

Teaching Engineering Students About Cognitive Barriers During Design for Sustainable Infrastructure

Nathan Daniel McWhirter

Thesis submitted to the faculty of Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
In
Civil Engineering

Tripp Shealy, Chair
Annie R. Pearce
Michael J. Garvin

15 November 2017
Blacksburg, Virginia

Keywords: sustainability, infrastructure, Envision rating system,
interdisciplinary education, decision making, behavioral science

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ABSTRACT

Sustainability is a complex socio-technical challenge that requires new ways of thinking. To help meet this challenge, I have created three case-based modules that teach engineering students how to apply sustainability principles and help them recognize potential cognitive traps, or barriers, that may prevent more consideration for sustainability during design. Each of my three case studies is built into a PowerPoint-guided module for undergraduate engineering classes, which may be taught in 1-3 class days. I have implemented each of the three modules in senior-level classes at Virginia Tech, assessed survey data, and scored student assignments. This work and the underlying literature background is reflected in three journal papers, one for each module. My case study modules, along with all associated teaching materials, are shared in the Center for Sustainable Engineering repository for other instructors to adapt and use.

Each module includes a case study about an infrastructure project recognized and awarded by the Envision rating system, demonstrating a case of sustainability done well. Adaptable PowerPoint slides are used to teach about the Envision rating system and credits particularly relevant to the project. Active learning assignments allow students to apply the Envision framework and design criteria to complex and ill-structured problems related to the case study. Slides also cover the relation of three selected *behavioral decision science* concepts to each case study; these include cognitive biases and barriers which tend to inhibit sustainability outcomes, as well as some potential solutions to mitigate or overcome such barriers. Paired with

the decision-making framework of Envision, awareness of these transdisciplinary concepts will allow students to more effectively manage the complex decisions found in real-world projects.

Results were assessed through a variety of methods to determine the modules' level of effectiveness in accomplishing defined student learning outcomes. Pre-module and post-module student surveys were employed to measure several indicators: changes in self-assessed confidence levels, perceptions of sustainable design (characteristics and barriers), and accuracy of module concept definitions. Each of several active learning assignments was scored on a simple rubric. Concept maps were also tested as further type of assessment, and scored with both traditional and holistic methods. However, fully integrating the concept mapping approach is left to the future work of others.

These modules are a significant contribution to engineering education, as they integrate diverse topics and disciplines into a unified and relevant teaching package. Over 350 students have already been reached through the three modules, and sharing the materials in a peer-reviewed repository allows for expansion, adaptation, and capacity building. Each module's content and pedagogy align with ABET accreditation requirements and ASCE's Body of Knowledge, making them relevant tools for equipping the future generation of engineers. Future development of similar case studies can build partnerships between academia and industry, as well as increase cross-disciplinary collaboration. These efforts will both improve undergraduate education and advance the profession.

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GENERAL AUDIENCE ABSTRACT

Civil infrastructure includes many systems including water and wastewater pipelines and treatment plants, power plants, roads, bridges, and parks, which must provide an adequate level of service to society. Civil engineers must sustain and improve these systems and the people's quality of life for many generations into the future. For this to happen, engineering students must be taught the immense value of sustainability and how to make effective decisions during design for sustainable infrastructure. My research involves three specific infrastructure projects: (1) the Historic Fourth Ward Park in Atlanta, Georgia, (2) the Tucannon River Wind Farm in Dayton, Washington, and (3) the West Park Equalization Facility in Nashville, Tennessee. Each of these has received an award from the Institute for Sustainable Infrastructure's rating system called Envision, and serves as a case study of sustainability done well.

For each of the three projects, I interviewed members of the engineering design team and gathered information about the project to write a case study, which was used as the basis for a PowerPoint teaching module. The modules connect engineering to the social sciences by discussing relevant cognitive and behavioral barriers in decision making, and then present the Envision rating system as a tool for sustainable design. After conducting a literature review of engineering education, I developed specific learning outcomes, before and after surveys, and a variety of active learning assignments to assess the student learning and effectiveness of each module. This thesis presents results from teaching the modules in classes at Virginia Tech, and

demonstrates their value as transdisciplinary links between engineering, sustainability, and decision making. The modules have been made publicly available at the Center for Sustainable Engineering website for other instructors to use in their own class teaching.

ACKNOWLEDGEMENTS

Above all, I thank God for blessing me throughout my life, and my parents and teachers for supporting my previous and ongoing learning. At Virginia Tech, my advisor Dr. Tripp Shealy has been such an inspiration, help, and encouragement for my graduate research experience. I would also like to thank my committee members, Dr. Annie Pearce and Dr. Michael Garvin, each of which I had the pleasure to have as my instructor for multiple classes. Their excellence and passion for civil engineering has inspired me. I am grateful to Virginia Tech for its programs that fit my unique interests, and for its wonderful motto, *Ut Prosim*.

I also thank several others who made this research possible, including the National Science Foundation for funding it. I wholeheartedly thank the engineers and project managers from each of the Envision projects, who through phone interviews, detailed documentation, and review of drafts enabled me to create each case study and module. For the Historic Fourth Ward Park case: Robby Bryant and Jen Ninete (HDR). For the Tucannon River Wind Farm case: Robert Healy (Burns & McDonnell) and Franco Albi (Portland General Electric). For the Nashville West Park case: Saya Qualls and Evan Bowles (Hazen & Sawyer).

This material is based in part on work supported by The National Science Foundation, through Grant 1531041. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

ATTRIBUTION

In this section I explain the breakdown of roles and responsibilities between myself and my advisor Dr. Shealy, who is a co-author on each of the included manuscripts. My roles included researching and selecting Envision projects for each of the case studies, contacting the project teams for interviews, and taking notes. Dr. Shealy played the larger role in conducting the interviews. Following each interview, we discussed together the focus for each case study and selected relevant behavioral decision science concepts to include. I wrote the case studies, devised student learning outcomes, put together all the PowerPoint modules, and created student surveys and active learning assignments related to Envision.

For the implementation phase, Dr. Shealy coordinated with other instructors at Virginia Tech to allow us to guest-teach in their classes for one or two sessions. In each class, he did the primary teaching on Envision and behavioral decision science while I assisted with explanations of relevant Envision credits and linked them to the decision-making concepts.

For post-module evaluation, I organized and evaluated all the student survey data and assignment submissions. Dr. Shealy recommended the statistical methods to use for analysis, and independently scored the rubric-based assignments to allow the reporting of interrater reliability.

For the journal paper manuscripts, I did the background literature research and wrote the content. Dr. Shealy assisted with introductions and conclusions, addressed my questions, and provided comments and revisions to the drafts.

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INTRODUCTION

Design for sustainability is a necessary consideration for civil engineers, both now and in the future. Although some sustainable design features are known and implemented in building and infrastructure projects, many practicing engineers still hold misconceptions and a limited view of what sustainability entails from a systems-thinking perspective. Furthermore, engineering students are not fully equipped in their undergraduate education regarding sustainability and socio-technical issues; these require transdisciplinary thinking and informed decision making to address complex and ill-structured problems in the workplace.

Many instructors have difficulty incorporating sustainability into the current engineering curriculum. There are few ready-made materials for instructors to easily teach sustainable engineering, much less with robust modules and active learning activities. I have addressed this need by creating three different case-based modules applying the Envision rating system for sustainable infrastructure. These uniquely create a transdisciplinary bridge linking psychological concepts (i.e. cognitive biases, barriers, and interventions) to engineering decision outcomes. I have used the behavioral decision science literature to support the relevance of particular concepts to each infrastructure project.

Each module includes a case study of an Envision-certified infrastructure project, has five defined student learning outcomes, and involves similar pedagogies for teaching and evaluation. Besides the transdisciplinary concepts, active learning and problem-based learning activities are heavily emphasized, and a flipped classroom format is used in one of the modules. Student learning outcomes are assessed through multiple methods: pre-module and post-module surveys are analyzed to determine self-reported confidence, active learning assignments are scored based

on a simple 0-1-2-3 rubric, and concept mapping activities can be analyzed to assess transdisciplinary knowledge integration.

Each of the three case study modules teaches a real-world application of the Envision rating system to sustainable design, with emphasis on complex socio-technical issues beyond just the engineering solutions. However, each one has a different focus and different learning outcomes. Table I below denotes each module’s theme and behavioral concepts.

Table I: Summary of module content

	Historic Fourth Ward Park	Tucannon River Wind Farm	West Park Equalization Facility
Module theme	Envision to solve community needs; meet complex requirements of various stakeholder groups.	Envision to manage complex sustainability challenges and overcome status quo procedures.	Envision to promote flood resilience; sustainable and holistic design considerations besides cost.
Behavioral concepts	<ul style="list-style-type: none"> • Choice overload • Bounded rationality • Satisficing 	<ul style="list-style-type: none"> • Status quo bias • Precommitment • Choice architecture 	<ul style="list-style-type: none"> • Take-the-best heuristic • Risk aversion • Regulatory focus theory

The first module is on the Historic Fourth Ward Park, part of the BeltLine greenway project in Atlanta, Georgia. The case study was written focusing on the complexities of multi-stakeholder decisions, and the main assignment asks students to integrate the priorities of community, city, and other stakeholders to create a comprehensive design and layout for the park. One class was given a second assignment, to make their design more sustainable by applying Envision credits. The cognitive barriers taught with this module, linked with the park’s actual design process, are choice overload, bounded rationality, and satisficing.

The second module is on the Tucannon River Wind Farm in Dayton, Washington. The case study focuses on the difference that company culture and commitment can make toward

achieving a more sustainable project, despite “upstream” practices and procedures that incentivize low cost over long-term sustainability and resilience. Students, assigned to play the role of either the project engineer or owner, submit a brief writing assignment: using the Envision rating system to address project challenges (engineer), or applying choice architecture to promote sustainability in the wind farm’s Request for Proposals bidding process (owner). Some of the students created concept maps to demonstrate their integration of transdisciplinary knowledge. The behavioral decision science concepts for this module include one cognitive barrier, status quo bias, as well as precommitment and choice architecture, two factors that can enable sustainability.

The third module is on the West Park Equalization Facility, a wastewater project in Nashville, Tennessee. It presents the case study not as a written document, but in slide format as part of a “flipped classroom.” The assignments include professional memos which students write in groups during each class, to recommend a wastewater tank solution to the client—first based on cost estimating, then on sustainability using the Envision rating system. At the end of session two, the instructor teaches the behavioral decision science concepts (take-the-best heuristic, risk aversion, and regulatory focus theory), and students submit a homework reflection about how these impact decision making and sustainability in the project.

Each module’s five learning outcomes align with ABET accreditation criteria. Table II on the next page shows each SLO mapped to ABET’s most recent list of seven student outcomes (ABET 2017, referenced on p. 103). With this information, instructors may determine how to incorporate the modules in their classes ensuring that these requirements will be met.

Table II: Module SLOs mapped to ABET student outcomes

	(1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	(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.	(3) an ability to communicate effectively with a range of audiences.	(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.	(5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.	(6) an ability to develop and conduct appropriate experiments, analyze and interpret data, and use engineering judgment to draw conclusions.	(7) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
Historic Fourth Ward Park							
SLO 1	X	X		X		X	
SLO 2	X	X	X	X		X	
SLO 3	X	X		X		X	
SLO 4		X	X	X		X	X
SLO 5		X		X			X
Tucannon River Wind Farm							
SLO 1		X		X			X
SLO 2		X		X			X
SLO 3	X	X	X	X		X	X
SLO 4		X	X	X			X
SLO 5		X		X			X
West Park Equalization Facility							
SLO 1	X	X		X			X
SLO 2	X	X		X	X	X	
SLO 3			X	X	X		
SLO 4	X	X		X		X	X
SLO 5			X	X			X

JOURNAL PAPER 1: Pedagogy and Evaluation of an Envision Case Study Module Bridging Sustainable Engineering and Behavioral Science

(Historic Fourth Ward Park)

Intended Outlet for Publication:

Journal of Professional Issues in Engineering Education and Practice,
Special Issue: Infrastructure Education in Civil and Environmental Engineering

Authors:

Nathan McWhirter¹

Tripp Shealy²

¹Graduate Research Assistant, Department of Civil and Environmental Engineering,
Virginia Tech, Blacksburg, VA. Email: nathandm@vt.edu

²Assistant Professor, Department of Civil and Environmental Engineering,
Virginia Tech, Blacksburg, VA. Email: tshealy@vt.edu

Abstract

Designing for sustainability demands systems thinking and problem-based learning focused on the types of ill-structured problems found in the real world. The approach detailed in this paper uses the Envision Gold certified Historic Fourth Ward Park on the Atlanta BeltLine as the basis for a case study. The purpose is to convey how aspects of behavioral decision science, as well as stakeholder involvement and leadership, inform real-world design decisions. The module was taught in two classes at Virginia Tech (n=23, n=43). Methods to evaluate learning include pre-module and post-module surveys, free-response questions, frequency tables and word clouds, and evaluation of homework assignments using a defined rubric. The dominating themes from both classes before the module about barriers to sustainable infrastructure related to cost and time. After the module, many students understood the role that humans' mental barriers like choice overload, bounded rationality, and satisficing play in decision making for sustainability. The case study, teaching material, and homework assignment are available in both one-day and two-day modules for other faculty to use. This paper is meant to guide others developing and assessing case study modules, and to encourage more open-access educational materials about sustainable infrastructure.

1.1 Introduction

Civil engineers are increasingly asked to solve complex problems that blur the lines between social and technical issues. Greater exposure to concepts from behavioral sciences can offer civil engineering students a new perspective and potentially new solutions that link human and social values to physical infrastructure systems (Shealy and Klotz 2017, Ottens et al. 2006). This is a necessary advancement towards more sustainable infrastructure. In effort to contribute

to this need, the motivation for this paper was to develop a problem-based case study module that not only teaches engineering students about sustainable infrastructure but also helps them recognize their own—and their clients’—decision biases such as satisficing, bounded rationality, and loss aversion. Such cognitive barriers may diminish consideration for infrastructure sustainability due to its large physical scales and long-time horizons.

This paper begins broadly by introducing the Envision rating system for sustainable infrastructure then explains the need in engineering education for more holistic and transdisciplinary learning that includes behavioral decision science. This is followed by the development, teaching, and assessment of the Historic Fourth Ward Park case study module. Detailed results and conclusions about student learning are presented based on teaching the module in two undergraduate classes, and future work is outlined. The case study is provided in the appendix and other teaching materials are publicly available through an online repository.

1.1.1 Sustainable infrastructure and Envision

Sustainable infrastructure is one of ASCE’s foremost strategic initiatives, and the well-known Infrastructure Report Card highlights solutions for deficiencies in this realm (ASCE 2017). In 2012, as an approach to promote more sustainable infrastructure, ASCE helped establish the Institute for Sustainable Infrastructure (ISI) and its rating system called Envision (ISI 2015). The Envision rating system is a holistic planning framework and decision-making tool for civil infrastructure projects. Other infrastructure (non-building) rating systems do exist, but they are typically somewhat limited in sector or scope. These include the Sustainable SITES rating system for landscapes, LEED ND for neighborhood development, and several minor rating systems in the transportation sector (Clevenger et al. 2013). Envision, however, is unique because it applies to projects across numerous sectors including water and wastewater treatment,

green stormwater infrastructure, multi-use parks and developments, roads and transportation systems, power plants, and renewable energy facilities.

The Envision rating system contains 60 credits organized into five categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk. Envision has a variety of uses throughout all stages of the design process: prioritizing projects, qualifying design firms, judging design proposals, guiding sustainable design and leadership, or as public recognition for sustainable projects already completed. A project team may choose to simply use the Envision checklist to guide project decisions, or it may pursue the full verification and award process for Platinum, Gold, Silver, or Bronze recognition. Applying the Envision framework to an infrastructure project allows engineers to more holistically consider design options and constraints. Envision verification promotes the infrastructure as a role model project to inspire and educate others. The Envision rating system framework, and Envision-certified projects, are now growing in recognition and use by engineering educators for teaching about sustainable design and decision making.

1.1.2 Needs and approaches in engineering education

Sustainability is inherently a transdisciplinary topic with many interconnected aspects. Literature about engineering education for sustainability reinforces the need for greater integration of learning across disciplines. An EPA-funded benchmark report of sustainability in engineering courses, programs, and research in U.S. higher education notes that “interdisciplinary thinking and teaching is a means to facilitate inclusion of sustainable engineering content into the curriculum” (Allen et al. 2009, p. 65). ASCE’s Body of Knowledge (BOK2) notes that social sciences and humanities are two of four “foundational outcomes” on which a student’s technical engineering education is based: “Students should be able to explain

the concepts in at least one area of social science [e.g. psychology or sociology] in order to explain how this area of social science can inform their engineering decisions” (ASCE 2008, p. 119). Similarly, the National Academy of Engineering recommends that “engineering educators should introduce interdisciplinary learning in the undergraduate curriculum and explore the use of case studies of engineering successes and failures as a learning tool” (NAE 2005, pp. 2-3).

Several researchers and educators have called for reorienting undergraduate engineering pedagogy to enable more transdisciplinary and sustainable thinking (Ashford 2004, Huntzinger et al. 2007, Allenby 2011). A survey of experts in Engineering Education for Sustainable Development (Segalàs et al. 2012) concluded that engineering students need better competencies in systemic and transdisciplinary thinking for sustainability, and recommended an active learning approach with multiple pedagogies including problem-based learning, lectures, case studies, tutorized exercises, and discussions/debates. However, restructuring engineering education to incorporate these methods is no easy feat. One barrier is a lack of high quality educational materials in sustainable engineering (Davidson et al. 2016).

Many active learning and problem-based learning approaches are already being used to integrate sustainability into civil engineering and construction (e.g. Pellicer et al. 2016). These methods strive to reach higher levels of Bloom’s cognitive taxonomy (knowledge, comprehension, application, analysis, synthesis, and evaluation) compared to a purely lecture-centered format (Bielefeldt 2013). Documented examples of sustainable engineering education, from low to high taxonomy level, involve: class activities and discussions, homework assignments, engineering case studies (Wang 2009, Newson and Delatte 2011), comprehensive design projects (Steinemann 2003, Chau 2007, Kevern 2011, Sisiopiku et al. 2015), and service learning projects (Pierrakos et al. 2013, El-adaway et al. 2015). Many of these approaches have

included instruction and activities with sustainability rating systems such as LEED and Envision. Detailed research has been done on assessing and improving these methods in civil and environmental engineering (Watson 2013, Bielefeldt 2013).

