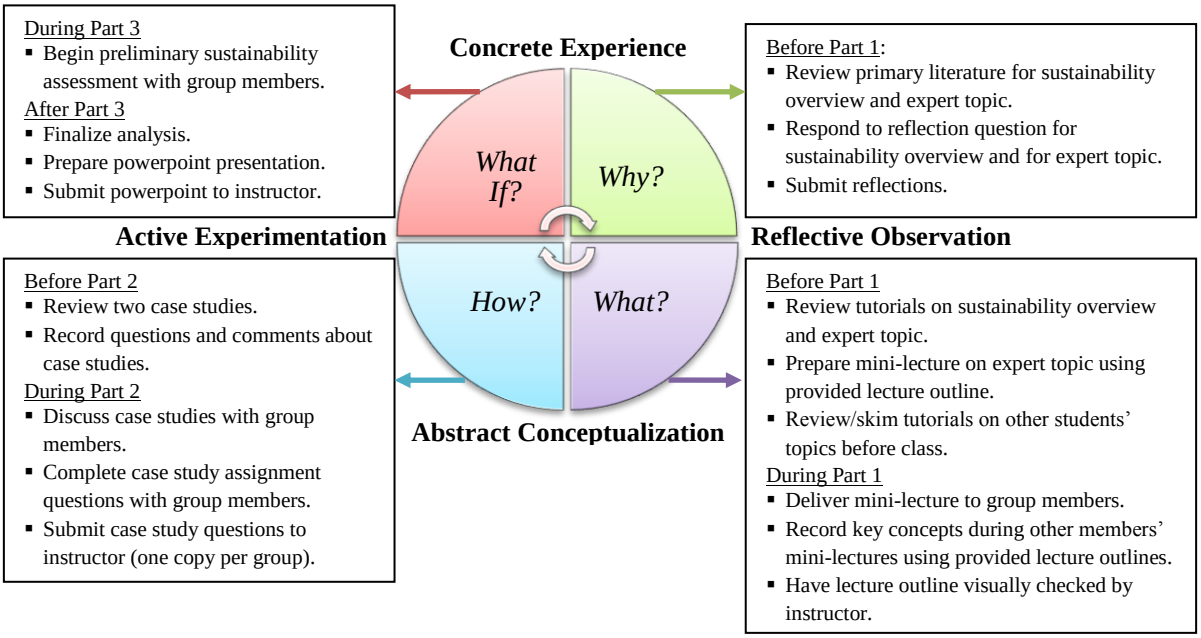

Figure 3. Sequence of class activities based on learning cycle.

Table 6. Summary of pedagogies to be applied during capstone design course with module implementation.

Pedagogy	Theoretical Basis	Method of Application
Inquiry-based teaching and learning	Constructivism	• Students engage in capstone design experience. • Embedded module guides students in producing a sustainability assessment for their project.
Collaborative Learning	Social Constructivism	• Students work in groups to learn module content and analyze related case studies. • Students work in groups to complete their project sustainability assessment. • Students prepare powerpoint presentations within groups to summarize sustainability assessments and to share with peers.
Learning-By-Teaching	Social Constructivism	• Students are responsible for becoming an expert on one of five sustainability topics. • Students are responsible for teaching their topic to group members.
Learning-Cycle-Based Instruction	Experiential Learning Theory	• Before class, each student is responsible for reading primary literature (CE) and responding to reflection questions (RO). • Before class, students review their assigned topic and prepare a mini-lecture for group members (AC). • During class, students take notes on all mini-lectures (AC). • Students review case studies and identify concept applications (AE). • Students apply concepts when preparing project sustainability assessment (AE).

MODULE IMPLEMENTATION

Implementation in CEE Capstone Courses

The developed sustainability module is intended to be implemented into existing capstone design courses in CEE. Before module delivery, the instructor should divide (or let the students divide) into groups of five, distribute workbooks, and introduce the module to students. It should be emphasized that the instructor will serve as a facilitator, while student groups are responsible for dissemination of content and completion of assignments. It should also be noted that module success will depend on students completing required assignments before class to ensure that in-class activities are completed in a timely manner. Furthermore, because of the collaborative nature of the module, the quality of the module experience is dependent on both individual and group contributions. It is recommended that instructors monitor student completion of benchmark assignments, such as lecture delivery, case study analyses, and sustainability assessment powerpoints. Some assessment suggestions are included in Figure 3.

