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Development and Assessment of Three Envision Case Study Modules Connecting Behavioral Decision Science to Sustainable Infrastructure

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Abstract

This paper introduces three case-based modules for teaching civil engineering students about decision making for sustainability. The purpose of these modules is to connect civil engineering design to recent advances in behavioral decision science. Students who recognize their own decision biases will be better able to manage their decisions and be better able to recognize how their designs influence stakeholder decisions in the future. The three case studies varied in design topic and behavioral decision science concepts, from land development (choice overload) to renewable energy (status quo bias) to wastewater infrastructure (risk aversion). The case-based modules were developed using structured interviews with engineering design teams from each of the case projects. Relevant concepts from behavioral decision science were identified while interviewing the engineering design teams. The developed modules were tested with over 280 undergraduate engineering students. Methods to evaluate learning include pre and post-module surveys and free-response questions. After the module, students were more likely to mention and articulate the role that humans' mental barriers, like choice overload, bounded rationality, and satisficing play in decision making for sustainability. They also recognized how tools like Envision can help reduce these cognitive biases. In addition to integrating diverse topics and disciplines into a unified and relevant teaching module, the intention is that other faculty can also use these cases. Slides (either one or two-day instruction), teaching notes, and grading rubrics are available for other instructors to download and use and can be found in the Center for Sustainable Engineering repository.

Introduction

Greater exposure to concepts from behavioral decision sciences can offer civil engineering students a new perspective and potentially new solutions that link human and social values to physical infrastructure systems [1], [2]. This is a necessary advancement towards more sustainable infrastructure [3]. In effort to contribute to this need, this paper explains three case-based modules that not only teach engineering students about sustainable infrastructure but also helps them recognize their own, and their clients', decision biases. Decision biases are systematic and predictable errors in judgment that can negatively impact engineering decision making.

Decision biases are especially prevalent in complex and ill-structured problems involving uncertainty and risk [4], the very types of problems and decisions that civil engineering students will face in their careers. For example, planning fallacy and optimism bias explain the high frequency of cost overruns and benefit shortfalls [5]. 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 [6]. Status quo bias also appears in engineering decision-making processes through procedures, codes, and standards, which maintain the status quo and limit sustainability. Such inconsistencies in normative decision processes can also lead to undervaluing innovative solutions [7], in part, due to loss averse preferences [8], [9]. Increasing the connections between behavioral decision science and engineering design for sustainability in the undergraduate curriculum can help civil engineering students more quickly recognize these biases and provide them mental strategies and tools to improve their decisions.

Rating systems as decision making tools

Increasingly, rating systems for sustainability act as tools to guide complex decision-making processes. These guides can help reduce cognitive bias like choice overload by narrowing the decision process [2]. Prior projects certified with these rating systems can act as role models to motivate future design teams past the status quo [10]. These tools, however, can also hinder the decision-making process if designers are unaware of their influence on their design choice. For example, rating systems tend to lead designers to anchor on lower levels of sustainability performance even when higher levels are economically and technically feasible [11]. Modifying the point structure so that decision makers are endowed points and points are lost, rather than gained, significantly influences levels of sustainability achievement [12].

As rating systems like Leadership in Energy and Environmental Design (LEED), the Envision Rating System for Sustainable Infrastructure, and others (Green Roads, Sustainable Sites, etc.) become increasingly utilized by industry professionals, they are also being taught in undergraduate courses [13]–[15]. For instance, the University of Utah has implemented a module on the Envision rating system in their capstone course [16] and Envision is taught to first year civil and environmental engineering students at the University of Colorado, Boulder [13].

By connecting how rating systems for sustainability inform design choice with behavioral decision science concepts and theories, such as, choice overload and status quo bias, can help ensure engineers recognize the limitations of these tools and the potential pitfalls when using them. The modules developed and presented in this paper are intended to help engineering students recognize their own decision-making processes. The modules are available for faculty to download and use through the Center for Sustainable Engineering.