Although many of these approaches involve semester-long courses or entire curricula, there is also a need for more concise educational modules on sustainable engineering (Davidson et al. 2016). For example, the University of Utah has implemented a module on the Envision rating system in a civil engineering capstone design course (Burian and Reynolds 2014). A benefit of sustainability modules is that they often include customizable materials to allow easy integration into existing classes; however, their brevity may present challenges to the depth of learning achievable. The most common form of evaluation is self-reporting through student surveys and questionnaires. Student assignments are typically assessed to determine the level of understanding and learning. Furthermore, concept mapping is gaining more use as a supplemental form of knowledge assessment (Watson and Barrella 2017, Borrego et al. 2009), and is a fitting method for the inherent interconnectedness of sustainability.

1.1.3 Behavioral decision science

Designers and engineers must be able to work across disciplines, but they must also understand human behavior and cognition, because predictable human biases exist which are not well known or understood by designers or engineers (Norman 2010). Although engineering programs require general education classes in humanities and social sciences, they typically place little emphasis on applying these bodies of knowledge to engineering decision making. Psychology and behavioral science literature point out that *cognitive biases* (systematic and predictable errors) and *heuristics* (mental shortcuts, rules of thumb) are especially prevalent in

complex and ill-structured problems involving uncertainty and risk—the very types of problems and decisions that engineers commonly face.

Cognitive biases and heuristics play a role in the realm of civil infrastructure (Van Buiten and Hartmann 2013), and are of the utmost concern considering its multi-trillion-dollar costs and significant impacts on sustainability. For example, the psychological concepts of *planning fallacy* and *optimism bias* explain the high frequency of cost overruns and benefit shortfalls; planners often “involuntarily spin scenarios of success and overlook the potential for mistakes and miscalculations” (Flyvbjerg 2007, p. 583). Decisions tend to be biased toward known, traditional solutions (status quo bias) and focus on present costs and benefits (cognitive myopia) rather than life-cycle or long-term sustainability (Weber 2017). Status quo bias also appears “upstream” in the decision-making process through procedures, codes, standards, and norms which maintain the status quo and limit sustainability achievement.

Designers and engineers may perceive sustainable solutions as more uncertain and risky, with greater potential for loss. *Loss aversion*, part of prospect theory (Kahneman and Tversky 1979), means that a loss has more psychological value than a gain of the same magnitude. Furthermore, social heuristics and norms (Beamish and Biggart 2010) lead to undervaluing innovative solutions. These cognitive biases are critical to address because decisions made for today’s infrastructure create path dependence: they dictate future performance of these systems for generations, determining resource consumption and climate-changing emissions for the life cycle of the project (Harris et al. 2016). Connections between behavioral decision science and engineering design for sustainability are becoming better understood through research, but public awareness must be increased in both professional practice and education. One way to help alleviate biases is through choice architecture interventions (Shealy et al. 2016). Teaching about

behavioral decision science and design for sustainability will also help engineers recognize their own cognitive processes, provide tools to better manage their decisions, and promote consideration of how those decisions will influence future infrastructure users.

1.2 Background: Cognitive barriers

Behavioral factors including cognitive biases and barriers exist in all types of decision making, including engineering. This section provides supporting knowledge from existing behavioral decision science literature on three cognitive barriers, which were chosen to align with the Historic Fourth Ward Park case study described in the next section. These cognitive barriers were identified through interviews and content analysis of the project team's documentation for Envision certification. Firsthand accounts of the project's decision-making process and sustainability aspects are meant to emphasize the case as an authentic, real-world scenario and teaching instrument.

The purpose of identifying the following cognitive barriers is to develop an open-ended assignment in which students experience these barriers for themselves. The barriers identified for teaching in the case are (1) choice overload, (2) bounded rationality, and the need for a (3) "satisficing" design solution. The following section provides a summary of literature for each barrier. The specific relation of each of these barriers to the Historic Fourth Ward Park is explained in the methods section on case study development.

1.2.1 Choice overload

Choice overload is most notably documented in the domain of personal consumer choice (Iyengar and Lepper 2000) and expounded by several other works and meta-analyses (Schwartz 2004, Scheibehenne et al. 2010, Chernev et al. 2015). These sources support the observations

that when decision makers are faced with too many choices, they are less motivated to choose, and tend to feel more responsible for their choices, frustrated with the process, and dissatisfied with the end outcome. In general, when decision makers are faced with choice overload, they rely more on heuristics and the status quo, which are associated with greater cognitive bias and less optimal decisions. Although the literature mostly pertains to the consumer domain, choice overload is also relevant to cases of multi-stakeholder infrastructure decisions like the Historic Fourth Ward Park.

Behavioral decision scientists recognize that how information is presented to the decision maker influences their choice. Query theory proposes that preferences are constructed, rather than pre-stored, and the order of options can predict the decision outcome (Johnson et al. 2007, Weber et al. 2007). Prospect theory, as stated previously, explains how decisions framed as loss instead of gain influences decision makers' willingness to take risk. Rearranging options and framing choices as loss or gain are forms of choice architecture. Just as there is no neutral building architecture—placement of stairwells, doors, and hallways influence how occupants navigate through a building—so too, choice architecture influences how decision makers navigate through choices. Choice architecture can also help overcome or mitigate the influence of choice overload by the following strategies:

1. reducing the number or complexity of alternatives (Johnson et al. 2012)
2. using technology and decision aids (Johnson et al. 2012)
3. choosing by advantages (Mossman 2013)
4. partitioning decisions (Shealy and Klotz 2014).

1.2.2 Bounded rationality

Bounded rationality, the second behavioral concept, means that the potential for rational or optimal decisions is limited by the decision maker's cognitive capacity, available information, and time (Simon 1972). Such limitations may be expected in complex decisions involving tradeoffs, as are commonly found in sustainability problems. Herbert Simon's theory of bounded rationality and problem-solving includes design, but others argue for more of a distinction, noting that design involves complex social processes beyond mere problem solving (Hatchuel 2002). In design problems, such as the Historic Fourth Ward Park, design ability can be improved (i.e. bounded rationality reduced) through better social interaction, especially involvement of the users and other stakeholders. Thus it is apparent that bounded rationality has major bearing on the stakeholder engagement process and decision-making performance. Cascetta et al. (2015) emphasize the importance of collaboration and consensus building in infrastructure design, rejecting misconceptions that "professionals are best placed to make decisions" or that "local political representatives...best represent stakeholders' interests" (p. 30). Envision's emphasis on stakeholder collaboration and teamwork helps achieve a transparent decision-making process while reducing the limits of bounded rationality.

1.2.3 Satisficing

"Satisficing" (Simon 1956) is the third behavioral concept included in the case study and taught in the module. Satisficing refers to the heuristic that in real-world situations, humans (including engineers) tend to settle for decisions that satisfy and suffice for essential requirements rather than seeking the most optimal solution. Satisficing is especially relevant in projects where delivery is needed quickly and there is a tradeoff between time/cost savings and achieving a more optimal solution. Because of uncertainties and time and budget constraints, full

optimization of a design is rarely feasible or appropriate, and satisficing simplifies decision-making. Satisficing is a necessary part of design decision making, but it is critical not to move forward with a “satisficing” option too hastily.

In the literature, Hatchuel (2002) describes how satisficing and heuristic decision-making processes were the basis of Herbert Simon’s entire theory of decision making. In addition to the centrality of satisficing in a bounded rational model of decision making (Cascetta et al. 2015), it was also investigated in engineering design applications. A study by Ball et al. (1998) recognized that designers fail to generate and evaluate multiple solution alternatives and tend to approach satisficing “through iterative improvements and the ‘patching’ of inadequacies” (p. 222). Designers often have little incentive to seek or develop more optimal solutions after a workable and satisfactory one has been found. The Fourth Ward Park, however, is a case in which the design process was a major priority, multiple alternatives were developed and compared, and a wide range of stakeholder input was incorporated before finalizing a solution. This makes it an example of satisficing done well, which resulted in a more “optimal” design.

1.3 Objective

This research study aims to help bridge the disciplinary divide between behavioral science and engineering decision making for sustainable infrastructure. It builds an Envision case study into modules that will aid instructors in teaching engineering education for sustainability. This is a similar approach to Richards et al. (1995), who used case-based active learning activities involving role playing and open-ended, ill-defined problems. Other Envision modules exist (Burian and Reynolds 2014), but this module and research are unique because of the trans-disciplinary approach merging Envision rating system, sustainability, psychology, and

engineering decision making. This case study, about Atlanta's Historic Fourth Ward Park, described further in the methods section, culminates in an assignment that places students in the role of a project design engineer tasked with creating a park design to meet priorities of multiple stakeholder groups. This is a type of student-centered, problem-based learning (PBL) activity which simulates an authentic and open-ended workplace engineering problem.

Module PowerPoint slides were developed to guide class instruction and discussion about the Envision rating system and credits. In addition, the slides include an introduction to behavioral decision science and emphasize the three previously described concepts. The overall objective is to define and effectively meet student learning outcomes for the module, which are focused on sustainability and holistic thinking. The learning outcomes are assessed through student surveys before and after the module, as well as scored homework assignments. The content for the case study modules is now available online, hosted by The Institute for Sustainable Infrastructure, for any educator to adapt and implement. The Historic Fourth Ward Park case can align with the objectives of a variety of courses, not just in civil engineering and construction, but also landscape architecture, land development, urban planning, public policy, or community engagement.

1.4 Methods

1.4.1 Case study development

Again, the purpose of this research study is to develop the case as a teaching instrument for related principles in decision making, with emphasis on student learning. The Envision case study detailed in this paper is the Historic Fourth Ward Park, part of the BeltLine urban redevelopment project in Atlanta, Georgia. The park received Envision Gold certification in

2016. After selection of this infrastructure project, an interview was arranged with two of the engineering project team members to get a firsthand description of decision-making processes and sustainability aspects that this project did exceptionally well. The project site was initially an abandoned brownfield covered in concrete, and the impervious surface was contributing to combined sewer overflow (CSO) flooding issues. In response to community input, the CSO issue was solved using a stormwater retention pond as the centerpiece for a multi-use community park. The park helped lead revitalization of the Historic Fourth Ward neighborhood and greatly improved the quality of life for nearby residents. This case is also unique because it was completed in 2011 before Envision existed; thus the rating system was used not during the design process but rather for verification and recognition of the sustainable efforts that were already finished.

From the interview, one major strength of the project became apparent. The collaboration and stakeholder involvement process between the community, City and BeltLine, and design/engineering teams allowed for more novel design options than a traditional sewer pipe or retention pond. Three of the project's most relevant and high-scoring Envision credits, which are emphasized in the case study and module, are:

- *Quality of Life 1.1 Improve Community Quality of Life*
- *Leadership 1.3 Foster Collaboration and Teamwork*
- *Leadership 1.4 Provide for Stakeholder Involvement*

The project engineers shared the documentation packet submitted for Envision verification, which was then used by the authors to write a detailed case study on the Historic Fourth Ward Park. The case study is a six-page document that describes the Atlanta BeltLine and site condition, sewer overflow problem and requirements, and several requirements of the three

main stakeholder groups (community members, city and BeltLine, and design/engineering team). Bulleted lists and brief descriptions are also provided of park elements and features proposed by the community, requirements of the city's master plans and policies, overall sustainability goals for the park, and the design team's functional and technical requirements. At the end of the case study, but before the module is taught, students are presented with this assignment: "*Create a design and layout for the park that integrates the priorities of the various stakeholders, and write a two-page rationale describing your choice of design elements.*" The case study is provided in the appendix. The intention is for students to face the barriers of choice overload, bounded rationality, and satisficing in the problem and their design decision process.

1.4.2 Relevance of cognitive barriers to the Historic Fourth Ward Park

The three behavioral decision science concepts described in the background literature as cognitive barriers to sustainable decision making are each related to specific aspects of the Historic Fourth Ward Park. *Choice overload* pertains to this case because the decision process was complex and the project involved numerous stakeholder groups with differing requirements, priorities, and interests. Designers were less able to simplify choices with design norms or the status quo because the park was such a novel and unconventional stormwater solution for the city. It also involved far more potential design choices than a conventional retention pond and sewer pipe. The involvement of multiple stakeholders opened more options and choices to be made, but also provided some constraints that simplified the choices.

For *bounded rationality*, stakeholder engagement meetings and public input were a major part of the process to improve the design consideration for specific priorities and concerns. The high degree of collaboration increased the overall cognitive capacity and available information; this reduced the "bounds" of rationality and promoted design decisions that were more beneficial

to all the people involved. Envision also helps in reducing bounded rationality because of its great emphasis on stakeholder collaboration and teamwork, as well as effective leadership, commitment, and management. Because of this, Envision projects are supported long-term and greatly celebrated by the community.

In terms of *satisficing*, the Historic Fourth Ward Park project did not merely address the basic engineering problem (CSO issues), but considered “Are we doing the right project?” and worked toward maximizing social and environmental benefits in the process. The project planners and teams truly excelled at stakeholder involvement, collaboration, and teamwork. Early stakeholder engagement meetings resulted in 11 core guiding principles, including multiple stakeholder priorities and technical requirements. The team then generated three design alternatives for the park according to these goals, which simplified the decision-making process and helped reduce the effect of choice overload.

After the case study was written, it was shared with the engineering design team members originally interviewed, who then verified that the problem context, decision-making process, and design considerations were accurately described.

1.4.3 Module slides and in-class activities

The class module, a PowerPoint-based lesson plan centered on the Historic Fourth Ward Park case study, was taught by the authors in two senior-level classes at Virginia Tech. The module was taught using both a one-day and a two-day format. The one-day module was taught in a class in the Building Construction (BC) department entitled “Sustainable Building Performance Management,” and the two-day module in a Civil and Environmental Engineering (CEE) class called “Sustainable Systems.” The lecture portion about Envision linked explanation

with motivation-based learning (Bielefeldt 2013) by explaining several reasons why students should care about the Envision rating system. Several reflection and discussion opportunities like “think-pair-share” provided chances for active learning, and allowed the instructor to gauge the students’ level of understanding. In the one-day module, the case study and park design assignment were given as homework to complete beforehand, and the class proceeded as follows:

1. Class discussion on completed park design assignment and process
2. Teaching about behavioral decision science, biases, and heuristics
3. Teaching and discussion about choice overload, bounded rationality, and satisficing
4. Teaching about Envision, its applications, and its credits
5. Exposition of three selected Envision credits, discussing links to the three behavioral concepts
6. Explanation of actual park design with video and master plan excerpt

In the two-day module, students were given time at the beginning of the first class to read the case study and complete the park design assignment. This class session followed up with the first four of the numbered topics above. At the end of the first day module, another assignment was given for homework: *“Review credits in the Envision manual. Select one from each category to improve your design’s sustainability and/or reduce the effects of these cognitive barriers. Write a summary describing the changes you made and what level of achievement this would meet within Envision.”* The second day’s session began with a small-group reflection on this assignment, including which Envision credits each student selected and how these credits helped improve the design. Class discussions were led on each of the selected credits, relating them to the three behavioral concepts and the real-life outcomes of the park. Finally, the two-day

module was concluded with a video of the completed park and a presentation of its program elements as published in the Atlanta BeltLine Master Plan (EDAW et al. 2009).

1.4.4 Student learning outcomes and evaluation

The student learning outcomes for this module are based on higher critical thinking levels of Bloom's cognitive taxonomy (Bielefeldt 2013):

1. Assess and evaluate multiple stakeholders' requirements and priorities for a design
2. Synthesize multiple stakeholder requirements and priorities into an appropriate and unified design
3. Make design decisions to create a solution to a complex and open-ended design problem
4. Assess the social, environmental, and economic sustainability of a design
5. Recognize mental barriers that may prevent more sustainable outcomes.

A variety of evaluation methods were used to gauge student learning and overall module effectiveness, like other documented approaches (Bielefeldt 2013, El-adaway 2015). These include a student survey given before and after the module, scored assignments based on an established rubric, written student feedback, and overall subjective assessment by the authors. The surveys asked students to rate their confidence level with each of the five above learning outcomes on a 5-point Likert scale. Other survey sections asked students about sustainability and sustainable design (including perceptions, characteristics, and barriers) and their proficiency with using Envision. The post-module survey added a free-response section for students to define each of the cognitive barriers and describe a way that it could be overcome. Assignment

evaluation included both assignments: the initial park design and description, as well as the additional activity applying Envision credits to improve the design.

1.5. Results and Discussion

1.5.1 Survey results: Student learning outcomes

Pre-module and post-module surveys were completed by most, but not all, of the students in each class. There were 23 completed surveys from the Building Construction (BC) class and 31 completed surveys from the Civil Engineering (CEE) class. Students' self-reported scores on their confidence with the learning outcomes significantly increased between the pre-module and post-module survey. Tables 1.1 and 1.2 display average scores for each student learning outcome (SLO). The Likert scale ranged from 1 (low confidence) to 5 (high confidence). Average confidence levels increased from 3.19 to 3.83 (20%) in BC class, and from 3.17 to 3.86 (22%) in the CEE class. A paired t-test indicated these results are significant ($p < 0.001$) for the overall increase in student learning confidence. The paired t-test is used with Likert scale to determine whether the mean difference between paired observations is significantly different from zero. A Mann-Whitney U test can also be used but a paired t-test, in this case, provides more protection against false negatives and provides the same protection against false positives (de Winter and Dodou 2010).

