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Bridging Engineering and Psychology: Using an Envision Gold Certified Project to Teach Decision Making for Sustainability

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Abstract

The objective of this research is to help engineering students develop the interdisciplinary skills required to address critical and rapidly evolving societal challenges. We designed a case study on the Historic Fourth Ward Park in Atlanta, a project recently certified Gold by the ISI (Institute for Sustainable Infrastructure) Envision rating system. The Envision rating system is a holistic planning tool that can help mitigate barriers in decision making to facilitate more sustainable outcomes across its categories of quality of life, leadership, resource use, the natural environment, and climate and risk. The Envision case study was used as the basis for a teaching module bridging engineering and cognitive psychology by highlighting the interconnectedness between these fields. Too frequently, engineering and design decision makers can become overloaded by choices when trying to optimally meet the needs of multiple stakeholders. Furthermore, because of human cognitive limitations, decisions are rarely fully optimized, instead often settling for a "good enough" solution. This case study and class module included several activities intended to increase undergraduate engineering students' awareness of cognitive barriers (specifically choice overload, bounded rationality, and satisficing) and their impacts on design decisions in engineering for sustainability. The case study provides an overview of the project context and requirements. Students developed, sketched, and rationalized their own design solution. A subsequent in-class instruction session presented new information from psychology and behavioral economics literature about selected cognitive barriers relating to the project, and explained how Envision can be useful to mitigate them. The students responded by investigating further ways that Envision could be used to improve their design solutions. Students' learning from the case study module was assessed with surveys before and after the module, which included their confidence level about each of the student learning outcomes, their level of agreement with certain statements about sustainability, and their knowledge about sustainable design and Envision. Survey results indicate that the module was effective in meeting the learning objectives; it also improved students' understanding of Envision and the role of cognitive barriers in decision making. These outcomes will help students recognize the impacts these barriers have on multiple stakeholder groups, as well as how certain planning tools and frameworks may be used to overcome them.

Introduction

There is currently great need for a restructuring of engineering education. As society continues to grow in technology, information, and complexity, the traditional approach of teaching information about a subject is becoming insufficient. Now in the Internet age, one of the greatest challenges is for students to make sense of an overabundance of information (Allenby 2011). Today more than ever, students need interdisciplinary knowledge to better address the complex and multifaceted engineering challenges and social problems of today and the future, with a more holistic understanding of the systems and context in which they operate.

Many traditional institutions, unwittingly or not, train students as “I-type” engineers, specialists with deep technical knowledge in a single area, but this approach does not prepare them to truly address major challenges or compete with outsourcing of jobs in the global economy. Studies have shown great need for educators to integrate engineering with other high-level skill sets, for example to work with local stakeholders and understand local cultures and regulations (Allenby 2011). Engineering education should strive to more closely represent the complexity of the real world by presenting case studies, open-ended problems, and other activities that bridge multiple disciplines. In “Educating the Engineer of 2020,” the National Academy of Engineering makes a strong case for interdisciplinary learning in the undergraduate learning environment within a framework of sustainable development (NAE 2005).

This being said, there is recognized need for sustainable thinking to be integrated into engineering education and design with a focus on active, student-centered learning methods (Huntzinger et al. 2007). This is now beginning to emerge in educational programs such as the Center for Sustainable Engineering (CSE), a partnership among five U.S. universities founded in 2005. The EPA-funded basis for CSE, an exhaustive report entitled “Benchmarking Sustainable Engineering Education,” states:

> “Education across and within the disciplines… is needed to make informed decisions on current lifestyles that will not impair future generations, i.e., lifestyles that are sustainable. Engineers will need considerably more awareness of the nature of politics, social processes, and the influence of institutions on sustainability choices; the much larger community of non-engineers needs a stronger understanding of the impact of engineering decisions on societal structures. Sustainable engineering offers an intellectual “commons” where new knowledge can be shared, developed, and adjusted” (Allen et al. 2009).

Several examples of new educational methods in sustainable engineering exist in the literature: Concept maps have been used to assess student learning gains in the interdisciplinary integration of green engineering (Borrego et al. 2009). Envision has been promoted as a useful set of criteria for a sustainable design rubric in engineering education (Watson 2013), and the University of Utah has used an Envision learning module to reinforce sustainability concepts in a capstone civil engineering course (Burian 2014). Active learning methods involving sustainable infrastructure have been implemented to “instill a culture of sustainability” and enhance decision making (Pellicer et al. 2015). Problem-based learning approaches with interrelated and mutually supportive assignments and projects varying in complexity and structuredness have been applied in construction education to address sustainable development and interdisciplinary challenges (El-adaway et al. 2015).