Case Studies

To bridge engineering for sustainability and behavioral decision science, three case studies were developed using actual Envision certified infrastructure projects. The cases vary in project type, including: land development (Atlanta's Historic Fourth Ward Park), renewable energy (Tucannon River Wind Farm in rural Washington state), and wastewater infrastructure (Nashville's West Park Equalization Facility). Engineering design teams and owners were interviewed and their Envision documents were reviewed. Relevant concepts from behavioral decision science literature were identified while interviewing the engineering design teams. After the cases were created each design team reviewed the case for accuracy. The following three sub-sections provide an outline for each of the cases and relevant behavioral decision science concepts.

Historic Fourth Ward Park

The first module developed was the Historic Fourth Ward Park, part of the BeltLine greenway project in Atlanta, Georgia. The case study focuses 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. The purpose of the park was also to provide storm water retention for the city. The module asked students to prioritize all of the stakeholder preferences for the park and make programing decisions about what should be included and where. The task was intentionally setup to induce *choice overload* among design options and layout possibilities. In addition, students were less able to simplify choices with design norms because the park was such a novel and unconventional storm water solution. It also involved far more potential design choices than a conventional retention pond and sewer pipe.

Students were asked to prioritize all of the stakeholder preferences for the park and make programing decisions before learning about the Envision rating system. The expectation was that when faced with too many choices, they would begin to feel frustrated with the process, and dissatisfied with the end outcome and reflect about any heuristics used and how these might have led to less than optimal decisions.

Bounded rationality was the second behavioral decision science concept embedded within the Historic Fourth Ward Park case study module. Bounded rationality means that the potential for rational or optimal decisions is limited by the decision maker's cognitive capacity, available information, and time [17]. Such limitations may be expected in complex decisions involving tradeoffs, as are commonly found in sustainability problems. Bounded rationality relates to the Historic Fourth Ward project through the stakeholder engagement meetings and public input, which were a major part of the process to improve the design consideration for specific priorities and concerns. In the actual project, students learned 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. During the module, students were asked to identify credits from the Envision rating system that rewarded community engagement and leadership.

Satisficing was the third behavioral decision science concept. It 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 [17]. 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, time and budget constraints, full optimization of a design is rarely feasible or appropriate, and satisficing simplifies decision-making.

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. Students made connections between satisficing when they felt overwhelmed by too many design options and learned about how the project team did not merely address the basic engineering storm water problem but how they considered "Are we doing the right project?" and worked toward maximizing social and environmental benefits in the process.

Tucannon River Wind Farm

The second module was 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 were assigned to play the role of either the project engineer or owner and asked to submit a brief writing assignment using the Envision rating system to address project challenges (engineer) or apply choice architecture to promote sustainability in the wind farm's Request for Proposals bidding process (owner).

Status quo bias (i.e. preference for the current state of affairs) was one of the behavioral decision concepts identified during interviews with engineers who designed the Tucannon River Wind Farm. The engineers described that too often, the 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. In the Request for Proposal (RFP) process, status quo bias can be overcome when the RFP is well-crafted to better serve the interests of the owner, 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 [18].

Directly related to the Tucannon River Wind Farm, the RFP bidding criteria prescribed by the state utility commission included only price and risk criteria, with no specific point value or incentive given to sustainability. Although the price was set during bid procurement, the owner (PGE) overcame this status quo bias of neglecting sustainability by hiring an additional consulting engineer, Burns & McDonnell (BMCD), to incorporate sustainable design improvements within the existing cost constraint.

Another possible intervention to overcome status quo is *precommitment*, which involves making a public commitment or otherwise taking steps to ensure that a present decision cannot be easily undone [19]. Related to sustainability, *precommitment* to reduce household energy use may diminish temporal discounting, reduce impulsivity, and/or encourage delayed gratification and self-control [20]. *Precommitment* was incorporated as a teaching point within this case module because it related to the well-known company culture of PGE and BMCD in which sustainability was a central value. For these sustainability focused companies, sustainable project-related decisions about 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.

Precommitment is one of the several types of *choice architecture*, which is defined as a method of influencing choice by changing how options are presented to the decision maker [2], [21]. Two major choice architecture strategies are (1) setting default options and (2) framing decision outcomes. *Choice architecture* has proven an effective strategy to mitigate cognitive biases and barriers, and it holds great promise for sustainability-related decisions. *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.