Table 1.1: Building Construction (1-day module) student confidence with learning outcomes

Learning outcome: “Select your confidence level to...”	Pre-module average	Post-module average	Percent increase
1. assess and evaluate multiple stakeholders’ requirements and priorities for a design.	3.17	3.78	19.2%
2. synthesize multiple stakeholders’ requirements and priorities into an appropriate and unified design.	3.04	3.83	25.7%
3. make design decisions creating a solution to a complex and open-ended design problem.	3.00	3.78	26.1%
4. assess the social, environmental, and economic sustainability of a design.	3.39	3.83	12.8%
5. recognize mental barriers that may prevent more sustainable outcomes.	3.35	3.91	16.9%
Average of all five SLOs	3.19	3.83	19.9%

Table 1.2: Civil Engineering class (2-day module) student confidence with learning outcomes

Learning outcome: “Select your confidence level to...”	Pre-module average	Post-module average	Percent increase
1. assess and evaluate multiple stakeholders’ requirements and priorities for a design.	2.94	3.81	29.7%
2. synthesize multiple stakeholders’ requirements and priorities into an appropriate and unified design.	2.90	3.65	25.6%
3. make design decisions creating a solution to a complex and open-ended design problem.	3.29	3.84	16.7%
4. assess the social, environmental, and economic sustainability of a design.	3.35	4.06	21.2%
5. recognize mental barriers that may prevent more sustainable outcomes.	3.35	3.97	18.3%
Average of all five SLOs	3.17	3.86	22.0%

1.5.2 Survey results: Sustainable design characteristics and barriers

In another section of the survey, students were asked to “list as many *characteristics of sustainable design* as you can think of,” and then to “list as many *common barriers to sustainable design* as you can think of.” The post-module survey for this section asked for any *new* characteristics or barriers they learned. Asking these questions is necessary to investigate the similarities and differences across students of different majors, discover how much they retained from the module content, and identify and address any common gaps in understanding about sustainability in future modules.

Word clouds were generated with these results, and frequency tables were created based on the top 10 most commonly mentioned words. The size of each word is proportional to its frequency as listed in the tables. Common words (of, in, to, the, it, etc.) and those which were part of the question (sustainable, design, characteristic, barrier) were excluded. In the few cases when two related words such as “choice” and “overload” had an identical word count, they were grouped as a phrase. Figure 1.1 shows the word clouds for *characteristics of sustainable design* listed pre- and post-module for the BC students and Table 1.3 shows the frequency analysis results for both the BC and CEE students.



Figure 1.1: Pre-module (left) and post-module (right) characteristics of sustainable design, BC

Table 1.3: Content frequency for characteristics of sustainable design

Characteristics (pre-module)		New characteristics (post-module)					
BC class (n=23)	CEE class (n=31)	BC class (n=23)	CEE class (n=31)	BC class (n=23)	CEE class (n=31)		
energy	16	use	14	Envision	4	leadership	12
material	8	environmental	12	stakeholders	4	quality of life	4
low	7	material	10	system	4	resource	3
green	6	energy	9			allocation	
net zero	6	friendly	7	rating	2	community	3
waste	5	green	5	community	2	natural world	3
efficient	5	efficient	5	building	2	climate	3
environment	5	social	5	retention	2	incorporate	3
building	5	water	4	pond		project	3
						Envision	3

Several insights are noted from this table. Building construction students associated sustainable design more with building energy use (e.g. low energy, net zero, efficiency), green or environmentally-friendly building materials, and waste reduction. The civil engineering students also listed material/energy use and efficiency, but a greater number of them mentioned the

environmental (friendly, green) and the *social* aspects of sustainability, indicating some understanding of the triple bottom line.

From the new characteristics listed post-module, the results indicate that students retained concepts taught. The building construction class listed Envision, stakeholders/community, and system (e.g. rating system, point system, ecological system). A few also mentioned the specific feature of the retention pond. The civil engineering class focused more specifically on the five Envision categories of leadership, quality of life (community), resource allocation, natural world, and climate. This is quite understandable since this two-day class had more time to focus on the three selected Envision credits covered in the module, and were also given the extra assignment using the credits to improve their park design. Interestingly, the most frequently listed characteristics from the civil engineering class (“use” before the module and “leadership” after) had at least 12 mentions (39% of the 31 students) each time, showing that the students learned and retained consistent information. But the top new characteristics from the building construction class (“Envision,” “stakeholders,” and “system”) only had 4 mentions each (17% out of 23 students). The building construction students also listed far fewer new words in comparison with the initial number. These results seem to indicate that student retention of basic concepts covered was better in the two-day module given to the civil engineering class. This could be partly due to the difference in student backgrounds and interests. Compared with the self-reported learning, the results in this section showed more variation between the two classes.

As mentioned previously, a similar question was posed for students to list their perceived *barriers* to sustainable design. Figure 1.2 shows the word clouds for barriers listed pre- and post-module for the civil engineering students and Table 1.4 shows the frequency analysis results for both the building construction and civil engineering students.



Figure 1.2: Pre-module (left) and post-module (right) barriers to sustainable design, CEE

Table 1.4: Content frequency for barriers to sustainable design

Barriers (pre-module)				New barriers (post-module)			
BC class (n=23)		CEE class (n=31)		BC class (n=23)		CEE class (n=31)	
cost	11	cost	15	choice overload	3	choice overload	10
time	8	time	8	mental	3	satisficing	9
construction	6	money	5	options	3	bounded	7
						rationality	
money	4	human	5	bounded	2	many	3
				rationality			
aesthetic	3	material	4	satisficing	2	mental	2
price	3	public	4	stakeholders	2	system	2
knowledge	3	available	3	always	2	always	2
constraint	3	lack	3	hard	2	human	2
material	3	educated	3	choose	2	difficult	2
lack	3	technology	3	achieve	2	thinking	2

The dominating pre-module themes from both classes were *cost* (money, price) and *time* barriers to sustainability. Besides these, the building construction students listed construction, aesthetics, and knowledge, while the civil engineering students listed humans/public, material, availability/lack, and education. Based on the prevalence of cost and time barriers to sustainability, the updated modules available to instructors are now geared to address these

aspects by providing evidence that the extra initial investment is worth the long-term benefits. The responses indicating lack of knowledge or education as a barrier to sustainable design are exactly what the module aims to overcome through its development. By providing this case of the Historic Fourth Ward Park as a role model of a sustainable project done well, and by focusing on Envision practices, students will learn that sustainable infrastructure projects are quite achievable and worthwhile.

After the module, several students remembered the impact that humans' mental barriers like choice overload, bounded rationality, and satisficing can have on sustainability. Building construction students had far fewer common responses about new characteristics and new barriers than the civil engineering students. Post-module, the most frequently listed new barriers by the building construction students ("choice overload," "mental," and "options") each appeared in only 3 of 23 student responses (13%), and "bounded rationality" and "satisficing" were each listed only twice. These distributed responses indicate room for improvement in this class's retention of main concepts. In contrast, each of the three behavioral concepts were mentioned by 7 to 10 (20-30%) of the 31 civil engineering students.

1.5.3 Survey results: Behavioral decision science definitions and examples

The post-module survey asked the students to demonstrate their understanding of the behavioral decision science concepts taught in the module (choice overload, bounded rationality, and satisficing) in a free-response question: "Define ____ and list at least one way that it can be overcome." Each student's responses were separately evaluated by two researchers on a 0-1-2-3 scale, which is a common approach used in similar educational research (Bielefeldt 2013). The scores are defined as: 0 for no response; 1 for weak; 2 for fair; 3 for good. Below are detailed

model answers for each concept based on the class module and teaching; Table 1.5 shows the average scores earned by each class on each part.

Choice overload

- Definition: Too many choice attributes or alternatives available; greater number or complexity of choices. Increases reliance on heuristics and defaults; may result in decision fatigue, frustration, dissatisfaction, and choice deferral.
- Solution: (1) simplifying/reducing choice attributes or the number of available options. (2) Using technology and decision aids: Envision may help by prioritizing or "weighting" design choices that achieve higher point values on credits. (3) Partitioning decisions in groups and over time, e.g. Envision's 5 categories.

Bounded rationality

- Definition: Human rationality is bounded because there are limits to our thinking capacity, available information, and time—especially when subject to ill-structured, uncertain, and complex decisions. This is why we use heuristics and "satisfice."
- Solution: Greater stakeholder engagement and public input processes overlap known information and thinking capacities to result in fewer gaps. Envision credits emphasize collaboration and leadership in the project planning process to encourage transparency and participation.

Satisficing

- Definition: People tend to make decisions by “satisficing” (a combination of sufficing and satisfying) rather than optimizing. Decisions are often simply good enough in light of

the costs and constraints involved. As a heuristic, satisficing individuals will choose options that meet their most basic decision criteria.

- Solution: Envision emphasizes holistic factors for sustainability which are often neglected, and awareness of these features makes them more likely to be considered as necessary criteria for a better "satisficing" solution. Community collaboration also increases the likelihood that the solution "satisfices" for more people. Fully understand the problem, generate and evaluate more solution alternatives (with multiple stakeholders); make iterative improvements.

Table 1.5: Average behavioral decision science free-response scores (out of 3)

Concept	Class	Definition	Solution
Choice overload	BC	2.6	2.0
	CEE	2.5	2.0
Bounded rationality	BC	2.0	1.7
	CEE	1.9	2.1
Satisficing	BC	2.4	1.8
	CEE	2.2	2.0

In general, the students performed better on the definitions than the solutions; a few may have skipped the second half of the questions. Choice overload was the best understood concept, followed by satisficing. Bounded rationality had the lowest scores. The building construction class consistently averaged slightly higher scores on the definitions, while civil engineering students scored higher on the solutions. Overall interrater reliability was 93.8% agreement between the two scorers for all datasets (95.1% agreement on the concept definitions and 92.6% on the solutions). The weighted kappa statistic, which accounts for the degree of disagreement between two raters, was used since scoring categories are ordered; it was calculated to be 0.943, indicating very good agreement.

1.5.4 Park design assignments

Homework assignments from each class were scored to determine the module's overall teaching effectiveness and student learning. This was not part of their course grades, so not all students made a submission. The first assignment evaluated was the case study park design assignment from the one-day building construction class: *“Create a design and layout for the park that integrates the priorities of the various stakeholders, and write a two-page rationale describing your choice of design elements.”* The rationale/description aspect corresponds to SLO 1: “Assess and evaluate multiple stakeholders’ requirements and priorities for a design,” and the visual design/layout to SLO 2: “Synthesize multiple stakeholder requirements and priorities into an appropriate and unified design.”

The two parts of the assignment (SLO1 and SLO 2) were given separate scores by each of the two scorers using the same 0-1-2-3 scale. Each assignment was scored on the effort given to visual design, detail, and neatness. The score reflected how well each design satisfied the case study's design requirements. The average scores (n=17 submissions) were 2.5 on the visual component and 2.5 on the description component. Inter-rater agreement was 82% on the visual scores and 76% on the description scores, and weighted kappa was 0.773, indicating good agreement.

It should be reiterated that this was a class of building construction students who generally had minimal experience or interest in design. Furthermore, this assignment was given before any in-class instruction; the students had only read the case study on the Historic Fourth Ward Park. Some overall conclusions on the student responses and the assignment itself are:

- Of all the stakeholder groups, community requirements (i.e. amenities and design features) were most thoroughly considered by the students, but the city requirements

(planning and land use policies, multi-modal transit integration, BeltLine context) were sometimes neglected.

- The assignment description could better emphasize that students need to focus holistically on the entire park context and triple bottom line elements of sustainability. Students often neglected one of the three aspects to the triple bottom line.

One of the submissions stood out because the student thoroughly supported each design feature by citing specific stakeholder requirements and relating it to the project context. This student's description below demonstrates recognition of a tradeoff between stakeholder priorities, which is essential to recognize in any public engagement process for a collaborative project:

“Parking was a major issue for both the public and the city. The public wanted a large amount of parking, in various spaces around the park. Meanwhile in the city's land use and zoning requirements, it states a desire to ‘discourage new surface parking lots, but encourage the use of existing neighborhood alleys for parking access.’ Trying to find a balance between these two desires I placed a few small parking lots around the edges of the park. Having a few smaller lots, which may fill up faster, will encourage on street parking, while also satisfying some of the public parking needs.”

This student also shows an understanding of “satisficing,” that the design cannot be fully optimized considering budget and time restrictions, but rather made satisfactory enough to all stakeholders. This quote also seems to imply choice overload and bounded rationality:

“Overall my design fills most of the desires of both the public and the city.

However, it may not be possible to have all the desired pieces of the park, due to budget and time restrictions. Even without worrying about time and money, I was not able to meet all of the desires for the park.”

The second assignment evaluated was the follow-up homework given during the two-day module in the civil engineering class. The assignment stated: *“Review credits in the Envision manual. Select one from each category to improve your design’s sustainability and/or reduce the effects of these cognitive barriers. Write a summary describing the changes you made and what level of achievement this would meet within Envision.”* This corresponds to SLO 4: “Assess the social, environmental, and economic sustainability of a design.” On the same 0-1-2-3 scoring scale, the average score on this assignment (n=43 submissions) was 2.4, with inter-rater agreement of 70%. Overall, the weighted kappa statistic was 0.698, indicating good agreement. From evaluation of this assignment the following observations were made:

- Overall, students recognized the usefulness of Envision, and pointed out sustainable design considerations that they hadn’t been included in their initial park design.
- Cognitive barriers were very seldom mentioned; this consideration should be required rather than optional to indicate whether students understood the connection to Envision.

1.5.5 Student feedback

Finally, a few comments from the post-module survey are included below to indicate student perceptions of the module and provide some insight on improving it for future use:

- “I liked this case study a lot. I think it was a great choice of project. I think understanding the scale of the site and having a full class period to propose the initial design would have

been beneficial. Maybe send an email ahead of time with the site details, and tell people to prepare for a design challenge rather than a normal class period.”

- “It would have been nice to know there was an assignment with the case study. Most of us just thought it was the survey... Additional background information on what we were doing would have been nice, as most of us [BC students] are not designers but implementers.”
- “I think the material and knowledge of cognitive barriers could have helped during the project. Also the time frame to complete was incredibly short.”
- “I would have liked to spend a little bit more time seeing the final design and discussing at least one point from each category of Envision that they achieved and why they chose certain points to seek out.”

Since the initial teaching of this module, its effectiveness for student learning has been assessed and evaluated in terms of the surveyed objectives by self-confidence ratings, word clouds, free-response answers, case study assignments, and survey comments. Based on these findings and a deeper investigation of the literature, the authors have updated the modules as described in the next section.

1.6 Conclusion

The educational approach detailed in this paper involves a module to teach sustainable infrastructure and decision making, using the Envision rating system and a case study on the Historic Fourth Ward Park. Considering current needs in engineering education, the module incorporates transdisciplinary thinking by teaching how human cognition (specifically choice overload, bounded rationality, and satisficing) can present barriers in engineering decisions, as

well as how they can be overcome. Problem-based learning is also incorporated, through the open-ended case study assignment asking students to create a park design that satisfies the requirements of multiple stakeholder groups.

The module has been taught in two senior-level classes at Virginia Tech. Student learning outcomes were defined and measured through multiple methods including pre-module and post-module surveys, content analysis, and assignment scoring. The students' self-reported confidence with the SLOs increased by an overall 20% and 22% in the two classes, word clouds indicated that students recognized Envision and behavioral decision science concepts as characteristics and barriers of sustainable design, and many students demonstrated thorough knowledge of the behavioral decision science concepts as taught in the module. A few apparent gaps in student learning indicated areas for improvement. Recent updates and improvements to the module slides include: instructor notes to aid teaching, discussion, and explanation of each slide; master format allowing division of material and activities between one, two, or three class days; emphasis on how Envision is a form of "choice architecture" to improve decision making; more understandable and relevant examples of the behavioral science concepts; detailed discussion of the project's actual design and Envision achievement; and a concept mapping activity to demonstrate and assess transdisciplinary knowledge integration.

Testing the use of the added concept mapping activity is future work. Concept maps are a method gaining prominence in engineering education to evaluate knowledge integration for interdisciplinary topics including sustainability (Watson and Barrella 2017, Watson et al. 2016, Borrego et al. 2009, Segalàs et al. 2008). This is not just an evaluation tool, but also allows students to mentally connect concepts and realize more interrelationships between the topics they are taught. The authors have devised a concept mapping activity using CmapTools software to

assign after the module, and included in the open-access module, asking students to “*Create a concept map showing connections between the park design process, behavioral decision science concepts, and individual Envision credits.*” This will demonstrate understanding of the connections discussed in class, some of which have been described in the Methods section of this paper. For example, how Envision’s Leadership credits for stakeholder involvement (LD1.3) and collaboration and teamwork (LD1.4) can reduce bounded rationality. Two main scoring methods, traditional and holistic, are appropriate for concept maps (Watson et al. 2016).

For those wanting to download and use this module in the future, the authors provide detailed notes and speaking points in the module’s PowerPoint slides, as well as a “readme” document to familiarize the instructor with the module’s focus, intent, and the resources that are included. This Historic Fourth Ward Park module and others created using Envision projects are shared in an online repository for instructors to use. The need for this type of module repository has been suggested by Davidson et al. (2016). These modules are searchable and tagged with keywords so that instructors can discover those with learning outcomes appropriate to their course goals, and adapt them if needed. In turn, following the methods detailed in this paper, other instructors can create and share their own teaching modules bridging behavioral science to engineering for sustainability. Beyond the benefits this provides to teaching sustainable engineering, it also provides contributors with opportunities for experience, attribution, and peer review feedback, meeting several demonstrated needs (Davidson et al. 2016). These modules are now being peer-reviewed to be hosted in the Center for Sustainable Engineering’s eLibrary at <http://csengin.syr.edu/electronic-holdings-library/>.

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**JOURNAL PAPER 2: Teaching Decision Making for Sustainable
Infrastructure: A Case Study Module on an Envision™-Certified Wind Farm**

(Tucannon River Wind Farm)

Intended Outlet for Publication:

International Journal of Sustainability in Higher Education

Authors:

Nathan McWhirter¹

Tripp Shealy²

¹Graduate Research Assistant, Department of Civil and Environmental Engineering,
Virginia Tech, Blacksburg, VA. Email: nathandm@vt.edu

²Assistant Professor, Department of Civil and Environmental Engineering,
Virginia Tech, Blacksburg, VA. Email: tshealy@vt.edu

Structured Abstract

Purpose – This research introduces a new case-based module approach for teaching sustainable engineering, linking the Envision rating system with behavioral decision science. Three complete modules are publicly available in a repository for any instructor to adapt, use, and review.