Although many institutions are developing lesson plans and resources about sustainable engineering, more of these need to be compiled into repositories of accessible and shareable materials (Davidson et al. 2016). The challenge to many instructors of teaching in new, innovative, and interdisciplinary ways can be greatly facilitated by such a base of shared teaching tools or modules. Davidson’s (2016) paper revealed some of the incentives for educators to create modules on sustainable engineering: the opportunity for attribution, to obtain peer review, and to easily assess, revise, and update the materials to track their success. Similarly, instructors would be likely to use such a repository of modules if it were easily searchable, peer-reviewed, and had clear learning objectives for assessment. This learning module approach also relates to a case library of workplace engineering problems which applied case-based reasoning (CBR) to provide a knowledge base and pedagogical support system (Jonassen et al. 2006).

Furthermore, there exists a growing body of relevant research in the fields of cognitive psychology and behavioral science which has seen little application to engineering and construction. Over the past half-century, researchers have identified many cognitive barriers[*], including biases and heuristics, that impact human decision making. *Cognitive biases*, systematic and predictable errors in estimation, are highly associated with uncertainty and risk, and can negatively impact engineering decisions in several ways. They have especially high stakes for complex and multi-stakeholder infrastructure decisions, but applying elements of behavioral science—including loss aversion, role models, and combined interventions—can improve these decisions (Shealy et al. 2016). Judgment heuristics are used in the construction industry to simplify decisions, but can lead to cognitive biases (Beamish and Biggart 2012). Public-private partnerships commonly used in infrastructure would be benefitted by an investigation of cognitive biases (Van Buiten and Hartmann 2013). Students increasingly need to become cognizant of how decisions are irrationally impacted by human cognition, and how such decisions can be improved to foster more sustainable outcomes to engineers and designers, their clients, and society at large.

The Presidential Task Force of the American Psychological Association has asserted the importance of psychology as a STEM discipline and an "effective interdisciplinary bridge" (APA 2010). The time has come for this bridge to be crossed to help address the psychology of complex decisions, which engineers face regarding sustainability. The authors have aimed to accomplish this through a new type of case study that integrates cognitive barriers with the Envision sustainable infrastructure rating system.

Objectives

The goal of this research is to help fill the need for innovative, interdisciplinary educational modules on sustainable engineering, as noted in the literature above. Our first teaching module is based on a case study about the Historic Fourth Ward Park on the Atlanta BeltLine, a noteworthy infrastructure project certified Gold by ISI's Envision rating system.

Envision is a decision-making framework, rating system, and certification program for sustainability in infrastructure projects such as parks, transportation, water, wastewater, and energy facilities. Like LEED for buildings, it includes a set of credits to assess a project's level

[*]Authors' note: In this paper, the term "cognitive barrier" refers to any cognitive bias, heuristic, limitation, or other finding from psychology, behavioral economics, and decision-making literature that prevents fully rational or "optimal" decisions—especially as they pertain to sustainability outcomes of an engineering project.

of sustainability, which includes many interrelated aspects. Envision includes 60 credits within five categories: Quality of Life (QL), Leadership (LD), Resource Allocation (RA), Natural World (NW), and Climate and Risk (CR). For each credit, a project can earn various amounts of points based on five different levels of achievement: Improved, Enhanced, Superior, Conserving, and Restorative. In contrast to many other rating systems, Envision is generally not prescriptive. There are often multiple ways to meet each credit, and evaluation criteria may involve actions, outcomes, specific targets, processes, commitments, or general accomplishments. Various types of documentation are suggested for each credit to support its verification.

The intent is to bridge the disciplinary divide between engineering and psychology by applying research from behavioral science to teach about the impact of cognitive barriers upon engineering decision making for sustainability. This interdisciplinary approach holds great promise for the future of engineering education. It is vital for students to understand how cognitive barriers are involved in real-world decisions in order to overcome them and promote more sustainable decision outcomes, especially in the realm of infrastructure where the need and impacts are so great.

This module is to eventually become part of a set made available in a peer-reviewable online repository of educational materials similar to the CSE database. These modules will include case studies on a variety of Envision-certified projects. Each case study and module will include a focus on several cognitive barriers relevant to that project, with open-ended assignments to facilitate active and problem-based learning.

Student learning outcomes

For the Historic Fourth Ward Park module, we defined the following learning outcomes: Students will…

- Analyze stakeholder priorities and preferences, and evaluate these aspects in the context of the specific project requirements.
- Synthesize given information to create a park layout and description that solves the problems and meets stakeholder needs.
- Assess their design's strengths, weaknesses, and overall value in terms of social, environmental, and economic sustainability.
- Discuss the challenges and cognitive barriers involved in the open-ended design process.
- Apply Envision as a decision-making tool to reduce cognitive barriers.
- Recognize characteristics of a sustainable design process.

This module was developed particularly for undergraduate students, but could also be adapted for use in professional development training sessions by engineers already in practice. In "Rethinking Engineering Education," Allenby noted: "All professionals are, at the same time, always students, and modules that reflect rapid technological evolution can be plugged in as appropriate" (Allenby 2011, p. 4).