West Park Equalization Facility

The third module developed to connect design for sustainable infrastructure and behavioral decision science concepts was the West Park Equalization Facility, a wastewater holding facility in Nashville, Tennessee. The case study assigns students professional memos which students write in groups during 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 the second class session, behavioral decision science concepts were introduced and students submitted a reflection about how these impact decisions and sustainability in the project.

Take-the-best heuristic was the first behavioral decision science concept related to the Nashville West Park Equalization Facility. *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 wastewater holding 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 was the second concept. In general, risk aversion 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. In 2010, a 1000-year flood event occurred in Nashville and caused damage to the project site. The flooding catastrophe demonstrated far greater project risk than the financial risk of a higher-costing facility, making the client (Metro Nashville's department of Water Services) more willing to spend money on mitigation. Risk and hazard management was further facilitated by Envision's Climate and Risk credits. The project team changed the design to place the new wastewater tank in a location less vulnerable to flooding. They assessed climate threat through a life-cycle carbon assessment, and also prepared for long-term adaptability ensuring that the tank, pump station, and park features were resilient against flooding and other extreme weather events.

The final behavioral decision concept was *regulatory focus theory*. The stakeholders of Nashville's wastewater project (client, designer, and community) were motivated differently depending on their prevention focus or promotion focus. This provided 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).

A summary of the three case modules and the related behavioral decision science concepts are listed in Table 1. The following section provides the methods for the course modules and the results and discussion provide insight about what students learned and retained.

Table 1: 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 design considerations besides cost.
Behavioral decision concept	• Choice overload • Bounded rationality • Satisficing	• Status quo bias • Precommitment • Choice architecture	• Take-the-best heuristic • Risk aversion • Regulatory focus theory

Case Study Implementation

PowerPoint slides were developed for each module 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 emphasized the previously described concepts. Slightly different active learning approaches were applied within each case study. The Historic Fourth Ward park module is problem based while the Tucannon River Wind Farm uses role playing and the West Park Equalization Facility module uses a flipped classroom approach.

During the ***Historic Fourth Ward*** module, civil engineering undergraduate students enrolled in a course titled Sustainable Systems (n=43) were told about Envision using motivation-based learning (Bielefeldt 2013). Students were told several reasons why they should care about the Envision rating system. Reflection and discussion questions were posed to students in class and asked to "think-pair-share". The activity provided a chance for active learning and allowed the instructor to gauge the students' level of understanding. Students were then given time in class to read the case study and complete an assignment asking them to make design decisions about what features to include in the historic park. At the end of the first day module, another assignment was given for homework. Students were asked to teview credits in the Envision manual and select one from each category to improve their designs' sustainability and/or reduce the effects of the cognitive biases mentioned in class. Students were required to write a summary describing the changes they made and what level of achievement this would meet within Envision.

The second day's session began with a small-group reflection on the prior 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.

Similar to the Historic Fourth Ward module, the ***Tucannon River Wind Farm***, module, was taught in a two-day format to a separate group of civil engineering undergraduate students (n=94 students) enrolled in a course titled Professional and Legal Issues. The first day included an overview about Envision and how to navigate its credits, then an activity and discussion with various Envision credits, and an introduction to the Tucannon River Wind Farm, giving the case study and role-playing assignments as homework. During day two, students discussed the homework about Envision and a brief overview about how PGE and BMCD actually addressed the challenges was provided. Then, behavioral decision science concepts including status quo bias, precommitment, and choice architecture were discussed and which Envision credits relate to these concepts.

Just like the two previous modules, the ***West Park Equalization Facility*** module was presented to a large undergraduate civil engineering course (n=145). The module was placed within the context of two main syllabus topics: (1) leadership and (2) design/construction industry processes. This module followed a flipped classroom pedagogy. Students were given a set of slides to review before each of the two class sessions. The main case study portion of the module was take-home. Students prior to class were asked to review the slides providing them general background information on wastewater infrastructure, and an explanation of the Nashville case including the sewer overflow problem and need for additional storage capacity. Students, on their own, were asked to approximate the 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: next to the existing tank, somewhere within the adjacent West Park, or in an undeveloped land parcel a few blocks away.