Design/methodology/approach – A case study was written about the Tucannon River Wind Farm, a project certified Gold by the Institute for Sustainable Infrastructure's Envision™ rating system. The case was used as the basis for an in-class PowerPoint module to achieve student learning outcomes related to sustainability.

Findings – Before and after surveys showed significant ($p < 0.001$) learning increases. Word clouds show changes in student perceptions of sustainable design. Rubric scoring of writing assignments and concept maps yielded valuable insights and improvements, and demonstrate the overall validity of the module approach.

Research limitations/implications – Modules lasting only one or two class days must be well integrated into courses and curricula to promote greater learning value. Concept mapping may be a useful addition, but involves a learning curve for both instructors and students.

Practical implications – By offering instructors access to a set of case-based modules, it becomes more practical for them to teach on Envision, sustainable infrastructure, and decision making.

Social Implications – The module exemplifies a project owner and an engineering firm strongly committed to social and environmental sustainability. Envision's Quality of Life and Leadership categories emphasize community well-being, involvement, and collaboration.

Originality/value – Sustainability teaching modules are growing in popularity, and this type offers a unique transdisciplinary focus meeting several needs in engineering education.

2.1 Introduction

2.1.1 Sustainable infrastructure and decision making

Civil infrastructure is a massive sector of engineering and construction which includes roads, highways, bridges, tunnels, water/wastewater systems, parks, and energy facilities. These are part of a larger socio-technical system including not only environmental performance such as energy efficiency, water and material use, but also quality of life, management, and leadership. Engineers who design and construct these physical systems play a critical role in constructing a more sustainable future. The need for sustainable infrastructure solutions is well-recognized by professional societies (American Society of Civil Engineers), leading institutions (Institute for Sustainable Infrastructure), and national academies (National Academy of Engineering).

Decision making for sustainability is inherently complex. One solution to manage this complexity is to use rating system tools during design and construction. One of the most well-known sustainability rating systems is LEED, Leadership in Energy and Environmental Design, which provides a standard for green buildings. Another is Envision, a framework developed by the Institute for Sustainable Infrastructure (ISI) for various non-building infrastructure projects. A primary way that rating systems influence decisions for sustainability is by providing a sort of checklist organized into categories and credits, with a defined point value or weighting attached to each. Envision offers varying point values across its 60 credits, and points also depend on the level of achievement (Improved, Enhanced, Superior, Conserving, or Restorative) reached for each credit.

However, rating systems alone are not a panacea. The core values of sustainability include resource conservation and renewable energy, yet many of the factors preventing these goals are behavioral-related rather than technical. For instance, rating systems may inadvertently set goals (anchors) that are too low, discouraging the ambition needed to achieve a level of sustainability performance that is technically and economically feasible (Klotz et al. 2010). The National Science Foundation's 2030 Strategic Plan for Engineering Design advocates for an expanded perspective on decision tools: "future design tools and methods should not only support analysis and decision making from a technological point of view, but also account for psychological, sociological, and anthropological factors based on fundamental understanding of these factors and their interaction" (Shah et al. 2004, p. 4).

2.1.2 Behavioral science applications

Problems in the engineering world call for holistic and integrative thinking to make effective decisions for sustainability. This effort must involve greater application of non-STEM disciplines to address the "psychological, sociological, and anthropological factors" referenced above. Thus a major focus of this paper is the application of behavioral science research, stemming from psychology, which sheds insight into many non-technical, non-economic barriers to better decisions. Many disciplines have advanced their theoretical foundations and empirical accuracy through recent behavioral findings, including economics (Camerer et al. 2003), law (Sharp 1995), and medicine (Chapman and Elstein 2000). One of the most revolutionary discoveries in behavioral science has been cognitive biases, predictable and systematic errors in decision making that transcend rational choice expectations (Weber and Johnson 2009).

Improving engineers' understanding of behavioral science will help guide the design of tools and processes to promote more sustainable solutions. At every stage in the design and

construction process there are opportunities to apply sustainability principles, but these decisions are often viewed as requiring extra effort and difficult tradeoffs. Uncertainty and risk aversion, often related to cost or time, are cognitive factors that often prevent owners, designers, and engineers from pursuing sustainable innovations in everyday projects. But even simple interventions can be fruitful: for example, providing an engineering project team with examples of similar “role model” projects that achieved high sustainability performance tends to promote the achievement of similar goals (Harris et al. 2016).

Also in engineering practice, quick judgments and misconceptions about “sustainable” design may lead to thinking that it costs more than traditional solutions. However, in rating systems, a higher sustainability score does not necessarily correspond to a higher monetary cost. For example, identifying a construction method to “reduce excavated materials taken off site” (Resource Allocation credit 1.6) reduces costs and earn a project team up to six points on the Envision rating system. Sustainable solutions may appear to cost more when framed in the short term (first costs), but reframing them based on life-cycle cost typically shows the sustainable option to be economically advantageous. Although engineers now have access to technologies like automated sensors, advanced materials, and modeling tools to design and construct more efficient and sustainable infrastructure, the barrier often lies at diffusion of these innovations, and progress is impeded by cognitive biases like status quo bias and social norms (Beamish and Biggart 2012).

2.1.3 Relevance to engineering education

Although promoting sustainability in the professional field is important, engineers’ methods of thinking and problem solving are largely formed during their educational experience. Therefore this is a powerful intervention point to change the future of engineering. For

undergraduate engineering programs, teaching behavioral science concepts concurrently with sustainability can help students recognize biases and inhibitors to sustainability and manage complex decisions. If such an approach becomes integrated with engineering education, it will elicit beneficial changes in professional practice. This paper focuses on three complementary ways in which engineering educators can instill sustainability thinking: transdisciplinary approaches, active and problem-based learning, and sustainable engineering modules.

Transdisciplinary approaches in education integrate concepts whose origins are found in different disciplines (Ashford 2004). The American Society of Civil Engineers' Body of Knowledge (BOK2) emphasizes that the disciplines of humanities and social sciences are foundational pillars upon which to build an engineer's technical education (ASCE 2008), yet often these courses are viewed as merely "checkboxes" for graduation. The complex nature of global and local sustainability dilemmas requires engineers trained in transdisciplinary systems thinking to understand interrelated social, environmental, economic, and even psychological dimensions of these challenges.

Engineering education can also help instill sustainability thinking through active, problem-based learning (PBL) methods (Thomas 2009, Guerra 2017, El-adaway et al. 2015). Active learning approaches involve students in meaningful, critical thinking activities. Similarly, PBL involves presenting students with complex and ill-structured problems to develop problem-solving skills and stimulate learning. PBL is commonly used for integrating sustainable development into engineering education: it promotes higher cognitive levels of student learning by allowing students to tackle the sort of complex and uncertain problems they will face with sustainability issues in the engineering workplace. Despite success, however, PBL methods are

still not well integrated into curricula to accomplish the sustainability learning outcomes of ASCE BOK2 (Bielefeldt 2013).

Lastly, sustainable engineering modules are a simple and convenient way for instructors to adopt new topics and material into their own classes. A few collaborative groups have begun to share sustainability modules and materials amongst engineering instructors: the Center for Sustainable Engineering (CSE), csengin.syr.edu, and the Center for Infrastructure Transformation and Education (CIT-E), cit-e.org. Engineering classes from first-year through senior capstone are now incorporating sustainability modules (Bielefeldt 2011, Watson and Barrella 2017). A civil engineering capstone course at the University of Utah used a module on the Envision rating system to reinforce sustainability concepts (Burian and Reynolds 2014). The current paper describes the design, implementation, and results of an Envision case study module which incorporates active learning and transdisciplinary connections to behavioral decision science. The module is now part of a shared repository where instructors may access, adapt, peer review, and create them, as called for by Davidson et al. (2016).

This paper provides an overview of behavioral science elements relevant to decision making for sustainability, specifically status quo bias, precommitment, and choice architecture. These three selected concepts are relevant to real-world engineering practice (as described in the following background section) and also to the Tucannon River Wind Farm case study (methods section).

2.2 Background: Behavioral decision science

2.2.1 Status quo bias

Within behavioral decision science, there are many cognitive biases and barriers to rational decision making. One of the most common is status quo bias, which can often appear “upstream” in the decision-making process. Mandated procedures, codes, standards, and norms are slow to change and may inhibit sustainability achievement. One example is the bid procurement process in construction. A business article from the firm McKinstry (Hamilton 2011) states that procurement processes unwittingly maintain the status quo by the “default” low-bid criterion, which tends to incentivize limiting the scope of work and excluding sustainable innovations. A research survey on the sustainability of procurement practices in the construction industry (Ruparathna and Hewage 2015) found that only 10% of all bidding procedures used value-based procurement over low bid, only 17% used life-cycle cost over initial cost, and only 30% incorporated social or environmental factors in bid evaluation.

Status quo bias can be overcome when a Request for Proposal (RFP) is well-crafted; then it can better serve the interests of the owner by creating “a race to the top, with bidders competing to propose the most creative, efficient solutions, rather than rushing to find the cheapest short-sighted fixes” (Hamilton 2011). When engineers and decision makers recognize the status quo as a bias, they are more likely to try to break out of it. Interventions to restructure the decision environment can also reduce the effects of status quo bias during infrastructure development. For example, presenting an “endowed” version of the Envision rating system—starting from a baseline of the “Conserving” (second-highest) level of achievement and allowing the potential loss of points—helps professional engineers overcome the status quo and nudge a

project from a Silver to Gold certification—about 15 percent of the total points (Shealy et al. 2016).

2.2.2 Precommitment

One intervention to overcome cognitive biases such as status quo is precommitment, a practical way to promote positive change without mandates. It involves making a public commitment or otherwise taking steps to ensure that a present decision cannot be easily undone. This keeps difficult goals from being undermined by future temptations or rash decisions (van Trijp 2014). Related to sustainability, precommitment to reduce household energy use may “diminish temporal discounting, reduce impulsivity, and/or encourage delayed gratification and self-control” (Frederiks et al. 2015). Similar precommitment strategies are a major factor in environmental and climate change advocacy, when difficult goals are needed to “protect the future at the expense of the present” (Lazarus 2009).

Precommitment can also be applied to achieving *project-level* and *organization-level* sustainability goals like renewable energy, life-cycle analysis, and disaster resilience, which involve high initial costs and delayed benefits. Construction literature notes that owners play a critical role as key drivers and stakeholders in sustainable construction practices, and that positive commitment amongst stakeholders involves cognitive and behavioral aspects to embed sustainable construction values into the organizational culture (Maduka et al. 2016). Company culture is one of the biggest drivers to make sustainability the default; organizations with committed leadership are the innovators and champions in this regard. Yet commitments further upstream, at a higher policy-making level, can do even more good: the Institute for Sustainable Infrastructure urges government and public agencies to require (i.e. pre-commit to) the use of Envision in Request for Qualifications and RFPs (ISI 2016). The American Public Works

Association (APWA) states a similar goal—that every RFP have a section devoted to sustainability (APWA 2012, p. 25).

2.2.3 Choice architecture

Precommitment is one of several types of “choice architecture,” a method of influencing choice by changing how options are presented to the decision maker (Thaler and Sunstein 2008). Two major choice architecture strategies are (1) setting *default* options and (2) *framing* decision outcomes differently. Choice architecture has proven an effective strategy to mitigate cognitive biases and barriers, and it holds great promise for sustainability-related decisions.

Choice architects (those who design choice environments) are comparable to building architects. There is no “neutral” building architecture: the size, shape, and materials of a building determine how users interact with the space. Thus there is also no neutral choice architecture: a default option, as well as the order, phrasing, or grouping of options, can affect the decision for better or worse (Thaler and Sunstein 2008, Johnson et al. 2012). The Envision rating system is an inherent form of choice architecture, as it guides and influences decision making. An engineering firm using Envision for a project will be guided or “nudged” to emphasize certain sustainability goals over others, since the number of points assigned to each Envision credit is meant as a subjective weight for its importance. For example, *Quality of Life 1.1- Improve Community Quality of Life* and *Climate and Risk 1.1- Reduce Greenhouse Gas Emissions* are each worth a maximum of 25 points, more than any other Envision credits. On the other hand, credits such as *Natural World 1.4- Avoid Adverse Geology* and *Resource Allocation 1.6- Reduce Excavated Materials Taken Off Site* are less emphasized because achieving them can only earn up to 5 or 6 points, respectively.

The Envision case study module described in this paper is an approach for engineering education linking sustainable infrastructure with transdisciplinary concepts from behavioral decision science. It incorporates role-playing, active learning assignments challenge students to: (1) use Envision credits to address seven specific sustainability challenges of the project; (2) consider choice architecture strategies for upstream decision makers to promote a more sustainable RFP and bid procurement process.

2.3 Methods

An educational case study was developed on an infrastructure project recently certified by the Envision rating system. This case study serves as a teaching instrument linking principles in decision making to sustainable engineering in the real world. It was used as the basis for a classroom module to achieve five defined student learning outcomes related to sustainable infrastructure and decision making. Accomplishment of student learning outcomes was “triangulated” with three primary methods of assessment: changes in self-reported learning outcome confidence, rubric-based scoring of student writing assignments and survey responses, and concept maps. Word clouds were also generated as visual representations of students’ perceptions of sustainable design. The full course module including the case study, PowerPoint slides, teaching notes, and assignments are under peer review to be posted at <http://csengin.syr.edu/electronic-holdings-library/>.

2.3.1 Case study development

The Envision case study detailed in this paper is on the Tucannon River Wind Farm in Dayton, Washington. The wind farm provides clean renewable electricity to 84,000 homes in the Portland, Oregon area and helped meet Oregon’s Renewable Portfolio Standard. The project

received the Envision Gold certification in 2015, becoming the first ever Envision-certified energy project.

The authors conducted a phone interview with a representative of both the project owner, Portland General Electric (PGE), and the engineering firm, Burns & McDonnell (BMCD). The discussion included questions on the project's planning and decision making, including challenges and tradeoffs, why and how Envision was used, and how the project excelled in sustainability. The project's greatest strengths included a strong emphasis on life-cycle analysis (including embodied energy and carbon emissions), resilience to extreme weather conditions and environmental hazards, and long-term leadership and planning. These efforts are reflected in high ("Conserving") levels of achievement on the following Envision credits: *Leadership 3.1 Provide for Long-Term Monitoring and Maintenance*, *Resource Allocation 1.1- Reduce Net Embodied Energy*, *Climate and Risk 1.1- Reduce Greenhouse Gas Emissions*, and *Climate and Risk 2.3- Prepare for Long-Term Adaptability*. The interviewees shared much of the project documentation that had been submitted to Envision for project verification, which the authors used to develop the case study document and module teaching slides.

The module includes several concepts from behavioral decision science related to the case study, which are taught in conjunction with the Envision credits mentioned above to show how Envision can help overcome cognitive bias and improve decision making. The three concepts are status quo bias, precommitment, and choice architecture. Status quo bias relates to the Tucannon River Wind Farm because the RFP bidding criteria prescribed by the state utility commission (to hire the project's general contractor) included only price and risk criteria, with no specific consideration or weight given to sustainability. This relates to the McKinstry article referenced in the background: contractors limit their scopes of work to win the low-bid war, but

better crafted RFPs can create a race to propose more creative, efficient solutions. For the Tucannon River Wind Farm, although the price was set during bid procurement, the owner (PGE) overcame this status quo bias of neglecting sustainability; it chose to hire an additional consulting engineer (BMCD) to incorporate sustainable design improvements within the existing cost constraint.

Precommitment was selected as a teaching point for decision making with this case because it related to the well-known company culture of PGE and BMCD in which sustainability was already a central value. For these “green” focused companies, sustainable project-related decisions related to life-cycle cost, net embodied energy, reduced emissions, and long-term resilience were much easier to make with correspondingly lower risk perception and status quo influence. Through a track record of success and public recognition (including Envision certification), these companies can serve as role models to show that sustainable practices are achievable.

Choice architecture was relevant to PGE because of their unfulfilled desire to see some sort of sustainability criteria in the bid requirements. The company could consider choice architecture interventions (e.g. defaults, framing) to promote the adoption of a sustainable procurement process. For instance, the Envision rating system could be set forth as a new *default* for best-value RFPs, or *framed* as a way to avoid losing money in long-term (life-cycle) operations and maintenance costs.

The case study document written by the first author introduces the company culture, including PGE’s integrated sustainability approach and five pillars of sustainability, then describes integrated resource planning, the request for proposals (RFP) and bid process, and

seven major sustainability challenges faced in the project:

- Requiring turbines with the lowest life-cycle costs and emissions
- Achieving a robust and long-lasting facility, resilient to hazards and disasters
- Procuring concrete resources in a very remote location
- Preserving the well-being of nearby residents and landowners
- Not disturbing the local wheat harvest, which coincided with peak construction time
- Supporting customers with desired renewable energy while keeping costs viable
- Conserving wetlands, surface water, floodplains, and other natural resources onsite

After having read the case study, students were assigned one of the following role-playing assignments, acting as either the engineering firm or owner:

- Burns & McDonnell: “Considering the information and challenges in this case, how would you apply the Envision rating system to achieve an innovative and sustainable, yet cost-effective project? Which credits would help the most with achieving sustainability goals?”
- Portland General Electric: “How might you promote the adoption of sustainability standards in the RFP bid specifications to incentivize a holistically sustainable design from all bidders? How would you propose this idea to the public utility commission?”

Each student was asked to write a one-page typed summary on his or her proposed solution to the assigned questions, focusing on the Envision manual and credits, and providing reasoning and support for the answers.

2.3.2 Module setup and pedagogy

The teaching module, in the form of a comprehensive PowerPoint presentation, was taught in two classes at Virginia Tech, first in a two-day format (n=94 students), then a one-day (n=80). The two-day module was taught in a Civil and Environmental Engineering class (CEE) called Professional and Legal Issues. The structure of each day's class session was as follows:

Day 1

1. Presented the module's learning objectives.
2. Taught about Envision and how to navigate its credits.
3. Led activity and discussion with various Envision credits.
4. Introduced the Tucannon River Wind Farm, giving the case study and role-playing assignments as homework.