Methods

Literature review and project selection

The authors began this research by conducting an in-depth review of psychology and behavioral science literature to determine common cognitive barriers and biases that impact decisions. A useful codex (Benson 2016) was found that groups 175 biases into four categories: too much information, not enough meaning, need to act fast, and what to remember. Using this and similar lists as a starting point, the relevant literature was compiled into an annotated bibliography of over 25 seminal works in the field involving recognized cognitive barriers to rational or "optimal" decision making. We also explored applications of these to infrastructure in the engineering, design, and construction literature, as noted in the introduction.

Concurrently, the authors began reviewing several Envision-certified infrastructure projects. We assessed them for uniqueness, innovation, and the potential to present interesting and effective educational activities. The Historic Fourth Ward Park in Atlanta was chosen, in part for its double function as both public park and stormwater management solution.

After selecting this project for the case study, the authors contacted a representative of HDR, the engineering firm cited in the Envision press release, who connected us with two of the project engineers involved with the park's design, construction, and stormwater function. We formulated a list of questions and topics to learn more about the project, which hinted at cognitive barriers but did not specifically mention them:

- What were the unique limitations, challenges, and uncertainties of the project, and how did they affect the design decisions you made?
- Trade-offs and value engineering
- Up-front vs long-term costs
- The project's planning horizon and life cycle

We discussed these points with the project engineers in an hour-long conference call interview, in which we noted their description of the project and the aspects that had been done particularly well. There were several technical victories with the innovative stormwater function of the park, but our biggest take-away was that the park's design process was characterized by all its stakeholder entities including the community working together, aligned toward a common goal, which made for very little opposition and few conflicts. We also learned that the project was "retroactively" certified by Envision several years after its completion. Although the designers did not know about Envision at first, they did follow the criteria of the Sustainable Sites Initiative, a similar rating system for landscape architecture.

The authors identified three cognitive barriers from our literature review that fit with the project base on our interview and the project documents: choice overload, bounded rationality, and satisficing. *Choice overload* was represented in the project because of the many stakeholder groups and potential design choices. This barrier often leads to suboptimal decisions through heuristics, reliance on default options, and choice deferral (Iyengar and Lepper 2000). With so many different interests involved, meeting everyone's needs proved challenging for the design team. *Bounded rationality* refers to the fact that decision making is limited in terms of cognitive capacity, available information, and time (Simon 1982). This is almost certainly a factor in every complex decision involving sustainability. Using tools like Envision can help expand design considerations. The engineers on the project seemed to agree with this justification when bounded rationality was described to them. Finally, "*satisficing*" refers to the finding that humans tend to settle for decisions that satisfy and suffice, rather than seeking the most optimal solution (Simon 1956). This is often involved in projects where delivery is needed quickly and there is a tradeoff between time/cost savings and achieving a more optimal solution. Knowing when to move forward with a design option is critical.

These barriers could have easily posed major challenges to the project, yet the teams overcame them to achieve a sustainable solution. The main reasons for this are the unique alignment of stakeholder goals and interests despite numerous design choices and requirements, and a collective determination to not be easily satisfied with any suboptimal solution. Once the case study was developed, the engineering team was given an opportunity to review it for accuracy and verify its depiction of cognitive barriers in the project.

Development of case study

These engineers also shared with us BeltLine master plans and documentation packets that had been submitted as documentation for several of the Envision credits. These resources were used to write a six-page case study about the Historic Fourth Ward Park (included in Appendix 1) to be used as the basis of our Envision teaching module.

The case study places students in the role of a project designer during the park's conceptual phase, and presents context and detailed information about the needs, requirements, and priorities of multiple stakeholders. Three main stakeholder groups include (1) the neighborhood and community, (2) City of Atlanta departments and the BeltLine, and (3) the design teams including HDR. After reading the case study, students are presented with this homework 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." Several maps, images, and proposed alternative designs from the Atlanta BeltLine Master Plan are included as appendices to assist with the activity.

This open-ended design assignment was used as a basis for class discussion and further learning about the cognitive barriers, which were presumably involved in the students' own design decisions. In addition to the case study document and assignment, a comprehensive PowerPoint presentation, supplemental resources, and an instructor lesson plan packet were created for the class instruction portion of the module.

Class implementation and surveys

The Historic Fourth Ward park case study module was implemented in two separate senior-level undergraduate classes at Virginia Tech. The first was a Building Construction (BC) class entitled Sustainable Facility Systems, which was composed of 25 students, primarily undergraduates with a few graduate students. The second was a Civil and Environmental Engineering (CEE) class called Sustainable Systems, which consisted of about 45 undergraduate students.