In class, 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. In the next take-home portion of the module, the case took an unexpected turn demonstrating the unpredictable changes that so often happen during engineering. Nashville's 1000-year flood event that occurred in 2010 was presented, along with FEMA's redrawn floodplain map. 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 using Envision as a guide. The final portion of the module was a brief presentation given in class 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 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.

Learning Objectives

The overall objective for each module was to define and effectively meet student learning outcomes. The learning outcomes were then assessed through student surveys before and after the module. The learning outcomes for each module are listed below:

Learning Outcomes for Historic Fourth Ward Park

1. Assess and evaluate multiple stakeholders' requirements and priorities for a design. (ABET Criteria 1,2,4,6)
2. Synthesize multiple stakeholders' requirements and priorities into an appropriate design. (1,2,3,4,6)
3. Make design decisions creating a solution to a complex and open-ended design problem. (1,2,4,6)
4. Assess the social, environmental, and economic sustainability of a design. (2,3,4,6,7)
5. Recognize mental barriers that may prevent more sustainable outcomes. (2,4,7)

Learning Outcomes for Tucannon River Wind Farm

1. Implement characteristics of a sustainable design process. (ABET Criteria 2,4,7)
2. Understand barriers, cognitive and otherwise, to a sustainable design process. (2,4,7)
3. Develop holistic solutions to difficult engineering challenges. (1,2,3,4,6,7)
4. Develop solutions to improve sustainability at an organizational/management level. (2,3,4,7)
5. Innovate beyond conventional solutions to improve a project's sustainability. (2,7)

Learning Outcomes West Park Equalization Facility

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

Assessment Methods

For all three modules, student perceived learning was evaluated through surveys given before and after the modules asking students to rate, on a Likert scale from low confidence (1) to high confidence (5), their level of confidence in ability to complete the learning outcome. A paired t-test was used to determine the significance of increase in learning outcomes and other changes in the pre- and post-surveys. A post module survey also included free response questions for students to demonstrate their understanding of the behavioral science concepts by: (1) defining each one in their own words and (2) describing a way that it could be overcome. Student's responses were scored on a 0-1-2-3 scale, a common approach used in similar educational research [13]. A score of 0 was given for no response, 1 for a weak response (below expectations), 2 for fair (needing improvement), and 3 for good (meeting or exceeding expectations).

The inter-rater reliability on assessment of post module definitions and descriptions for the *Historic Fourth Ward Park* was 94 percent agreement between the two scorers for all datasets (95 percent agreement on the concept definitions and 93 percent on the solutions). The weighted Cohen's Kappa statistic, which accounts for the degree of disagreement between two raters, was 0.943, indicating very good agreement. Internal validity for the *Tucannon River Wind Farm* was 93 percent agreement and a weighted Cohen's Kappa statistic of 0.94.

The assessment of the *West Park Equalization Facility* was slightly different than the previous assessment method. After the module concluded with a presentation on decision-making concepts, 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. Of the 145 individual assignments, the authors elected to assess a random sample of 50 students. The overall percent agreement between the two independent scorers was 90 percent and weighted Cohen's Kappa of 0.82.

Results and Discussion

Historic Fourth Ward Park

Students' self-reported scores about their confidence with the five student learning outcomes (SLOs) significantly increased between the pre- and post-survey. Table 2 below displays frequency of students who indicated they were confident or very confident in their ability for each SLO, which ranged from 1 (low confidence) to 5 (high confidence) on a Likert scale.

Table 2: Percent of students who received the *Historic Fourth Ward* case study module indicating "confident" or "very confident" (Likert 4-5)

Learning outcome	SLO 1	SLO 2	SLO 3	SLO 4	SLO 5	Average
Pre-module	29%	26%	42%	52%	42%	38%
Post-module	77%	58%	65%	81%	77%	72%
Increase	**48.4%**	32.3%	22.6%	29.0%	35.5%	34%

The evident increase for all SLOs demonstrate that students perceived they gained proficiency in these skills. 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 0.05. Notably, the SLO with the highest increase was *SLO1: Assess and evaluate multiple stakeholders' requirements and priorities for a design*. The module was intentionally setup to make students struggle with how to prioritize multiple stakeholder requirements and then provide them with Envision to help in the process. The second highest increase was about the behavioral decision science concepts, *SLO 5: Recognize mental barriers that may prevent more sustainable outcomes*.