Day 2

1. Led class reflection and discussion on students' homework and use of Envision.
2. Provided brief overview of how PGE and BMCD actually addressed the challenges.
3. Taught and discussed behavioral decision science concepts including status quo bias, precommitment, and choice architecture. Discussion included how each one impacts sustainability and which Envision credits relate to it.
4. Followed the teaching of each concept by describing two to three related Envision credits, and detailing PGE and BMCD's achievement on each credit.
 - Status quo bias:
 - *Leadership 3.2- Address Conflicting Regulations and Policies*
 - *Leadership 3.3- Extend Useful Life*
 - *Climate and Risk 2.3- Prepare for Long-Term Adaptability*

- Precommitment:
 - *Leadership 1.1- Provide Effective Leadership & Commitment*
 - *Leadership 3.1- Plan for Long-Term Monitoring & Maintenance*
- Choice architecture:
 - *Resource Allocation 1.1- Reduce Net Embodied Energy*
 - *Climate and Risk 1.1- Reduce Greenhouse Gas Emissions*

5. Summarized overall take-away points and showed video of the wind farm's construction.

The rationale is now described for one credit related to each behavioral concept. *Climate and Risk 2.3- Prepare for Long-Term Adaptability* relates to status quo bias because it is beyond the typical scope of most construction projects, and Conserving and Restorative levels are the only options: a team must greatly surpass the industry status quo to gain any points at all. *Leadership 3.1 Provide for Long-Term Monitoring and Maintenance* relates to precommitment because the team has to be very committed to put such comprehensive plans in place during the early stages of a project. *Resource Allocation 1.1- Reduce Net Embodied Energy* relates to choice architecture because it requires a significant amount of effort to conduct the entire life-cycle assessment; the process of collecting and computing all this information increases awareness and incentivizes making reductions compared to industry norms.

The one-day module was taught in an Environmental Life Cycle Analysis class (LCA), which was required for a minor in Green Engineering. For this class, students received the case study without the assignments; instead an overview of the Envision rating system was given to students to read before class. The class was structured similarly to the two-day module with the following differences:

- Only three Envision credits, with relevance to life cycle analysis, were included:
 - *Leadership 3.3- Extend Useful Life*
 - *Resource Allocation 1.1- Reduce Net Embodied Energy*
 - *Climate and Risk 1.1- Reduce Greenhouse Gas Emissions*
- The introductory teaching on behavioral decision science was abbreviated, focusing on “cognitive bias and ways to influence decisions” related to the concepts of status quo bias, precommitment, and choice architecture. This section was presented after the Envision credits.
- An assignment was given at the end of the module, to use a concept map to “show the connections between this project’s challenges, barriers to sustainability, behavioral decision science concepts, and individual Envision credits.” This was assigned as optional extra credit due to constraints of the class, and 22 submissions were received.

2.3.3 Student learning evaluation methods

The first method of evaluating student learning was through surveys given before and after the modules. The first section of each survey asked students to rate, on a Likert scale from low confidence (1) to high confidence (5), their level of confidence with the following five learning outcomes of the module:

1. Implement characteristics of a sustainable design process.
2. Understand barriers, cognitive and otherwise, to a sustainable design process.
3. Develop holistic solutions to difficult engineering challenges.
4. Develop solutions to improve sustainability at an organizational/management level.
5. Innovate beyond conventional solutions to improve a project’s sustainability.

A paired t-test was used to determine the significance of increases in learning outcomes and other changes in the pre- and post-surveys. The survey also included a section about the students' perceptions of sustainable design, both its characteristics and barriers. Frequency tables and word clouds were generated to show the most commonly listed words before and after the module; these are included in the Results section. In a free-response section, the post-survey asked the students to define each of the behavioral decision science concepts and describe their applications. These were scored for accuracy by each of the authors, with internal validity demonstrated by percent agreement and weighted Cohen's Kappa statistics.

Survey self-reporting is acknowledged as a limited method to assess student learning, yet concept mapping is widely noted as relevant for the complexity and interrelatedness of sustainability concepts (Lourdel et al. 2007, Borrego et al. 2009, Watson 2013). For the LCA class only, the case study homework was not assigned. Instead, some of the students (n=22) created a concept map about the Tucannon River Wind Farm. Creating a concept map allowed each student to demonstrate his or her understanding of transdisciplinary linkages between engineering, sustainability, and behavioral science concepts. This provided opportunity for more meaningful assessment of how well this learning was achieved, and how effective this module was in its effort to bridge these disciplines. The assignment read as follows:

“Create a concept map to show the connections between this project's challenges, barriers to sustainability, behavioral decision science concepts, and individual Envision credits. Consider both the upstream RFP challenges faced by Portland General Electric and the engineering challenges and tradeoffs faced by Burns & McDonnell. Refer to the Envision manual for specific credits to include in your concept map.”

Three different scoring methodologies for concept maps include traditional, holistic, and categorical (Watson et al. 2016). The traditional method assesses knowledge breadth, depth, and connectedness by the number of concepts, hierarchies, and cross-links, respectively, but without any consideration given to quality or correctness. Traditional is the easiest method and can be automated. Although holistic or categorical can provide much more accurate and detailed results, it requires much more time to assess, as well as multiple scorers to validate. Both traditional and holistic methods were used to score the 22 concept maps, and the results were compared.

2.4 Results and Discussion

2.4.1 Surveyed learning outcomes

The survey results indicate significant increases in students' confidence with the learning outcome skills. These were presented on a 5-point Likert scale where 1=low confidence and 5=high confidence; pre-module and post-module averages for each class are shown in the tables below. Table 2.1 shows an overall increase from 3.31 to 3.80 (14.9%) in the two-day CEE class; Table 2.2 demonstrates a similar increase from 3.30 to 3.76 (14.1%) in the one-day LCA class. A paired t-test indicated p-values far smaller than 0.001 for each individual learning outcome and the overall increase, confirming the validity of these learning gains.

Table 2.1: Civil Engineering (2-day module) student confidence with learning outcomes

Learning outcome: “Select your confidence level to...”	Pre-module average	Post-module average	Percent increase
1. Implement characteristics of a sustainable design process.	3.27	3.88	18.9%
2. Understand barriers, cognitive and otherwise, to a sustainable design process.	3.35	3.86	15.2%
3. Develop holistic solutions to difficult engineering challenges.	3.32	3.66	10.3%
4. Develop solutions to improve sustainability at an organizational/ management level	3.34	3.84	15.0%
5. Innovate beyond conventional solutions to improve a project’s sustainability.	3.27	3.76	15.0%
Average of all five SLOs	3.31	3.80	14.9%

Table 2.2: Life Cycle Analysis (1-day module) student confidence with learning outcomes

Learning outcome: “Select your confidence level to...”	Pre-module average	Post-module average	Percent increase
1. Implement characteristics of a sustainable design process.	3.30	3.79	14.8%
2. Understand barriers, cognitive and otherwise, to a sustainable design process.	3.46	3.86	11.6%
3. Develop holistic solutions to difficult engineering challenges.	3.26	3.70	13.4%
4. Develop solutions to improve sustainability at an organizational/ management level	3.29	3.75	14.1%
5. Innovate beyond conventional solutions to improve a project’s sustainability.	3.18	3.71	16.9%
Average of all five SLOs	3.30	3.76	14.1%

2.4.2 Sustainable design characteristics and barriers

Student perceptions about the meaning of sustainability are worth noting, since the term may have different connotations to different people. In one section of the surveys, students were asked to “list as many *characteristics* of sustainable design as you can think of,” and to do the same for *barriers* to sustainable design. After the module, students were asked to list any *new* characteristics and barriers they learned about. Word clouds were generated from the bulk text of the responses, broken down by class and by question. These word clouds display the size of each word as proportional to its frequency (number of mentions). However, phrases are broken up, and that the prevalence of individual words cannot indicate the context in which they were used, thus offering limited conclusions. Common words (of, in, to, the, it, etc.) and those which were part of the question (sustainable, design, characteristic, barrier) were excluded from the word lists. In a few cases when two related words such as “status” and “quo” had an identical word count, they were manually grouped as a phrase in the table.

Figure 2.1 shows, for the CEE class as a sample, characteristics of sustainable design listed before and after the module. As may be expected, the pre-module answers were dominated by widely known core concepts of sustainability, particularly the environmental. Post-module results demonstrate students’ retention of some sustainability and decision-making concepts and themes taught in the module. Nearly one-third of the class listed “leadership,” one of the major focuses of Envision, as a new characteristic. Envision itself, as well as its aspects of “community” and “quality of life,” were also listed as new characteristics of sustainable design, which had not been evident in the pre-module survey. For more detail, Table 2.3 shows the word frequency table including both classes.

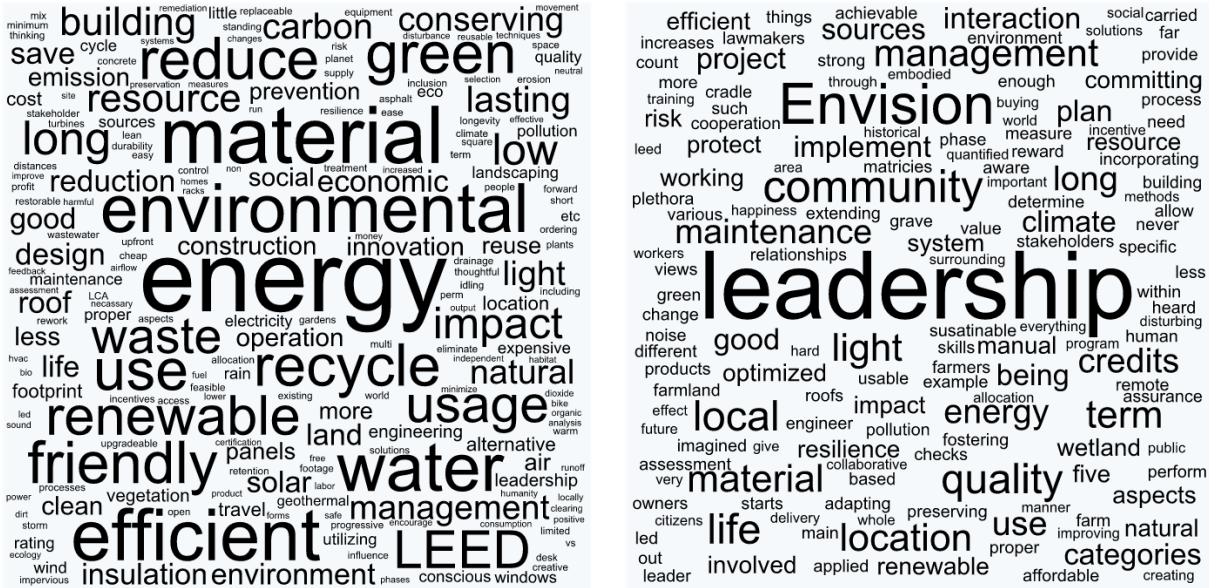


Figure 2.1: Pre-module (left) and post-module (right) characteristics of sustainable design, CEE

Table 2.3: Content frequency for characteristics of sustainable design, both classes

Characteristics (pre-module)				New characteristics (post-module)			
	CEE class (n=94)	LCA class (n=80)		CEE class (n=94)	LCA class (n=80)		LCA class (n=80)
energy	35	energy	41	leadership	30	Envision	12
material	22	material	28	Envision	11	energy	9
efficient	18	efficient	27	community	7	nudge	9
water	16	low	26	quality of life	6	use	8
environmental	16	use	22	local	6	leadership	8
use	12	environmental	19	management	5	life	7
recycle	12	water	16	term	5	system	7
reduce	12	renewable	16	location	5	rating	5
friendly	12	reduce	15	light	5	reduce	4
green	12	impact	14	material	5	point	4
renewable	11	recycled	14	maintenance	4	differs	4

Judging from the word frequencies in the table above, the two classes had quite similar ideas of sustainable design before the module, including energy/material/water efficiency, the environment, reducing consumption, recycling, and using renewable resources. As mentioned above, the CEE class most frequently mentioned “leadership” as a new characteristic—possibly attributable to their role-playing assignment using Envision. The LCA class, however, noted

“Envision” more often than leadership, likely because the one-day module focused on Envision as a whole. Interestingly, neither “precommitment” nor “choice architecture” was frequently mentioned in either class, but the related concept of “nudge” did appear in the LCA class’s list.

Responses to the next question, *barriers* to sustainable design, are shown in the word clouds in Figure 2, this time using the Green Engineering LCA class as a sample. These barriers, as might be expected, are heavily cost-related; even Green Engineering students believe that sustainability is expensive. After the module, over one-eighth of the students recalled and noted the module concept of status quo bias. Yet cost was still a commonly listed barrier. Table 4 shows the word frequency table for both classes.



Figure 2.2: Pre-module (left) and post-module (right) barriers to sustainable design, LCA

Table 2.4. Content frequency for barriers to sustainable design, both classes

Barriers (pre-module)				New barriers (post-module)			
CEE class (n=94)		LCA class (n=80)		CEE class (n=94)		LCA class (n=80)	
cost	35	cost	30	cost	10	status quo	13
money	23	money	18	bias	8	bias	11
time	14	time	11	status quo	7	cost	7
stakeholders	8	material	8	project	7	rating system	5
politics	7	location	8	community	6	commit	4
construction	6	technology	7	local	5	people	4
resources	5	economic	7	people	5	use	3
availability	5	expense	6	getting	4	everyone	3
owner	5	availability	6	area	4	getting	3
public	4	stakeholders	6	material	4	assessing	2
economic	4	lack	5	money	3	mindset	2

From the frequency table, cost (money, economic, expense) is the largest perceived barrier to sustainable design, with over one-third of each class listing such concepts. Perceived cost and time barriers certainly impact industry adoption of sustainability. Also common to both classes' pre-module responses are stakeholders, availability, and materials/resources. After the module, several students from each class listed "bias" and "status quo" as major barriers to sustainability. "Rating system" and "commit" were listed in the context of *overcoming* barriers. Yet overall, the number of responses indicating specific concepts from the module was lower than expected.

2.4.3 Behavioral decision science: concept definitions and examples

After the in-class teaching on behavioral decision science, the post-module survey measured students' retention and understanding of the three main concepts. This free-response section included the following two-part questions, each consisting of a definition and an application of the concept:

- Define status quo bias in your own words, then list a way that it can be overcome.

- Define precommitment in your own words, then describe how it can be used to facilitate a more sustainable project.
- Define choice architecture in your own words, then name and briefly describe the two types of choice architecture covered in class.

The following model answers were developed based on the module's teaching and used as the basis for scoring student responses.

Status quo bias

- Definition: A general tendency to maintain the way things are currently done; an industry norm, common practice, or "do-nothing" option that owners/designers/engineers follow if there is no strong preference for an alternative. Relates to risk/loss aversion.
- Way to overcome: Choice architecture/nudges (defaults, framing, Envision), role models, and incentives. Raise awareness of problems (potential losses) with the status quo and long-term benefits of alternative innovative/sustainable solutions. Lifelong learning and education.

Precommitment

- Definition: Making a public commitment to a goal beforehand to align future behavior and choices.
- Application: An organization could commit to a sustainability-related goal (reduce emissions, use renewable energy, use Envision, "design with community in mind," etc.) and make it part of the culture, leadership, long-term business plans, public image, etc.

Choice architecture

- Definition: A method of influencing choice by changing how options are presented.

- Two types: Defaults imply a recommended or suggested action (as a "do-nothing" status quo) reduce cognitive effort, and may reduce trade-offs of the decision. Framing can be done as a loss or gain; noting potential losses rather than gains (e.g. lose money in long term if you *don't* design sustainably) can encourage better decisions.

Student responses were scored on a 0-1-2-3 scale, defined as 0 for no response, 1 for weak, 2 for fair, and 3 for good. This scoring system is based on previous educational research scales (Bielefeldt 2013). Again, responses were scored by two researchers; the inter-rater reliability was very good with 92.5% agreement across all datasets. The weighted kappa statistic was used since the scoring categories are ordered: overall it was 0.941, also indicating very good agreement. The average scores, by class and by topic, are presented in Table 2.5.

Table 2.5: Average behavioral decision science free-response scores (out of 3)

Concept	Class	Definition	Application
Status quo bias	CEE	2.5	2.2
	LCA	2.7	2.3
Precommitment	CEE	2.0	1.7
	LCA	2.3	2.0
Choice architecture	CEE	1.4	1.0
	LCA	2.0	1.5

The students who responded to each question generally grasped the behavioral decision science aspect of the module, despite its brevity and the novelty of the concepts. The lower scores were due in part to several students receiving “0” scores for no response. One notable observation is that the average scores decreased steadily from one question to the next; this may indicate survey fatigue since these questions were at the end. Furthermore, some students may have overlooked the fact that each question was made up of two parts requiring distinct answers. Overall, the quantity and quality of survey responses will be improved in the future in several

ways: referring to the post-survey as a quiz, notifying students ahead of time that they will be quizzed on the module material, and requiring answers to all questions in the survey.

2.4.4 Role-playing writing assignments

Student assignments were collected and scored by each of the authors on the same 0-1-2-3 scale as the survey free-response. The CEE class (n=120) was split into two groups so that each student would complete one of the two role-playing assignments (either as an engineer from BMCD or owner from PGE) in applying Envision to the case study. Each task required a one-page typed summary with reasoning and support for the answers. The average score for the BMCD assignment was 2.5 out of 3, and for the PGE assignment it was 2.25. The overall inter-rater agreement after scoring these BMCD and PGE assignments was 87.5% and the weighted kappa statistic was 0.828, indicating a high level of consistency between the two scorers.

Students in the first subset played the role of the wind farm's engineering firm Burns and McDonnell (BMCD), with the task of applying Envision to solve important engineering and sustainability challenges: *“Considering the information and challenges in this case, how would you apply Envision to achieve an innovative and sustainable, yet cost-effective project? Which credits would help the most with achieving sustainability goals?”* This assignment tested three of the student learning outcomes:

- (1) Implement characteristics of a sustainable design process.
- (2) Develop holistic solutions to difficult engineering challenges.
- (5) Innovate beyond conventional solutions to improve a project's sustainability.

Results from the BMCD group yielded an average score of 2.5 out of 3. Since this assignment was given after the first class session's teaching about Envision, the students seemed

comfortable with using the Envision manual. When points were deducted, it was often for the following:

- Neglecting one or more of the major challenges listed in the case study.
- Failing to name specific Envision credits relevant to these challenges.
- Inaccurate understanding or lack of explanation for the Envision credits used.