The class implementation was done with two alternative options, consisting of either one or two class days. The BC class followed the one-day option since only one class period was available. With this option, the pre-module survey, case study, and design assignment were posted on the class website to complete as homework before the class, which was taught by the authors. The class session began by asking reflective questions about the assignment and calling on students to answer and discuss, then teaching about the three selected cognitive barriers (choice overload, bounded rationality, and satisficing) and explaining how they could impact decision making in this project. After this, an introduction was given to the Envision rating system, explaining how it could be used as a framework to help overcome these barriers and facilitate better decisions for sustainability. Three selected Envision credits corresponding to the project's strengths were presented for investigation: Quality of Life (QL)1.1 Improve Community Quality of Life, Leadership (LD)1.3 Foster Collaboration and Teamwork, and LD1.4 Provide for Stakeholder Involvement. The class discussed how the use of these credits may mitigate or otherwise affect the cognitive barriers to sustainability. The class session was concluded with a video on the completed Historic Fourth Ward Park with a brief review and discussion of its Master Plan elements as they related to students' own park design features and layouts.

For the CEE class, a two-day implementation option was used. In this case, the pre-module survey and case study document were distributed at the start of the first class, and students were given 30 minutes to complete them. The park design assignment was first done individually, and then compared with their classmates. From this point, the same discussion questions were used and transitioned into the teaching on cognitive barriers for the remaining portion of class. A general introduction to Envision and its credits was given, then the first class session was concluded with an *additional* homework assignment: "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, and write a summary describing the changes you made." Students were provided with a link to access the Envision manual. The second class day, a similar discussion was led, asking students which credits they chose and why, and how Envision helped make their design more sustainable and reduce cognitive barriers. The class concluded like the other, with a review of the three selected Envision credits, the park's Master Plan elements, and video showing the completed park. In both implementations, the follow-up surveys were given after the final day of class instruction. Since survey self-reporting is known to be a limited method for assessing learning, the students' class design assignments were also collected for further evaluation by the instructor; a sample of each is included in Appendix 2.

Again, student learning from the module's implementation was assessed by surveys given before and after the module. The pre-module survey was intended to gauge their confidence level about the learning outcome skills, perceptions about sustainability and its barriers, and previous class or work experience. The post-module survey was similar, but included additional questions on the cognitive barriers taught in class and the usefulness of Envision. Copies of both full surveys are included in Appendix 3.

Survey Results and Analysis

Completed survey sets from the first class (BC) resulted in a 23-student sample size, and from the second class (CEE), a 31-student sample. These were analyzed separately because the classes were in different departments and the module formats differed slightly. The purpose was not to combine the data but to show versatility in application to both engineering and construction programs, and with different amounts of class time.

Student learning outcome confidence

With the first section of the survey, "Skills," the goal was to improve student's self-reported confidence level with the student learning outcomes (SLOs) on a 5-point Likert scale, ranging from 1 (low confidence) to 5 (high confidence). These survey objectives, reproduced in the tables below, were slightly adapted from the "lesson plan" learning outcomes listed in the Objectives section. It is acknowledged that this is a limited method, but our future work includes the addition of a graded concept mapping activity (Borrego 2009, Watson 2015) as a more objective assessment of the learning outcomes. Learning was also subjectively assessed based on the collected design assignments. To analyze the survey data, first a Wilcoxon signed-rank test was done with the sets of pre-module and post-module survey data for each SLO. The results are significant, with the p-values from both classes' datasets ranging from <0.001 to 0.04. Results from the BC class are shown below in Table 1 and those from the CEE class in Table 2.

In addition, the points for all five SLOs were combined for each individual student, and a paired t-test was done with the pre and post survey results. This method also indicated high probability that student learning increased, with p-values of <0.001 for both the BC class and the CEE class.

Table 1: Building Construction class (1-day module) SLO confidence survey results

Learning outcome: **"Select your confidence level to…"**	**Pre module average**	**Post module average**	**Percent increase**	**p-value**
1. assess and evaluate multiple stakeholders' requirements and priorities for a design.	3.17	3.78	19.2%	<.01
2. synthesize multiple stakeholders' requirements and priorities into an appropriate and unified design.	3.04	3.83	25.7%	<.01
3. make design decisions creating a solution to a complex and open-ended design problem.	3.00	3.78	26.1%	<.001
4. assess the social, environmental, and economic sustainability of a design.	3.39	3.83	12.8%	.04
5. recognize mental barriers that may prevent more sustainable outcomes.	3.35	3.91	16.9%	<.01
Average of all five SLOs	3.19	3.83	**19.9%**	

Table 2: Civil Engineering class (2-day module) SLO confidence survey results

Learning outcome: **"Select your confidence level to…"**	**Pre module average**	**Post module average**	**Percent increase**	**p-value**
1. assess and evaluate multiple stakeholders' requirements and priorities for a design.	2.94	3.81	29.7%	<.001
2. synthesize multiple stakeholders' requirements and priorities into an appropriate and unified design.	2.90	3.65	25.6%	<.001
3. make design decisions creating a solution to a complex and open-ended design problem.	3.29	3.84	16.7%	<.01
4. assess the social, environmental, and economic sustainability of a design.	3.35	4.06	21.2%	<.001
5. recognize mental barriers that may prevent more sustainable outcomes.	3.35	3.97	18.3%	<.01
Average of all five SLOs	3.17	3.86	**22.0%**	

Not only did the averaged confidence level for all students increase, but so did the number of students rating themselves at a higher confidence level (1-5) for each SLO after completing the module. In the BC class, the number of students at levels 1-3 decreased and the number of students at 4-5 (higher confidence) increased by 43 percent. Similarly in the CEE class, the number of students at levels 1-3 decreased and the number of students at 4-5 increased by 33 percent.