Implementation in Other Undergraduate Engineering Courses

The sustainability module could be implemented into undergraduate courses other than CEE capstone design. For instance, integration of the module into an undergraduate CEE course would only require that students select a project on which to conduct a sustainability assessment. For instance, in a civil engineering systems course at the Georgia Institute of Technology (GT), students complete a sustainability analysis of existing infrastructure systems [57]. Incorporation of the module into a non-CEE course would require that discipline-specific case studies be selected for Part 3, and the directed case-study questions (4) be adjusted if necessary. Thus, the module can be slightly modified for application in a variety of engineering courses.

Time Requirements

Integration of the sustainability module into an undergraduate course requires that sufficient time be allotted to module delivery (Table **7**). It is estimated that the module can be completed using nine hours of class time, which represents three weeks of classroom instruction for a three-credit course. Part 1 will require almost three hours of class time to allow students to deliver 20-30 minute presentations to group members on the five sustainability themes. Part 2 will require 1-2 hours of class time for students to analyze case studies, while 2-3 hours should be provided for students to complete the sustainability assessment. Students will also be required to dedicate time before class to ensure that in-class activities do not take longer than the allotted time. The in-class time commitment was set to have a substantial impact on student sustainability learning, while not detracting excess time from the actual capstone project.

Table 7. Summary of pedagogies to be applied during module implementation.

Module Component	Assignment(s)	Time Requirement (hr)
Part 1		
Before class	Review all materials on sustainable development and sustainability theme. Prepare min-lecture. Read tutorials for remaining sustainability themes.	2-3
In class	Students deliver lectures and take notes on other students' lectures.	2.5-3
Part 2		
Before class	Read BedZED case study and additional case study.	1
In class	Answer directed case study questions in groups.	1-2
Part 3		
Before class	Brainstorm about sustainability aspects of capstone project.	1
In class	Complete preliminary sustainability assessment using provided guidelines.	2-3
In/after class	Summarize results in powerpoint format to share with peers.	2-3

SUMMARY AND CONCLUSIONS

A sustainability module for integration into CEE capstone design courses was developed to facilitate horizontal integration of sustainability into undergraduate curricula. The following points describe the theoretical basis, development, and implementation of the module.

1. Active learning and learning-cycle-based instruction, founded on social-constructivist and experiential learning theories, are effective pedagogies for teaching students about sustainability.
2. The module was developed to encourage students to apply sustainability principles in final design projects by guiding them in learning sustainability concepts, identifying sustainability concepts in case studies, and conducting a preliminary sustainability assessment.
3. The sustainability module can be implemented into CEE capstone courses, or it can be slightly modified to be incorporated into other engineering courses.

Though the proposed sustainability module cannot alone transform an undergraduate curriculum, it can be used to supplement other sustainability initiatives. While some efforts may focus on disseminating sustainability concepts in new or existing courses, inclusion of a sustainability module in capstone design allows students to practice simultaneous application of sustainability and technical knowledge. Current undergraduate students will soon be responsible for local and global development projects that will impact both humans and the environment. Thus, combating current trends in poverty, resource consumption, and environmental degradation using a sustainable development paradigm requires that undergraduate curricula equip future engineers to engage in sustainable design.

FUTURE WORK

Future research objectives have been outlined to quantify outcomes of integrating the sustainability module into a CEE capstone course at GT. First, the effect of module delivery on student sustainability knowledge will be evaluated. Concept map [58, 59] and Structure of Observed Learning (SOLO) [60, 61] assessments will be administered before and after module implementation (test treatment). In addition, assessments will be completed before and after a traditional design experience (control treatment). Results from test and control treatments will be compared to determine if student participation in the module has a positive impact on sustainability knowledge. Second, the impact of module integration on final student capstone projects will be characterized. A methodology for systematically determining the extent of application of sustainability principles (Table 1) in student design projects will be developed. Next, capstone design projects completed by GT undergraduates in CEE since 2000 and projects resulting from the modified capstone experience will be evaluated and compared. The results of this project will aid in improving sustainability education both at GT and abroad.

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Mary Katherine Watson is a PhD student in Environmental Engineering at Georgia Tech (GT). Through support from a National Science Foundation Graduate Research Fellowship, she is currently conducting research to assess and improve the quality of sustainability education in civil and environmental engineering (CEE) at GT. In addition to research in the field of engineering education, Mary Katherine is the founding president of the GT chapter of the American Society for Engineering Education (ASEE). Also at GT, Mary Katherine completed an MS in Environmental Engineering with research focused on biological treatment of organic surfactants. Prior to enrolling at GT, she received BS and MS degrees in Biosystems Engineering from Clemson University where she conducted research on optimization and modeling of freshwater algal growth for production of biofuels and bioproducts.

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

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