To further evaluate whether students were able to not just recognize mental barriers but define the behavioral decision science concepts taught in the module, the post-module survey asked students to demonstrate their understanding of the cognitive biases 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." Student responses were evaluated on a 0-1-2-3 scale. The scores were defined as: 0 for no response; 1 for weak; 2 for fair; 3 for good. Table 3 shows the average scores earned on each part.

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

Concept	**Definition**	**Solution**
Choice overload	2.5	2.0
Bounded rationality	1.9	2.1
Satisficing	2.2	2.0

In general, the students performed better on the definitions than the solutions. Choice overload was the best understood concept, followed by satisficing. Bounded rationality had the lowest scores but students seemed to have a better understanding about how to overcome it. One reason why choice overload might have been so memorable was students were setup to experience the effect. In the process likely used satisficing to develop their design decisions. One student explains their an understanding of satisficing, in the quote, "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 student response also seems to imply choice overload and bounded rationality.

Tucannon River Wind Farm

Similar to the Historic Fourth Ward park, the survey results indicate significant increases in students' confidence with the learning outcome skills. These were, on a 5-point Likert scale where 1=low confidence and 5=high confidence. The frequency of students who indicated they were confident or very confident in their ability to meet the SLO, pre-module and post-module, are listed in Table 4. A paired t-test indicated p-values that met the confidence level of 0.05 for each individual learning outcome and the overall learning gains.

Table 4: Percent of students who received the *Tucannon River Wind Farm* case study module indicating "confident" or "very confident" (Likert 4-5)

Learning Outcome	**SLO 1**	**SLO 2**	**SLO 3**	**SLO 4**	**SLO 5**	**Average**
Pre-module	37%	46%	44%	45%	40%	42%
Post-module	72%	67%	57%	68%	65%	66%
Increase	**35.1%**	21.3%	13.8%	23.4%	24.5%	24%

The SLO with the highest frequency increase was *SLO 1: Implement characteristics of a sustainable design process*. The SLO about the cognitive biases was *SLO 2: Understand* *barriers, cognitive and otherwise, to a sustainable design process*, which saw a 20 percent increase in how students perceived their confidence to meet this learning outcome. While the increase was not the highest, the majority of students perceived they understood barriers, cognitive and otherwise, to a sustainable design process.

To better assess students' ability to understand the cognitive barriers to sustainable design, after the teaching on behavioral decision science, the post-module survey measured students' retention and understanding of the three-main behavioral decision science concepts. This free-response section included the following two-part questions, each consisting of a definition and an application of the concept: (1) Define status quo bias, in your own words, then list a way that it can be overcome; (2) Define precommitment in your own words, then describe how it can be used to facilitate a more sustainable project; (3) Define choice architecture in your own words, then name and briefly describe the two types of choice architecture covered in class.

Model answers were developed based on the module's teaching and used as the basis for scoring. 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. The average scores by topic are presented below in Table 5.

Table 5: Average behavioral decision science free-response scores (out of 3)

Concept	**Definition**	**Application**
Status quo bias	2.5	2.2
Precommitment	2.0	1.7
Choice architecture	1.4	1.0

Students generally grasped the behavioral decision science aspect of the module, despite the novelty of these concepts in civil engineering. The lower scores were due in part to several students receiving "0" scores for no response. Excluding the blank responses, the overall average score increased from 1.9 to 2.5.

West Park Equalization Facility

The average increase across all five SLOs was 34 percent. 75 percent of the students felt confident in meeting these learning outcomes after the module. The evident increases for all SLOs demonstrate that students perceived they gained proficiency in their skills. 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 0.05.