The second subset of this class played the role of the wind farm owner Portland General Electric (PGE) and was tasked with ways to improve the state-mandated Request for Proposals process to incentivize a more sustainable design from the bidding contractors: *“How might PGE promote the adoption of sustainability standards in the RFP bid specs to incentivize a holistically sustainable design from all bidders? How would you propose this idea to the state’s public utility commission? Look especially at Leadership credits.”* This assignment involved the following student learning outcomes:

- (1) Implement characteristics of a sustainable design process.
- (4) Develop solutions to improve sustainability at an organizational/management level.

Some of these students’ proposed solutions included: restructuring the point-based bid scoring system for cost and risk to include an Envision component, requiring sustainability-related contractor qualifications (e.g. Envision Sustainability Professional), a precommitment to sustainability, or plans for multi-stakeholder collaboration and teamwork. These changes in the status quo could be helped by choice architecture framing: PGE could emphasize to the utility commission that Envision is an indispensable tool for RFPs to promote Oregon's renewable energy requirements as well as numerous social, environmental, and economic benefits.

Despite these relevant solutions, there were a larger number of poor responses on the PGE assignment than the other (the average score was 2.25). Several students evidently did not

understand the concept of the RFP or bidding process. Most of the lost points stemmed from some sort of misunderstanding of the assignment, which allowed necessary clarifications to be made in updates to the case study.

2.4.5 Concept map scores

As stated previously, students in the LCA class created concept maps to show complex connections between the project challenges, barriers to sustainability, behavioral decision science concepts, and individual Envision credits. The students' concept maps were independently scored by two researchers using both the traditional and holistic approaches defined by Watson et al. (2016). The traditional scoring method is completely objective, based on (1) number of concepts, (2) depth of hierarchies, and (3) number of cross-links; it gives no consideration to quality or correctness. One advantage of this method is that digital concept map files created with the software CmapTools can be scored automatically with a parsing script.

The holistic method, on the other hand, is considered more appropriate for the topics in this module where some of the connections and relationships may be difficult to understand. It includes subjective scoring on a 0-1-2-3 scale for each of three aspects: comprehensiveness, organization, and correctness, yielding a maximum score of 9. The aspects are described as:

- *Comprehensiveness*: both depth and breadth, including the behavioral concepts.
- *Organization*: a meaningful and easily interpreted structure.
- *Correctness*: proposition links and descriptions must be logical.

As expected, the two scoring methods produced quite different results. There was often great disparity between a student's relative traditional score and holistic score. The traditional method rewarded students with a greater number of concepts and cross-links, while the holistic

method rewarded correctness and logical structure. For instance, the student with the highest traditional concept map score (172) included 70 concepts and 8 cross-links, but scored only 6.25 out of 9 with the holistic method due to deficiencies in organization and correctness. One of two students with the highest holistic score (8.25) had a very well-structured and organized concept map but scored only 72 with the traditional method due to a lack of cross-links. Holistic correctness and quality are considered more important than a large number of concepts for this type of module. Table 2.6 shows statistics on the scoring of each method. Percent agreement on the holistic method was low because it was more subjective and also included many possible outcomes (half-point scoring increments were used, with total scores ranging from 0 to 9).

Table 2.6: Concept map scores (average of two scorers)

Metric	Traditional method	Holistic method
Highest score	172	8.25
Lowest score	40	3.75
Average score	91.5	6.3
Median score	79	6.25
Percent agreement	83%	41%

Weaknesses in the concept map submissions indicated several opportunities for improvement. For one, most students showed plenty of depth on Envision, but neglected to include the full breadth of decision science (status quo bias, precommitment, choice architecture). This seems to indicate a gap in understanding between the module concepts and thus a need for more than one day of instruction. However, another contributing factor is that students lacked understanding about how concept mapping should be done. Updates to the module slides now include more detailed explanation of concept map elements, an example concept map, and a tutorial video to watch before completing the assignment. Concept mapping

is most appropriate within a curriculum in which it is used consistently and often, so some instructors may choose to utilize this activity and some may not.

2.4.6 Student feedback

Student feedback was also requested in the post-module survey. Several opportunities for improvement were noted, but the following positive responses indicate that students truly appreciated what they learned in the module:

- “I enjoyed learning about Envision. I think that it is a practical means of going about sustainability. Before learning about Envision, my issue with sustainability being implemented into projects was just how impractical and costly some of the requirements are. Envision allows sustainability to be applied in a way that makes the infrastructure better, more efficient, and possibly cheaper if the leadership principles of Envision are implemented throughout the project.”
- “Already being familiar with LEED through class and internships it was very interesting and relevant to learn about Envision the way we did. I noticed a number of parallels and would recommend making this a topic that is extensively covered and meshed into all parts of the CEE curriculum.”

2.5 Conclusion

2.5.1 Summary and contribution

With growing concerns for sustainability in the built environment, engineers must create infrastructure system solutions that transcend disciplinary boundaries, synthesizing and integrating concepts from the pillars of humanities and social sciences into the technical sphere. Such a transdisciplinary effort must become a bigger part of undergraduate education, with early

encouragement to consider the psychological and sociological aspects of decision making in the engineering business environment.

This teaching approach of the Envision case study module has attempted to address sustainable engineering and decision making from the psychological perspective (Manning 2009). Teaching students to recognize cognitive barriers and choice architecture tools will promote better management of their own decisions and clients, as well as recognition of how the infrastructure systems they construct influence downstream user behavior. The Tucannon River Wind Farm module promotes the learning of necessary transdisciplinary concepts spanning engineering, sustainability, and behavioral decision science. Grounding the instruction in a real-world case study helps make such theoretical concepts more tangible and realistic. For concepts more often associated with psychology and social sciences, relating them to an engineering context helped illustrate their importance in all of decision making.

The results of this educational study rely on multiple methods to evaluate its effectiveness. Each form of assessment provided insight and added validity to the results. First, surveyed confidence scores demonstrated that students learned what was intended. Second, word clouds graphically displayed how the module affected students' sustainability knowledge. Third, rubric-based scoring of assignments provided a more detailed view into student learning: from each one-page submission, it could be judged how well the student achieved certain learning outcomes. Furthermore, concept maps are an emerging opportunity to assess students' transdisciplinary knowledge integration between engineering, sustainability, and decision-making concepts. Overall, results from these two initial classes have already brought about updates and improvements to the case study and module, which will increase their future effectiveness for student learning.

The Tucannon River Wind Farm module is one of three different Envision modules created by the authors. Of the two others, one focuses on community and multi-stakeholder needs and tasks students with designing the Historic Fourth Ward Park in Atlanta, Georgia. Another, on Nashville's West Park Wastewater Equalization Facility, follows a flipped classroom format in which students work in groups to write professional memos recommending to a client the size and placement of a wastewater tank.

The complete module content was first shared with several engineering instructors who teach infrastructure or sustainability-related classes at other universities across the United States, and now all three are under review to be posted in the Center for Sustainable Engineering at <http://csengin.syr.edu/electronic-holdings-library/>. With this repository, instructors may access the modules to adapt and use in their own classes, and also create and contribute their own modules. Each one comes with a "readme" file and detailed instructor notes to facilitate the slide presentation and class activities. The teaching can be further facilitated by this paper's supporting literature about the behavioral decision science concepts.

2.5.2 Challenges and needs for future research

Although students did appreciate and learn from this brief module, they would certainly benefit from more thorough coverage of the content, perhaps extending it to three class days instead of one or two. Survey results and assignment evaluations demonstrate some challenges with teaching new topics in only one or two lectures. For instance, in students' post-module survey responses about sustainable design, the number of responses indicating specific concepts from the module (i.e. precommitment as a characteristic, status quo bias as a barrier) was somewhat low. In the free-response survey questions about behavioral decision science concepts,

several students answered poorly or not at all. Future implementations of this module should spend more time to explicitly emphasize these points.

A single class session also did not allow time for adequate instruction on concept mapping, and more specific instructions and explanation are needed on the key elements (concepts, propositions, hierarchies, and cross-links). Without propositions (descriptive connections between the concepts) structured properly, it is difficult to judge correctness for the holistic scoring method. Instructors who consider adopting the concept mapping assignment for this module should do so judiciously. It will be valuable in any setting where concept mapping is already used, but otherwise there is a learning curve involved.

These are a few of the limitations with the brevity of such modules. A single Envision module cannot facilitate *deep learning* of sustainability knowledge (Burian and Reynolds 2014) or decision-making theory. Yet when embedded within a course and curricular context that also emphasizes sustainability, transdisciplinary knowledge, and complex, ill-structured problems, the modules are made much more effective. As noted in the student feedback, Envision should become a topic that is “extensively covered and meshed into all parts of the CEE [Civil and Environmental Engineering] curriculum,” along with other sustainability content. This is one reason these new modules are intended to be shared in a repository, to allow for educators to customize and “scaffold” this new content appropriately within their own classes.

With the backing and support of ISI and other interested groups, the Envision case study module may become a widely used teaching method among university educators. Exponential growth of Envision, rating systems, and decision-making tools for sustainable construction demonstrates that this need cannot be ignored. Students, engineers, and the general public can all

benefit from greater awareness of the behavioral and cognitive factors that impact our decisions for sustainability and future generations.

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JOURNAL PAPER 3: Case-Based Flipped Classroom Approach to Teach Sustainable Infrastructure and Decision Making

(Nashville West Park)

Intended Outlet for Publication:

International Journal of Construction Education and Research

Authors:

Nathan McWhirter¹

Tripp Shealy²

¹Graduate Research Assistant, Department of Civil and Environmental Engineering,
Virginia Tech, Blacksburg, VA. Email: nathandm@vt.edu

²Assistant Professor, Department of Civil and Environmental Engineering,
Virginia Tech, Blacksburg, VA. Email: tshealy@vt.edu

Abstract

Design, engineering, and construction for more sustainable and resilient infrastructure involves complex decisions with considerable risk and uncertainty. To prepare students for such challenges, accreditation agencies and professional organizations like ABET, ACCE, and ASCE are placing more emphasis on complex engineering problems, as well as student learning outcomes related to sustainable design, professional issues, and communication. The case-based module developed and tested in this study aims to address such needs by integrating several pedagogies, including problem-based learning, a flipped classroom, and transdisciplinary content on behavioral decision science. The module presents a case overview of a wastewater project in Nashville, Tennessee. Team-based active learning involves writing professional memos proposing the number and placement of holding-tanks, first based on a cost estimate and later for an extreme flood scenario. Three decision-making concepts (take-the-best heuristic, risk aversion, and regulatory focus theory) are taught at the end of class. Students write individual reflections relating these to the Nashville case study. Evaluation methods include rubric scoring and content analysis, as well as pre-module and post-module surveys. The teaching on sustainability, resilience, and decision-making broadened students' considerations beyond initial costs to include a more holistic design perspective. This module is under peer review and will be made available to instructors at <http://csengin.syr.edu/electronic-holdings-library/>.

3.1 Introduction

The field of construction is indispensable to society. It provides essential assets, and involves large capital commitments and high-stakes decisions for both buildings and infrastructure. The decisions made today by designers, civil engineers, and contractors shape the

enduring impacts of these systems on human quality of life and the natural environment for decades. As the world faces a growing population, constraints of non-renewable resources, and natural disasters, society must prioritize sustainability in construction. Despite the prevalence of complexity and uncertainty, social and environmental considerations must become embedded into decision-making processes.

There are many definitions, ideas, and concepts about sustainability, but the overarching goal of all of them is to “ensure the well-being of current and future generations within the limits of the natural world” (Nature Sustainability). Knowing key characteristics of sustainability is helpful for understanding how to implement it. Thus, rating systems for sustainability act as tools to guide complex decision-making processes toward more sustainable outcomes. Perhaps the most well-known rating system is the U.S. Green Building Council’s LEED (Leadership in Energy and Environmental Design), launched in 2000, which sets forth standards and offers public recognition for green buildings. Since LEED, other rating systems have been created for non-building construction, including landscapes (Sustainable SITES Initiative–2005), roads (Greenroads–2007; INVEST–2009), and neighborhood development (LEED ND–2009). In 2012, the Envision rating system was created to bring together these systems, with the versatility to be used for any type of non-building infrastructure project. Like other rating systems, Envision includes credits as quantitative metrics for sustainability.

As rating systems become increasingly utilized by industry professionals, they are also being taught in undergraduate courses. The growing complexity of the world necessitates that students not only be technical problem-solvers but also understand the underlying social and environmental context (Allenby 2011). Considering this need, the “triple bottom line” of sustainability is incorporated into many engineering and construction programs using

applications of the LEED rating system (Tinker and Burt 2004, Wang 2009, Kevern 2011, Hyatt 2011). More recently, the Envision rating system is also being included in some classes (Bielefeldt 2013, Burian 2014). Rating systems themselves are not a panacea for sustainability, but they do facilitate connections to practical, real-world case studies (certified projects) and complex decision-making scenarios, which are powerful ways to promote meaningful learning.

Sustainability is a recognized learning outcome in governing educational standards such as ABET and ACCE. The American Council for Construction Education (ACCE) accreditation standards include a student learning objective to “understand the basic principles of sustainable construction” (ACCE 2016). More broadly, in October 2017, the Accreditation Board for Engineering and Technology (ABET) updated its criterion for student outcomes including a requirement for complex engineering problems in educational curricula. Complex engineering problems are characterized as:

- “involving wide-ranging or conflicting technical issues,
- having no obvious solution,
- addressing problems not encompassed by current standards and codes,
- involving diverse groups of stakeholders,
- including many component parts or sub-problems,
- involving multiple disciplines, or
- having significant consequences in a range of contexts” (ABET 2017).

These points are also largely definitive of sustainability problems, which are inherently complex, transdisciplinary, and often ill-structured, so a focus on sustainability is a logical choice for advancing pedagogy in engineering and construction education.

In addition, the American Society of Civil Engineers (ASCE) Body of Knowledge (BOK2), as part of a vision for civil engineering in 2025, used Bloom's Taxonomy as a framework to define and promote high levels of achievement on 24 learning outcomes (ASCE 2008). ABET and ASCE learning outcomes have many parallels, and each of them covers the areas of problem solving, sustainable design, professional issues, and communication. For problem solving, both emphasize the importance of complex and/or ill-defined problems. For the sustainable performance of complex systems, these organizations promote holistic design considerations beyond just social, environmental, and economic. ABET and ASCE both note the importance of professional and ethical responsibilities for informed judgments, and also stress the ability to communicate effectively in different ways with a variety of audiences.

The research described in this paper has aimed to combine several important pedagogies: sustainable engineering modules, case studies, problem-based learning, and a flipped classroom. The goal is to facilitate student learning bridging many disciplines: engineering, sustainability, and cross-disciplinary concepts from “behavioral decision science”—a term here including decision making, psychology, behavioral science, and cognitive biases. This is done through a case-based module about the Envision-certified West Park Equalization Facility, a wastewater infrastructure project in Nashville, Tennessee. The pedagogies and decision science are described in the Background, and details of the module and classroom setup are included in the Methods section.

3.2 Background

The trend to incorporate concepts of sustainable engineering into U.S. engineering curricula was acknowledged by an early benchmark study (Allen et al. 2009). Potential strategies to do so include add-on, integration, or rebuilding, yet smaller changes are more common since

staff viewpoints are often resistive to change (Kolmos et al. 2015). The add-on approach to incorporating sustainable engineering is usually by developing new classes, with research and accreditation as primary drivers (Kolmos et al. 2015). Another, perhaps better approach is the integration of sustainability modules into various classes throughout an engineering curriculum (Allenby et al. 2009, Watson and Barrella 2017). Creation of such modules has been the goal of the Center for Sustainable Engineering (CSE), which collects sustainability topics and activities into a common repository to allow educators to share and collaborate (Davidson et al. 2016). The module detailed in this paper aims to be part of such a collaborative effort.

Case studies, another important pedagogy, can be incorporated into teaching modules about sustainability (Elleithy and Leong 2014, Flynn et al. 2016). Case studies, based on real-world civil engineering projects like Nashville's West Park described below, are an effective way to increase students' understanding and appreciation of sustainable engineering and construction. Student feedback often indicates a high appreciation and desire for case study material (Wang 2009). Case study assignments are also more effective to achieve higher cognitive understanding about sustainability, corresponding to Bloom's Taxonomy levels of application and analysis (Bielefeldt 2013). Essays, or reflective writing, is a common evaluation approach, and is employed in the module described in this paper.

In addition to case studies, active learning approaches are often used to teach sustainability-related topics. One of the most valuable approaches is *project-based learning* (Segalàs et al. 2012). A related but more concise approach is *problem-based learning* (PBL). PBL promotes cognitive and professional skills through complex, ill-structured, interdisciplinary, real-world problems, which are directly reflective of sustainable development issues (Steinemann 2003). Interdisciplinary, problem-based scenarios are desirable to embed

sustainability in the curriculum; appropriately designed activities incorporate multi-stakeholder scenarios, span disciplinary boundaries, and are focused to teach problem solving (Dobson and Tomkinson 2012). PBL is more empowering to students compared to traditional approaches to learning and helps them better recognize the usefulness of what they are learning (Matusovich et al. 2012).

The final pedagogical approach integrated into the module described in this paper is the “flipped classroom,” which has been growing recently as a method to promote active learning in engineering (Velegol et al. 2015). It involves assigning lectures (either PowerPoint or video) for students to view outside of class and learn at their own pace. The take-home lectures are often accompanied by a brief survey, quiz, or activity to verify student participation and understanding. A primary advantage of a flipped classroom is that classroom time is designated for *applying* the material in team-based active learning or PBL assignments, while students are able to ask questions as needed. The method offers many advantages: a review of research studies on flipped classrooms indicated overall “positive gains in problem-solving skills, conceptual understanding, student retention, and satisfaction with flipped classes” (Kerr 2015). Similarly, the flipped classroom approach has been noted as especially beneficial for involvement, learning personalization, and student-teacher interaction (Marks et al. 2014). For these reasons, a flipped classroom was selected as the format for this Envision case study module.

In addition to teaching about sustainability, the module also included content on cognitive biases and barriers to more sustainable design and construction. The purpose of this was to help students become more aware of their own decision-making process and equip them

to help future clients make improved decisions for sustainability. The following subsection describes the theoretical approach to decision making used in the module.