Knowledge of sustainable design

One purpose of the module was to improve students' knowledge and competence with the Envision system. To measure if this was achieved, the question "How proficient are you in using the Envision rating system for sustainable infrastructure?" was ranked on a 5-point Likert scale ranging from 1 (Not at all proficient/never heard of it) to 5 (Extremely proficient (ENV SP)). Survey results show that the average score increased from 1.35 to 3.17 (a 135% increase) in the BC class, and from 2.03 to 3.59 (a 76% increase) in the CEE class.

A related goal here was that students would find Envision to be helpful in the design process. Another set of questions was asked of only the CEE class that had completed the second homework assignment using the Envision manual. The three-part question was "In general, how helpful did you find the Envision manual and credits in… (1) helping you make informed design decisions? (2) improving your design's sustainability outcomes? (3) reducing the effects of choice overload, bounded rationality, and/or satisficing?" The Likert scale for this question ranged from 1 "extremely harmful" to 5 "extremely helpful," so it was able to show that a few students actually found Envision unhelpful. However, the overall results indicate that the students did find Envision to be a useful tool for the three points above. The average responses are 3.87, 4.13, and 3.87, respectively. The higher score (4.13) for the second question indicates that the students found Envision most useful for the purpose of improving a design's sustainability outcomes.

The other questions in this section were free-response, asking the students to list as many "characteristics of sustainable design" and "common barriers to sustainable design" as possible. On average, the students listed 3.7 characteristics and 3.5 barriers. By categorizing and counting the most common responses from the BC class (n=23), we discovered what sustainable design meant to these students. The two most commonly listed characteristics were related to energy efficiency (13 responses) and environmental friendliness (11 responses). Other common responses involved durability, low life-cycle cost, minimal waste, renewable resources and energy, and green materials.

For the barriers to sustainable design, by far the most common response was cost (19 of 23 students). Following this were time (8 responses), habits or status quo practices (6 responses), attitudes, perceptions, or norms (5 responses), lack of knowledge, resources, or information (5 responses), and complexity of design and construction (5 responses).

The post-survey asked for any *new* characteristics or barriers they learned about. On average, the students listed 1.3 new characteristics and 1.5 new barriers. The new characteristics, not surprisingly, corresponded to Envision, stakeholders, and community involvement. The new barriers included mental and cognitive barriers, as well as challenges with stakeholders and cooperation.

For the results above, our measures of confidence levels and mean numbers of concepts listed were similar to those used by Watson (2013) in a detailed analysis of students' sustainable design abilities and conceptual sustainability knowledge through surveys, rubrics, and concept maps. Watson's conclusion was that "while student surveys may be simple and provide a rough assessment of student knowledge, more objective tools, such as cmaps [concept maps], are suggested to supplement survey results to provide a more accurate and detailed view of student knowledge (p. 182). Thus a concept mapping activity will be considered as an addition to this module and future case study modules.

Understanding of cognitive barriers

In the final section of the post-survey, each student was asked to define each of the cognitive barriers taught in class and list at least one way that each could be overcome. These short-answer responses were manually scored into three categories: 0 (no response or incorrect), 1 (somewhat correct but vague or incomplete), and 2 (clear and fully correct). Scores assigned to the CEE class are shown in Table 3.

Table 3: Student understanding of cognitive barriers (CEE class, n=31)

Cognitive barrier	**Incorrect**	**Somewhat Correct**	**Correct**
Choice overload definition	3 (10%)	7 (23%)	21 (68%)
…way to overcome	6 (19%)	11 (35%)	14 (45%)
Bounded rationality definition	9 (29%)	13 (42%)	9 (29%)
… way to overcome	9 (29%)	3 (10%)	19 (61%)
Satisficing definition	7 (23%)	4 (13%)	20 (65%)
…way to overcome	9 (29%)	8 (26%)	14 (45%)

At best, about two-thirds of the class got the answers fully correct. Choice overload appears to have been the easiest concept to grasp. Two samples of student responses, somewhat correct (“1” score), and correct (“2” score), are given below for each cognitive barrier:

Choice overload:

(1) “Too many directions to go in; Can be improved by have clear goals”

(2) “Choice overload simply means there are so many choices that one reverts to the norm or gets so overwhelmed that a poor decision is made. One way this can be overcome is by meeting with stakeholders and allowing the community to participate in the design process. The wants and needs of the people who will enjoy the finished project are the ones who can help make choices that will allow the project to succeed.”