Notably, the greatest increase in confidence for any one learning outcome was for *SLO 1: 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. The SLO about the behavioral decision science concepts embedded into the module was *SLO 5: Explain the impacts of cognitive biases and heuristics on engineering decision making*. More than 60 percent of students were confident or very confident in their ability to explain the impacts of cognitive biases on design.

Table 6: Percent of students who received the *West Park Equalization Facility* case study module 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%

To better assess students understanding of the behavioral decision science concepts, 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. The frequency of concepts mentioned are listed in Figure 1. *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 just 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.

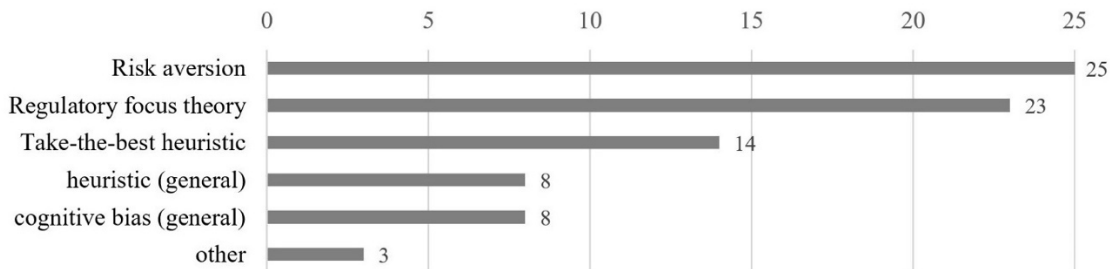

Figure 1: Number of students mentioning each decision-making concept (n=50).

Teaching the value of sustainability was the module's main goal and is thus most essential for students, as even simple awareness can help engineers overcome biases and make more sustainable decisions. However, in each of the three modules, students were able to draw connections between engineering topics and cognitive barriers inhibiting sustainability. Allocating more time for each of the modules might promote a more thorough presentation and thus more specific student understanding of how these concepts relate to the project's decision making.

Students provided feedback saying, "I think the material and knowledge of cognitive barriers could have helped during the actual project" another said, "the time frame to complete the case study was incredibly short." Another student said, "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."

Based on these findings and a deeper investigation of the literature, the modules have been updated to further emphasize the behavioral decision science concepts and re-arrange content to reduce the time spent on slides and increase the amount of time students have to work through the cases. The updated modules are now available for other faculty to download and use through the Center for Sustainable Engineering.

Conclusion

New approaches are needed in engineering education to equip rising engineers with tools and ways of thinking to solve complex and ill-structured problems indicative of sustainability dilemmas. The main objective of developing these modules was to meet this need. By incorporating knowledge of concepts from behavioral decision science into case-based modules, students gained a new understanding about the cognitive biases to sustainable engineering. 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. Students in each of the three modules appear to understand Envision and how this tool can work to alleviate decision biases. Though, there is still room to help students grasp the concept of choice architecture.

Several different evaluation methods were used to gauge each module's effectiveness in accomplishing its intended learning outcomes. The first was 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 significant ($p<0.05$) 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 24% and 44% after completing the module.

The surveys also included a free-response section in the post-module survey asking students to define and list solutions or applications of each of the behavioral concepts taught in the module or reflect about which biases they faced during the design process. 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 expected, indicating the two-day module is not likely enough to solidify full understanding of the behavioral decision science concepts.

Still, these teaching modules offer unique benefits and fill gaps in the current engineering curriculum. Even as a starting point for others to build upon. The development of these modules has opened many possibilities for future research. Some of these include: (1) leveraging and building partnerships and communication between academia and industry, as was done through contacting project engineers for the Envision case studies. This can allow practicing engineers greater input into the future of undergraduate education. (2) Having students work in multidisciplinary teams with non-engineering classes such as psychology, sociology, landscape architecture, planning, and public policy. (3) Creating similar modules geared toward introductory freshman and sophomore classes, to present sustainability and decision-making concepts earlier in the curriculum. These modules are now available in the Center for Sustainable Engineering repository at http://csengin.syr.edu/electronic-holdings-library/. They are available for other instructors to download, adapt, and use in other courses.

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