3.2.1 Behavioral decision science

Formal multi-criteria decision analysis strategies are taught in many engineering curricula. However, such processes, including mathematical decision support systems (DSS), are still evolving and require increased fieldwork research to make a valuable impact on industry (Arnott and Pervan 2010). More often, practicing engineers build their decision-making capabilities on an acquired body of knowledge, simplified models, and professional expertise. These can be classified as *heuristics*: mental operations, shortcuts, or rules of thumb that simplify a decision under uncertainty (Tversky and Kahneman 1974). Heuristics are often immensely helpful, but can also lead to *cognitive biases*, systematic and predictable errors in judgment that negatively impact decision outcomes. Engineering students would benefit from an expanded awareness and understanding of these and other concepts from behavioral decision science.

This module focuses on three specific decision-making concepts linked with the Nashville case study: (1) take-the-best heuristic, (2) risk aversion, and (3) regulatory focus theory. These were identified with support from the latest Behavioral Economics Guide (Samson 2017). Each of the concepts is described with supporting literature.

Take-the-best heuristic is a shortcut in which the value of a decision alternative is judged based on a single good reason, an attribute that discriminates most effectively between the options (Gigerenzer and Gaissmaier 2011, Gigerenzer and Goldstein 1996). For example, in budget-constrained projects, decisions may be made with cost as the key driving factor.

The second concept is *risk aversion*, which is a major component of Prospect theory (Kahneman and Tversky 1979). Risk is typically defined as the expected consequences

associated with a given activity, or probability multiplied by consequences (Faber and Stewart 2003). Prospect theory can be summarized as “losses loom larger than gains.” In engineering and construction, a particularly risk-averse industry, numerous losses are possible in terms of money, assets, and human life. Engineering risk analysis can be done methodically and analytically (Faber and Stewart 2003), but heuristics are also used. Because building and infrastructure projects are so expensive and critical to society, it is especially imperative to avoid losses—including climate hazards and natural disasters like floods. Envision’s category of Climate and Risk provides a helpful framework for reducing many project-level risks.

The third decision-making concept involves the theory of motivation through gains and losses. *Regulatory focus theory* describes how human motivation and self-regulation operate according to two distinct focuses: promotion and prevention (Florack et al. 2013). This is essentially a parallel to the choice architecture strategy known as framing (Johnson et al. 2012). Messages presented in gain frames are more persuasive when the message is promotion focused, whereas loss-framed messages are more persuasive when the message is prevention focused (Lee and Aaker 2004). These concepts are relevant to sustainable engineering decisions, as different ways of framing can influence motivations for sustainability. Consider for example a gain-related frame about the Envision rating system: it adds value to a project, *promoting* long-term stakeholder satisfaction and public recognition. A loss-related frame could be that an Envision-guided design *prevents* loss, damage, and destruction of an infrastructure project by making it resilient against floods and extreme weather events.

Many other insights can be gained from studying how loss or gain framing influence motivation. Changing the framing of point values in the Envision rating system from gain (promotion focus) to loss (prevention focus) increased professional engineers’ consideration for

sustainability achievement (Shealy et al. 2016). Framing can also involve the financial incentives (reward vs. penalty) for construction contractors. Incentives for contractors are better framed as rewards [i.e. bonuses] than as penalties (Darrington and Howell 2011). Further study of the effects of gain and loss frames in construction offers “concepts and strategies that could better align economic incentives with project-optimized behavior” (Darrington and Howell 2011).

Considering the relevance of such behavioral concepts to engineering and construction, students will benefit from learning about them and their applications in decision making. In this module, students played the role of engineers for the Nashville wastewater project. After going through two group activities, the class was taught about these three behavioral decision concepts and then asked to submit a reflection linking these new ideas to their decision-making process. Full details of this reflection assignment are presented in the Results section.

3.3 Methods

The process of creating the case study module began by selecting an Envision-related infrastructure project. The West Park Equalization Facility in Nashville was certified Envision Platinum in 2016 (ISI 2016) and the engineering firm responsible for Envision documentation offered the project as a case study. Combined sewer overflows in the city prompted the need for 21 million gallons of additional wastewater storage capacity. The case was unique because of Nashville’s historic 1000-year flood event in 2010, which required changes to the project plans. This setback actually prompted the design team to place the wastewater tank inside the dilapidated West Park, and use cost savings to fund park upgrades, enhance public space, and improve infrastructure integration, among other benefits (ISI 2016). The teaching module uses

this Envision case study as the basis for a role-playing scenario in which student teams act as engineers in the design decision-making process.

Each of the behavioral decision science concepts has relevance to the West Park wastewater project. *Take-the-best heuristic* demonstrates a potential way that design decisions in the Nashville project might have been poorly made. In fact, this heuristic was presented to the students by focusing the first assignment on cost estimating. The cheapest design option was a single tank in the small site located just outside of the park, which would have been the obvious choice to a cost-driven decision maker. However, emphasizing sustainability concepts by teaching Envision later in the module mitigates the negative outcomes of this heuristic by pointing out many other factors beyond cost that must be considered for a holistically sustainable decision.

Risk aversion is relevant to the Nashville project in several ways. In general, it is a major reason for the persistence of status quo practices and norms, such as the common preference and incentives for low initial costs over life-cycle sustainability and resilience. Nashville's flooding catastrophe in 2010 demonstrated far greater project risk than the financial risk of a higher-costing facility, making the client (Metro Nashville's department of Water Services, collaborating with Parks and Recreation) more willing to spend money on mitigation. Risk and hazard management was further facilitated by Envision's Climate and Risk (CR) credits; the project team changed the design to place the new wastewater tank in a location less vulnerable to flooding. They "assessed climate threat" (CR2.1) through a life-cycle carbon assessment, and also "prepared for long-term adaptability" (CR2.3) ensuring that the tank, pump station, and park features were resilient against flooding and other extreme weather events (ISI 2016).

Corresponding to *regulatory focus theory*, the stakeholders of Nashville's wastewater project (client, designer, and community) are motivated differently depending on their prevention focus or promotion focus. This can provide insight into how the problem should be framed to promote flood resilience and sustainability. Obviously, flood risk communication has a much higher effect upon people with a prevention focus (de Boer et al. 2014). In the Nashville project, both the client and the designer were likely prevention-focused, especially in the post-flood context. The choice of regulatory framing also relates to stakeholder involvement, collaboration, and teamwork, which are components of Envision's Leadership credits. To gain approval and support for the project, the designer must consider which potential gains should be promoted (e.g. park amenities, improved public space, transportation connectivity) and also which existing benefits should not be lost (e.g. environmental health, greenspace, views).

Class implementation

After identifying the three decision-making concepts and verifying them with the engineering design firm, a three-part PowerPoint module was created to present the Nashville case study to a large senior-level civil engineering class at a large university in the eastern U.S. entitled Professional and Legal Issues (n=145). The module was placed within the context of two main syllabus topics: (1) leadership and (2) design/construction industry processes. Following the flipped classroom pedagogy, students were given a set of slides to review before each of the two class sessions. Students were also required to complete short activities and an online quiz for each, which were graded for completion.

Part 1, the main case study portion of the module, included take-home slides teaching general background on wastewater infrastructure, then explaining the Nashville case including the sewer overflow problem and need for additional storage capacity. Students, on their own,

considered the design challenge: conduct an approximate cost estimate (given relevant RS Means tables on water tanks, tree removal, grading, excavating, and piping) to decide on the number of tanks and where to place them. There were three options: students could choose a single 21 million gallon tank, two medium tanks, or three small tanks. Similarly, there were three placement options shown on a map of the site: next to the existing tank, somewhere within the adjacent West Park, or in an undeveloped land parcel a few blocks away. In class, after students had formulated solutions independently, the instructors began by leading a brief class discussion for students to share their individual ideas. Then students gathered in groups of 3-4 to reconcile their design ideas and cost estimates and then, acting as the project's engineering team, write a brief professional memo to communicate their proposed solution to the client.

Part 2, the next take-home portion of the module, demonstrated the unpredictable changes that so often happen with engineering and construction projects. Nashville's 1000-year flood event that occurred in 2010 was presented, along with FEMA's redrawn floodplain map, as the impetus for design revisions. The slides then taught about the Envision rating system as a framework to promote sustainability and resilience in the face of such challenges. The second in-class session was organized similarly to the first, but this time, armed with the tool of Envision, student groups revised their initial project design to be more sustainable and resilient. They were required to explain the application of at least one Envision credit from each category (Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk).

Part 3 of the module was a brief presentation given in class by the instructors after the student groups submitted their Envision memos. It included pictures and explanations of the actual Envision-awarded design for the West Park and some of its sustainable attributes. The instructors then introduced the three decision-making concepts (take-the-best heuristic, risk

aversion, and regulatory focus theory) and facilitated a short class discussion on each concept's relevance to the project. As a final homework assignment, students completed a one-page individual reflection on the relevance of these concepts to decision making and sustainability.

Following the example of other sustainability modules (El-Adaway et al. 2015, Bielefeldt 2013), this study evaluated student learning using multiple methods. These included pre-module and post-module surveys, as well as rubric-based scoring and content analysis of two group memo assignments and one reflection assignment. The results are presented in this order, beginning with student self-assessment of learning outcome achievement, and followed by the scoring and analysis of each memo and reflection.

3.4 Results and Discussion

3.4.1 Surveyed learning outcomes

Before the module, students were required to complete a brief survey to self-assess their confidence with each of five defined student learning outcomes (SLOs) for this module. The module overall addresses ACCE requirement #18, “understand the basic principles of sustainable construction,” and each SLO correlates to several of the 7 recently updated ABET outcomes (ABET 2017, p. 4):

1. Understand multiple design elements associated with planning wastewater infrastructure (ABET Student Outcomes 1, 2, 4, 7).
2. Make sound engineering design decisions based on cost estimates (ABET 1, 2, 4, 5, 6).
3. Explain and defend decisions by writing professional memos to a client (ABET 3, 4, 5).
4. Adapt a design solution to be more sustainable and resilient in the face of unexpected changes (ABET 1, 2, 4, 5, 6, 7).

5. Explain the impacts of cognitive biases and heuristics on engineering decision making (ABET 3, 4, 7).

The survey used a 5-point Likert scale for each learning outcome, where 1 indicates low confidence and 5 high confidence. After completion of both class sessions and all the module activities, the students re-assessed their confidence levels. The increase in learning is reported by the percentage of students in the class denoting “confident” (4) or “very confident” (5) with each SLO. This is a metric previously used in engineering education for sustainability (Weatherton et al. 2012). The pre- and post-module results are presented in Table 3.1 below.

Table 3.1: Percent of students indicating “confident” or “very confident” (Likert 4-5)

Learning outcome	SLO 1	SLO 2	SLO 3	SLO 4	SLO 5	Average
Pre-module	19%	60%	63%	34%	30%	41%
Post-module	68%	78%	83%	81%	64%	75%
Increase	49%	19%	20%	47%	34%	34%

Averaged between all five SLOs, the learning metric increased from 41% before the module to 75% after the module. The evident increases for all SLOs demonstrate that students perceived they gained proficiency in these skills. Notably, the greatest increase in confidence for any one learning outcome (49%) was for SLO 1, students’ understanding of planning wastewater infrastructure. Having Envision as a planning tool may have helped in this regard. The next largest increase was for SLO 4, related to sustainability and resilience (47%). Paired t-tests were used to compare each student’s pre-module and post-module responses, and all p-values met the confidence interval below 0.001.

3.4.2 Initial group memo based on cost estimating

Students were asked to determine their own solution individually before class as part of the flipped classroom approach. During the first in-class session, students sat in teams of three to four (37 groups total) and were allotted about 35 minutes to complete the first group memo assignment, which read as follows: *“By the end of class, your Activity Group will compare your individual solutions for the Nashville Wastewater project, and arrive at a consensus to make a recommendation to the client. Submit a one-page professional memo detailing your recommendation (following rubric guidelines, which you may use as a template) by the end of class.”* Three main components were required of this submission: (1) placement of tanks, (2) number of tanks, and (3) design considerations, including cost estimates.

The lowest-cost solution for the design problem was to construct a single 21 million gallon wastewater tank next to the existing smaller tank. Through estimating, students found that a single large tank was less costly than two medium or three small tanks, and placing it as close as possible to the existing tank and pump station minimized the cost of site and utility work. Consistent with the estimating assignment, students perceived cost as the primary driver in these design recommendations; thus, the majority of groups (54%) chose a single tank (Figure 3.1, left). The predominating tank placement (Figure 3.1, right) was either in the bottom-right side of West Park (62%) or next to the existing tank (33%)—both close to the pump station.

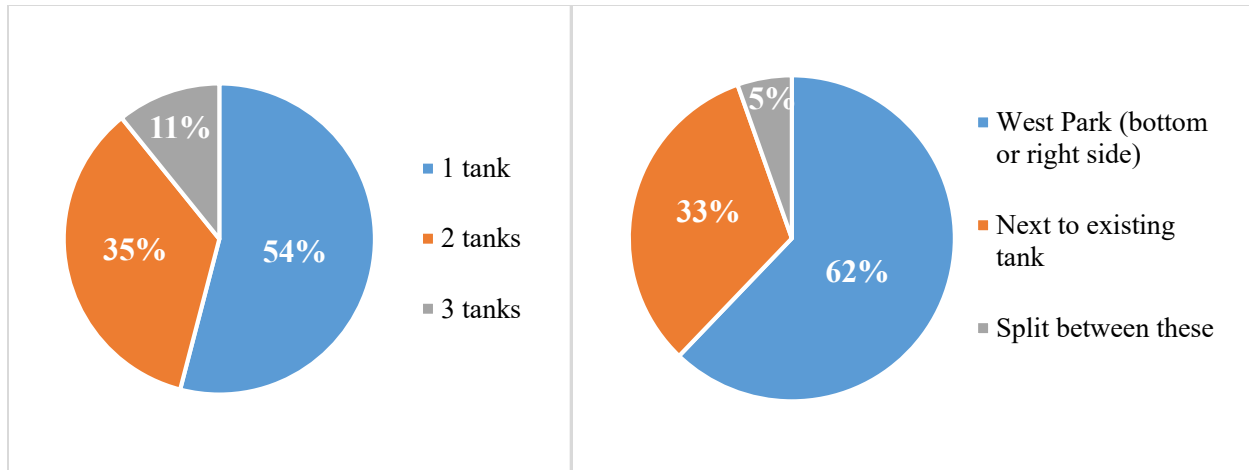


Figure 3.1: Initial memo, number of tanks (left) and placement of tanks (right)

The memo also required students to list and describe all of their planning and design considerations. Those commonly listed besides cost included community impacts, size or fit in the existing spaces, environment/land use, and aesthetics (Figure 3.2).

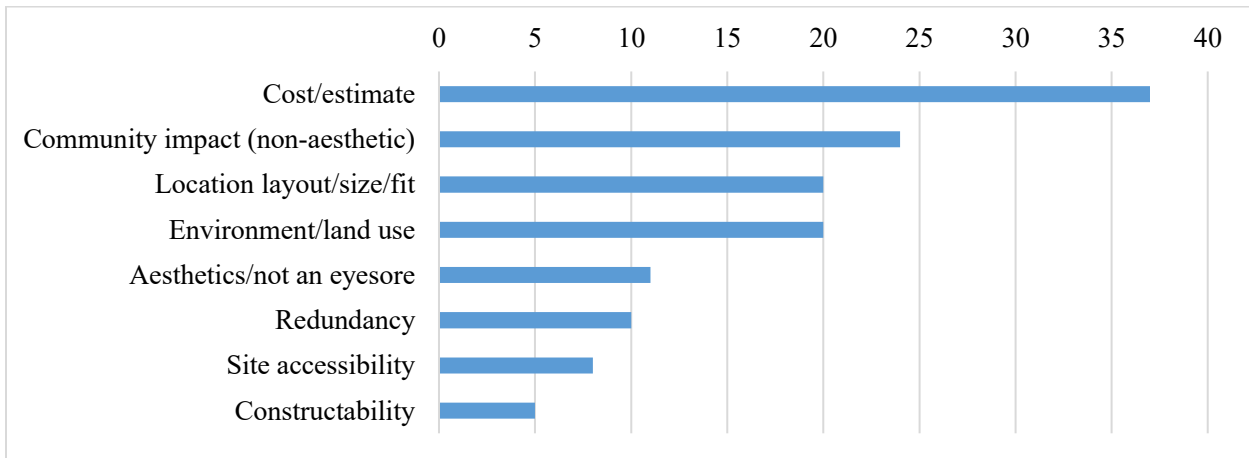


Figure 3.2: Initial memo design considerations, number of groups mentioning (n=37)

To evaluate the quality of the memos, a scoring rubric was created with the following criteria, based on the module's student learning outcomes:

- Describes design priorities and considerations (SLO 1)
- Includes reasonable tank placement and number of tanks based on cost estimate (SLO 2)

- Memo is professionally written and follows rubric requirements (SLO 3)

The scoring scale was defined with three possible values, where 3=good, 2=fair, and 1=weak, similar to one used by Bielefeldt (2013). Each group's memo submission was scored by two independent scorers. The average was highest for the category of describing design considerations (2.84 out of 3), followed by tank design and estimate (2.76) and then memo writing (2.59). The overall percent agreement between the two independent scorers was 92.8%. The weighted Cohen's Kappa statistic was 0.82, indicating very good agreement. The lower scores for memo writing are partially attributable to the time limitation during class.

3.4.3 Group memo using Envision rating system

For the second assignment, after submitting their cost estimates in the first class, the student teams reconsidered their initial recommendations for the wastewater tank(s) based on Nashville's flood. Sustainability, resilience, and the Envision rating system were now major priorities for the design. With 30 minutes of class time, each team was required to complete Envision's checklist spreadsheet to determine the applicability and feasibility of each credit, and to explain the application of one credit from each category in their memo.