Bounded rationality:

(1) “Being limited by one current understanding of the topic and the possible alternatives to complete a project. It can be overcome by completing a design process from the very beginning phase and brainstorming the entire time to ensure the decision maker doesn't rely on previous experience.”

(2) “Bounded rationality is when our thinking capabilities are limited so arriving at a solution is difficult. A way to overcome this is to get many perspectives on a problem.”

Satisficing:

(1) “sufficing and satisfying meaning we do what we can to make the project great for the environment and the stakeholders. Can be overcome by trying to meet all requirements.”

(2) “Satisficing essentially occurs when you settle too early in the design process. The Envision credits were helpful because they gave general ideas that may spark creativity and sustainable thinking that could ultimately further the project. A way satisficing can be avoided is through an iterative design process. After each iteration the stakeholders should be shown the design and provide feedback on how it could improve.”

After the free-response questions, students were given one last multiple-choice question to gauge their perception of cognitive barriers’ level of impact upon engineering decision making for sustainability: “Cognitive barriers to sustainable decision making…”

(1) do not exist.
(2) exist but *do not significantly affect* decision making.
(3) exist and influence decision making, but *do not seriously affect* a project’s outcome.
(4) exist, influence decision making, and *can seriously affect* a project’s outcome.

In both classes, the majority of students (15/23 in the BC class and 27/31 in the CEE class) selected the fourth option. Yet the two-day module was better in communicating the seriousness of these barriers than the one-day module: 87% of students in the CEE class chose option 4, compared to 65% in the BC class. This difference can be attributed to their extra day of instruction and additional homework activity.

Limitations and student comments on module

Students' explanations of cognitive barriers (Table 3) were less accurate than expected. There could be several reasons for this: for one, the survey was an ungraded, out-of-class assignment, so there was little incentive for students to try their best. Although definitions for each cognitive barrier had been specifically provided in the module, the ways to address them were complex and the answers not entirely concrete or definitive. Although the open-ended format and subjective assessment of the student assignments made it somewhat difficult to extract and apply results, concept mapping will be a valuable next step (Watson 2015, p. 60).

Finally, after the follow-up survey, students were asked to provide comments and ways that the module could be improved. The most significant and recurring suggestions were:

- Explain up front that the case study involves a "design challenge" and write-up
- Include better site maps with a scale and more context
- Work in collaborative teams for the park design assignment
- Modify the design assignment for better relevance to "non-design" BC students
- Include more in the module about the real-life design application of Envision

Conclusions and Future Work

The learning objectives for the case study require merging complex and diverse concepts about sustainable engineering design and behavioral decision making. When introducing the topics and case study about the Historic Fourth Ward Park to the classes, we were skeptical of students' ability to recognize the connection between the concepts, let alone devise methods to reduce them. However, the slides and teaching notes provided plenty of detail: they began by introducing the cognitive barriers related to decision making and included examples that students could relate with. Throughout the lecture, students were given opportunities to discuss connections between the case study, Envision credits, and the cognitive barriers they learned about.

Student responses were generally well-thought-out and accurate. For example, when asked how Quality of Life Credit 1.1: Improve Community Quality of Life reduces potential cognitive biases, students responded by making connections to multiple barriers, saying "The criteria can narrow down the vast amount of possible choices by prioritizing or 'weighting' those that improve quality of life over those that do not," reducing choice overload, and "Accounting for the community may reduce the effects of bounded rationality by involving more stakeholders."

By the end of the class, students were making comments about Envision not only being able to highlight sustainable design features but to develop better decisions, whether or not the project is evaluated or certified by ISI in the future. Ultimately, including a lecture not just about Envision or sustainability but incorporating aspects of behavioral decision making seemed to help the students recognize why such tools are helpful, beyond the recognition for sustainability after the project is complete. Being able to articulate this connection will help them explain to future employers and clients the benefits of such tools, as they begin to work on real-world projects with real implications for sustainability.

Future steps for this module include making some modifications based on the student comments listed above as well as instructor feedback. The survey questions on “Perceptions” about barriers to sustainability (Appendix 3), which yielded inconclusive results in this study, will be rephrased for better clarity and improved results. The module’s teaching notes and lesson plans will be refined slightly to more explicitly address these points, showing how sustainability can be measurably and strategically integrated into any project, achieve multiple stakeholder priorities, and push beyond “satisficing” to higher levels of achievement. Finally, the addition of a concept mapping activity, as noted by Borrego (2009) and Watson (2015), will be pursued to provide a more objective measure of the module’s effectiveness in linking students’ knowledge between the disciplines of engineering, sustainability, psychology and decision making.