The new design recommendations from most groups (63%) included shifting the placement of the tank(s) away from the floodplain to the right side of West Park (Figure 3.3, right). Several groups (24%) moved the tanks even further to the undeveloped auxiliary land parcel, which required even more of a cost tradeoff for clearing trees and installing more piping. Very few groups recommended a design in any part of the 100-year or 500-year floodplain. Furthermore, the majority of the class (78%) chose to construct two or three tanks (Figure 3.3, left) for redundancy and resilience, even though they cost more than a single tank.

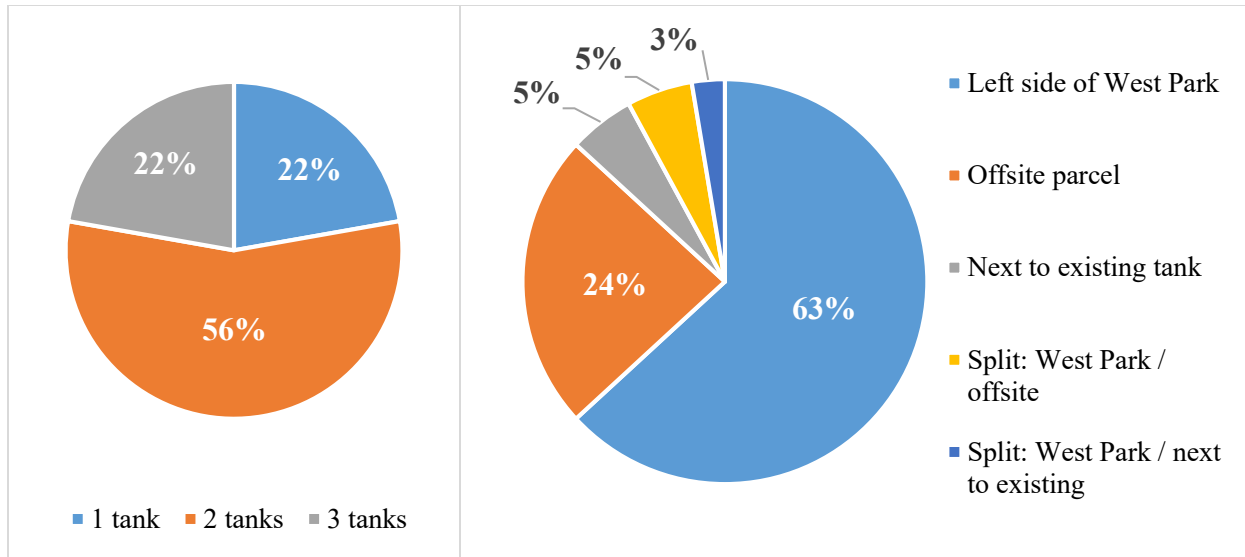


Figure 3.3: Envision memo, number of tanks (left) and placement of tanks (right)

Furthermore, the design considerations mentioned in this memo, shown in Figure 3.4, covered a broader range than the initial memo. Key concepts in this assignment were added as four new categories to the chart: Envision, sustainability, risk/safety, and resilience. Community impact was a major consideration, and was mentioned more frequently than before. Cost was still a main factor, but not emphasized as much as before. Although environment, sustainability, and resilience were mentioned, there could have been better connections made between Envision and these factors. Students' application of Envision credits centered on the floodplain issue but could have been more beneficial with more time to review all of the credits.

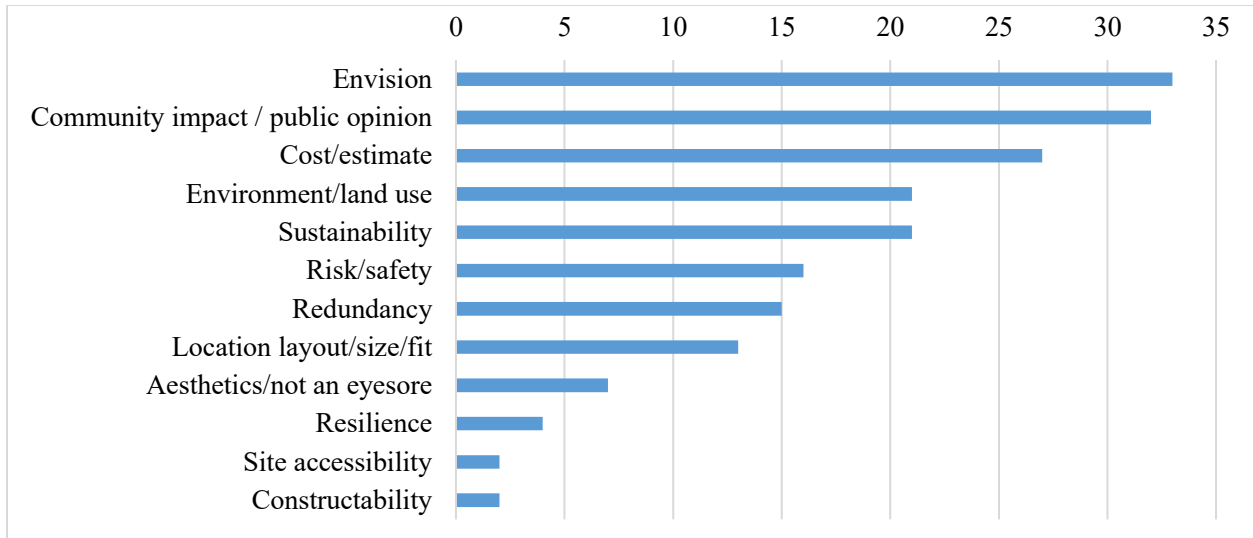


Figure 3.4: Envision memo design considerations, number of groups mentioning (n=37)

As with the first memo, a 3-2-1 scale rubric was used for scoring, with the criteria:

- Memo is professionally written and follows rubric requirements (SLO 3)
- Understanding of Envision and degree of application (SLO 4)
- Selection of specific and relevant Envision credits (SLO 4)

Averages of both scorers were highest for the selection of Envision credits (2.58 out of 3), followed by memo writing (2.49), and understanding of Envision (2.41). For this assignment, the overall percent agreement between the two independent scorers was 91.9%, and weighted Cohen's Kappa was 0.86. It was straightforward for students to select applicable credits, but more difficult to truly understand their full intent and applications within the limited class time. The Envision Manual had been provided to students before class with instructions to read its introduction and familiarize themselves with the system, yet in the future it is recommended to focus on deeper study of a few particularly relevant credits rather than the entire rating system.

3.4.4 Individual reflections: Behavioral decision science

After the module concluded with a presentation on decision-making concepts (take-the-best heuristic, risk aversion, regulatory focus theory), students were asked to write an individual reflection to explain how one or more of these topics related to their own decision-making processes in the module. This activity corresponded to SLO 5: “Explain the impacts of cognitive biases and heuristics on engineering decision making.” Of the 145 individual assignments, the authors elected to assess a random sample of 50 students. The scoring scale and procedure were identical to the previous two memos, but broken down into the following three criteria:

- Selection of decision-making concept(s) and explanation of relevance
- How a greater awareness of these concepts can promote sustainability outcomes
- How thinking changed (3 ways: before and after using Envision, considering losses versus gains, working individually vs. in groups)

The concepts were listed according to the frequency of mentions (Figure 3.5). Risk aversion was listed most frequently, by 25 of 50 students, perhaps because it is more familiar and easier to understand. Regulatory focus theory was the next most prominent, with 23 of 50 students mentioning this concept. Take-the-best heuristic had 14 mentions. A few students did not mention any of the three specific concepts taught in the module, but discussed the relevance of cognitive biases and/or heuristics more generally.

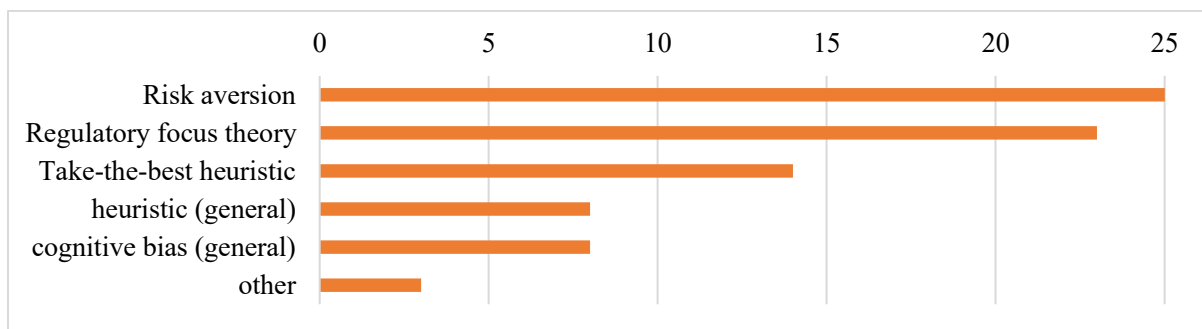


Figure 3.5: Decision-making concepts, number of mentions (n=50).

Averages of both scorers were highest (2.64 out of 3) for the second criterion, students' description of the concepts' value for sustainability outcomes. Next highest was for the concept selection and relevance (2.59), then describing how their thinking changed (2.56). The overall percent agreement between the two independent scorers was 90.0%, and weighted Cohen's Kappa was 0.82. Teaching the value for sustainability was the module's main goal and is thus most essential for students, as even this simple awareness can help engineers overcome biases and make more sustainable decisions. However, allocating more time for the module could promote a more thorough presentation and thus more specific student understanding of how these concepts relate to the project's decision making.

3.5 Conclusions

The Envision case study module on Nashville's West Park aimed to integrate interdisciplinary content on sustainable infrastructure and behavioral science through several pedagogies: modules, case studies, active and problem-based learning, and a flipped classroom. With two group memo assignments, the results show how students' decision-making priorities changed when focusing on sustainability versus just initial cost. Becoming aware of flood risks and applying the Envision rating system broadened students' considerations to produce a more holistic design. With evaluation of student learning through surveys, content analysis, and rubric scoring, the module effectively addresses educational needs represented in ABET and ASCE learning goals about complex and ill-defined engineering problems, holistic and sustainable design, professional and ethical responsibilities, and professional communication (ABET 2017, ASCE 2008). The student reflections also indicated that the majority of students grasped the relevance of behavioral science to engineering decision making, both for this case study and for sustainability in general.

However, the results of scoring the group memos indicate the need for a better foundation of sustainability concepts. Several individual reflections stated that sustainability had not been not previously taught or thoroughly emphasized in the curriculum, and also that the module felt rushed, which diminished learning effectiveness. Yet most students were genuinely interested in the Envision and sustainability content, which further supports integrating the content more thoroughly in the curriculum. In post-module feedback, one student recommended this key need: *“Maybe make it [Envision] more popular with teachers. It’s an interesting idea but just because I heard about Envision on 2-3 days of classes in my entire college career doesn’t make it a huge aspect that one takes into account when doing AEC in heavy civil projects.”* If teaching sustainability through active learning is as valuable as the literature would suggest, such an approach needs to become integrated and widespread in the undergraduate civil and construction engineering curriculum.

Learning gains for sustainability modules are most significant when sustainability is incorporated throughout the curriculum and the module is effectively integrated into the course (Watson and Barrella 2017). This is one of the biggest challenges to the use of sustainable engineering modules; effective integration of content throughout a course and curriculum is far more difficult than an add-on approach (Kolmos et al. 2015). Yet it is quite necessary. With the vast and growing emphasis on sustainability in both accreditation standards and strategic visioning, engineering and construction curricula would benefit from “scaffolding” such a module over one or more weeks by integrating sustainability, Envision, and decision making within the big picture of the course and discipline. In this Professional and Legal Issues course, the module was placed within the context of two main syllabus topics: (1) leadership and (2)

design/construction industry processes. Besides the module material, the course instructor assigned students other readings related to sustainability.

Another challenge faced with this module was the limited class time. Even though students reviewed material before class, instructor explanation in the 50-minute class sessions was limited in order to leave sufficient time for class discussions and memo activities. Without much student background in wastewater planning or sustainability, more time and guided explanation would have been helpful. In post-module feedback, the most frequently cited issue (by 19 students) was that the module activities were too rushed for them to learn effectively. This need was understood by the class's instructors, who proposed extending the module to three class days for future implementations. The other prominent feedback was to include more details or explanation on the content, scenario, or assignments (14 students). This was addressed by updating the module with a few clarifications, although the module's PBL-related approach is by definition somewhat open-ended and not fully defined.

3.5.1 Opportunities for future work

Concept mapping is an emerging pedagogical tool which provides great value for sustainable engineering. This approach allows students to organize and show relationships between various concepts using hierarchies and cross-links. While surveys and rubrics “provide a rough assessment of student knowledge,” concept maps can offer “a more accurate and detailed view” of students’ sustainable design abilities and conceptual knowledge (Watson 2013, p. 182) to complement this module’s evaluation methods. Concept maps have been used to assess student learning gains in the interdisciplinary integration of green engineering (Borrego et al. 2009). Three main scoring methods—traditional, holistic, and categorical—provide different

ways of understanding student learning (Watson et al. 2016). The holistic method, which is scored on a subjective rubric for comprehensiveness, organization, and correctness, is likely the most fitting considering the complex and transdisciplinary concepts involved in this module.

Another opportunity to build on this research lies in expanding its degree of transdisciplinarity. This may be done in the future by bringing students from an engineering class together with a psychology or sociology class to work on an assignment in interdisciplinary teams. One example of such an approach (Byrne and Mullally 2016) involved collaboration between chemical engineering and sociology students to address sustainability issues.

The Nashville West Park case study module is under peer review to be made available in the Center for Sustainable Engineering repository at <http://csengin.syr.edu/electronic-holdings-library/>. Its accessibility allows educators with different areas and levels of expertise to adapt and teach it in their classes, and create similar modules. The repository makes it more practical and effective to teach Envision, sustainability, and transdisciplinary concepts in engineering education.

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CONCLUSIONS

New approaches are needed in engineering education to equip the rising generation to solve complex, transdisciplinary, and ill-structured problems indicative of sustainability dilemmas. This main objective of this thesis was to meet a need for accessible modules on sustainable engineering and Envision, while incorporating knowledge of transdisciplinary concepts from behavioral decision science. Although cognitive biases and barriers commonly inhibit sustainable outcomes in decision making, they may be mitigated or overcome with the application of Envision and choice architecture strategies.

The three modules detailed in this thesis (Historic Fourth Ward Park, Tucannon River Wind Farm, and West Park Equalization Facility) combine several pedagogies which are key for teaching sustainable engineering: case studies, active and problem-based learning, and transdisciplinary content. Each module includes five defined student learning outcomes, which align with ABET student outcomes as shown in Table II of the introduction.

Several different evaluation methods were used to gauge each module's effectiveness in accomplishing its intended learning outcomes. The first is pre-module and post-module surveys, which provided self-reported student confidence (on a 5-point Likert scale) with each learning outcome. Based on paired t-tests, the increases in confidence were very significant ($p < 0.001$) for all learning outcomes in all modules. The percentage of students in each class indicating "confident" or "very confident" (Likert levels 4-5) for each SLO increased on average between 23.5% and 43.6% after completing the module. The surveys also included a section which asked about students' perceptions of sustainable design, namely its characteristics and barriers. For the first two modules, frequency tables and word clouds were created from the responses to display

the ways that student perceptions changed. After the module, many students mentioned aspects of sustainability pertaining to community, stakeholders, leadership, and others included in the Envision rating system, as well as cognitive and behavioral barriers that were taught. Finally, a free-response section in the post-module survey asked students to define and list solutions or applications of each of the behavioral concepts taught in the module. These were scored for accuracy on a 0-1-2-3 (weak, fair, good) rubric. While many students answered correctly, this assignment showed lower student proficiency than the others, indicating that a one or two-day module is not enough to solidify full understanding of the behavioral concepts.

Scoring of student assignments was also done with the 0-1-2-3 rubric. The assignments varied both within and across modules, including a visual park layout, brief write-ups and decision rationales, group professional memos, and concept maps. Some rubrics were split into multiple categories of evaluation based on specific student learning outcomes. Averages were good, typically around 2.5 on the 3-point scale. These assignments demonstrated that students understood sustainability and the use of Envision better than they did the behavioral concepts. Going beyond survey results, this rubric evaluation of the active learning assignments provides a second indication that student learning outcomes were met. A concept mapping methodology (left to future work for full development) can provide a third to allow triangulation.

However, there are still a few limitations in methodology. (1) The modules assume some prerequisite civil engineering knowledge: for one of the Tucannon River Wind Farm assignments students must understand how a Request for Proposals works, and for the West Park module, they must be familiar with cost estimating. (2) For the surveys, response rate was not 100% of the students enrolled in each class, and some answers were left blank. Furthermore, Likert scale self-reporting is inevitably affected by response biases; students may report higher confidence

levels influenced by knowledge of what the researchers are seeking. (3) The study did not control for differences between class populations, so fair and commensurable comparisons cannot be made. (4) The study is not longitudinal; it did not follow up with the students weeks, months, or years later to assess their long-term retention of knowledge gained from the module.

From the overall endeavor, I have found that my teaching modules offer unique benefits and fill gaps in the current engineering curriculum. Even as a starting point for others to build upon, my research has already made significant impacts. It has introduced over 350 students to the reality of cognitive biases and barriers, and explained how the Envision rating system and other behavioral interventions can guide and improve decision making during the design of sustainable infrastructure. Yet there remain several challenges for future work, namely improving the depth of learning for new topics. This may be done by allocating more than one or two class sessions to each module. I also recommend that instructors who use these modules adapt and integrate them effectively within the particular course and curriculum, including any necessary background instruction on sustainability.

My work has opened many possibilities for future research. Some of these include: (1) Perfecting and effectively integrating concept mapping as an assessment method. (2) Leveraging and building partnerships and communication between academia and industry, as I did through contacting project engineers for the Envision case studies. This can allow practicing engineers greater input into the future of undergraduate education. (3) Having students work in multidisciplinary teams with non-engineering classes such as psychology, sociology, landscape architecture, planning, and public policy. (4) Creating similar modules geared toward introductory freshman and sophomore classes, to present sustainability and decision-making concepts earlier in the curriculum. I challenge educators to pursue these opportunities.

This thesis has detailed the background, implementation, and assessment of three case-based sustainable infrastructure modules. These are part of the final product, and are now under peer review for publication in the Center for Sustainable Engineering repository at

<http://csengin.syr.edu/electronic-holdings-library/>.