Considering these improvements, as well as strengthening our approach’s connection to transdisciplinary literature and the larger educational system, the authors intend to create additional case studies and modules to provide more examples of how cognitive barriers affect real-world engineering decisions in the workplace. The goal is to host these case-based modules in a repository (potentially on the Envision website) as teaching material for instructors to download, use and adapt. In accordance with Davidson’s findings (2016), the intent is that these resources can be searched, assessed, revised, and updated as needed, with ratings and feedback incorporated as a sort of peer review each time an instructor uses the module.

Envision case study modules and workshops can become a common method for advancing interdisciplinary learning, whether in-class activities for students or development workshops for working professionals. Anyone can benefit from an awareness of cognitive bias in decision making, but this is especially critical for civil engineers, who will require these skills to respond to complex global challenges with infrastructure that is holistically sustainable.

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Appendix 1: Historic Fourth Ward Park case study

An Envision Case Study:
Historic Fourth Ward Park - Atlanta, GA
Clear Creek Combined Sewer Basin Relief Project

This case study puts you, the student, in the place and time of a designer working on this project that received the Envision sustainable infrastructure certification. You will be presented with relevant background information and then instructed to synthesize the elements into a park design. In your next class, you will learn about and discuss the decision-making process and use of Envision, and use this knowledge to improve your design.

Introduction to BeltLine and Site Condition

Vision for Atlanta BeltLine

Envision documentation for the project (credit QL1.1) describes the Atlanta BeltLine as a sustainable urban redevelopment "emerald necklace" that will provide a network of public parks, multi-use trails, transit, and new development along a historic 22-mile railroad corridor circling downtown. The project is committed to improving community livability within the City of Atlanta, and is planned to connect 45 neighborhoods. The proposed Historic Fourth Ward Park, adjacent to the BeltLine, will become one of the first parts in this comprehensive effort and connecting

Project Site and Problem

The "Atlanta BeltLine Master Plan: Subarea 5 Freedom Parkway, Historic Fourth Ward Park Master Plan Report" (henceforth referred to as "master plan") gives a description of the preexisting site conditions. It is abandoned industrial and commercial property around the neighborhoods of Old Fourth Ward, Poncey-Highland and Inman Park, within Subarea 5 of the planned Atlanta BeltLine. The property includes contaminated brownfields and is generally unsafe. Furthermore, many of the area's parks are in disrepair and lacking certain facilities. The site is largely covered by concrete, with considerable grade change and little vegetation, and it suffers from frequent flooding caused by combined sewer overflow (CSO) issues. If nothing is done to fix these issues, continued overflows will inhibit growth and development in the neighborhood. Atlanta's Department of Watershed Management is considering a tunnel project to reduce these problems.

QL1.1 also describes how the desire for a park in Atlanta's Old Fourth Ward has grown out of conversations from local citizens, who first convened to discuss stormwater issues in 2003. The group formed the Park Area Coalition (PAC), which ultimately evolved into the Historic Fourth Ward Park Conservancy. This group's primary goal for the project is to address the stormwater problem using a retention pond instead of a tunnel system. In addition to this stormwater function, a park would relieve the need for greenspace, provide neighborhood amenities, and serve as a hub linking the Old Fourth Ward with other parts of Atlanta and the BeltLine.

Clear Creek Combined Sewer Basin Relief Project

Documentation submitted for credit LD1.4 describes the City of Atlanta's authorization of this combined sewer relief project for 5 acres in the North Avenue area. It will address stormwater issues and also provide park amenities as the first component in the 25-year Atlanta BeltLine planning effort.

The project must detain stormwater runoff for an 800-acre drainage area within the Clear Creek combined sewer basin upstream (south) of North Avenue. It will detain stormwater runoff to offer capacity relief to the CSO system. It must be designed to handle flow from a 100-year storm event to reduce flooding in the surrounding drainage area. The City of Atlanta's Department of Watershed will provide funding for functional engineering components to benefit the CSO project, but not for purely artistic or decorative amenities.

Stakeholder Involvement

QL1.1 states that all efforts working toward the park have included a considerable number of stakeholders. The Historic Fourth Ward Park Master Plan acknowledges nearly 90 participants from numerous organizations. Existing master plans for the Old Fourth Ward and the BeltLine take into account the priorities and concerns of these stakeholders, the neighborhood, and adjacent developments; as well as the relationship of this park with the larger Atlanta park system.

LD1.4 describes the public input and design process, in which meetings were organized to allow Old Fourth Ward Park residents, businesses, and private stakeholders to contribute ideas, feedback, and questions to the project design efforts. Some of their ideas may differ from city priorities, but all plans must align with the Atlanta Strategic Action Plan (ASAP) and other master planning policies. Stakeholder priorities are described in the following pages.

Priorities of Stakeholder Groups

Neighborhood and Community

According to the public involvement section of the master plan appendices, residents of the Old Fourth Ward neighborhood desire a stormwater retention pond rather than the City's typical tunnel installation. It is important to them that the stormwater feature is not just an engineering solution, but also an amenity. They want soft landscaped edges to the pond, with as few railings as possible, a walkway all the way around the pond, and no streets bisecting it. Most would prefer a single larger pond over two smaller ponds.

As for the park, its guiding principles derived from stakeholder engagement are documented in LD1.3. The community wants a connected open space with clearly defined edges, which should be safe, secure, easy to maintain, and coherent with the adjacent neighborhoods. It should be a beautiful environment with views of the water and plenty of trees. The residents desire park amenities including an amphitheater, bouldering, and picnic shelters, and want existing streets within the park area closed to through traffic (LD1.3). The master plan appendices add that the neighborhood is diverse, so the design must accommodate children and families as well as being ADA accessible for the elderly and handicapped. Also, future condo and rental units to be developed will require passive open lawn areas, dog parks, community gardens, and playgrounds.

Following is a list of other park program elements that were proposed in the community-driven design and documented in the master plan:

- A soft edge to the lake (without allowing access to the water)
- A dog park (clearly defined; within the less desirable/underutilized parcels of the park)
- Trails (multi-use, including pedestrian, bike, in-line skating, etc.)
- Sport fields, active recreation areas, and large lawn space
- Interesting water features (perhaps a waterfall, or some type of interactive fountain
- A skate park, tennis courts, and a recreation center
- Flexible spaces for community interaction and events (spaces for meeting rooms)
- Picnic areas (both smaller scale picnic tables, and pavilions for larger gatherings)
- Public restroom facilities
- Concession stands (to be located in small kiosks throughout the park)
- A library (with a focus on children's literature, and a potential space to hold smaller events, such as movie screenings)
- Wayfinding devices that speak to the historic and industrial character of the area
- Adequate parking space and a variety of parking options
- Future street connections across the BeltLine

<u>Atlanta City Departments and BeltLine</u>

The City of Atlanta now places great importance on human-scaled initiatives and open public spaces compared to mass infrastructure projects. The most pressing priority for this site is to overhaul the long-neglected water and sewer infrastructure in order to reduce overflows and increase capacity (LD1.3). Although the park is a unique design project, it must still comply with the overarching themes of the Atlanta Strategic Action Plan (ASAP) listed in the master plan appendices, which are:

- Redevelopment should be at a density sufficient to support public transit;
- Design should celebrate the distinct character of the area through the BeltLine Trail and public art opportunities;
- The layout of streets should promote cross-BeltLine connectivity;
- Redevelopment should respect the existing historic context and promote the preservation of historic resources, wherever possible.

Other relevant city policies detailed in the appendices include:

- <u>Housing:</u> Promote diverse, mixed-income developments, housing affordability, maintenance and rehabilitation.
- <u>Community facilities:</u> Expand parks and public open space, improve accessibility, and protect environmentally sensitive lands. Encourage visibility and surveillance of the park, provide convenient pedestrian access to and from the adjacent green space, and include core park sites within a 0.5-mile travel distance for every child.
- <u>Cultural resources:</u> Transform existing transportation corridors into greenways that reflect the industrial and rail heritage of the City. Represent and reflect elements of the City's cultural, social, economic, and architectural history. Safeguard the City's historic aesthetic, and foster civic pride.

- Transportation: Link development to multi-modal transportation infrastructure to enhance accessibility and mobility, regional access and connectivity. Link transportation strategies to jobs, land use, recreational, and environmental systems.
- Urban design: Preserve cultural, historic, and natural resources and neighborhoods. Encourage a grid of smaller blocks and connected streets to improve access to the BeltLine, reduce congestion, and further the urban character of the area.
- Land use and zoning: Preserve single family neighborhoods and mixed-use redevelopment in areas adjacent to the BeltLine. Enhance and encourage compatibility with the "small-town/downtown" character of the neighborhood. Discourage new surface parking lots, but encourage the use of existing neighborhood alleys for parking access.

There are several tennis court complexes in the area, and the City has an adequate supply of these. The Old Fourth Ward has a recently renovated recreation center with community meeting space, and the City has a policy of no new recreation or community centers.

Finally, the master plan also includes several sustainability goals for the park design:

- Minimize urban heat island effect
- Tree preservation, canopy maximization, drought-tolerant landscapes
- Use native and adaptive plant species to minimize maintenance and water needs
- Improved stormwater management, capture, and use for irrigation
- Reduce impervious surface, use porous pavements
- Use rain gardens or constructed wetlands to promote infiltration
- Go beyond NPDES pollutant discharge regulations to explore ways to make stormwater management visible and educate the public.
- Reduce water use (drip irrigation) and energy use (LED streetlights)
- Facilitate and encourage transit, bicycle, and walking access

Design Team

You are a member of the project's design team, which includes landscape architecture and engineering firms. In addition to incorporating the requirements of the other stakeholder groups, you must meet the project's main technical requirements, which are documented in LD1.3. Out of these, the biggest priority is to create a functional and beautiful park that provides capacity relief to the Clear Creek combined sewer for 22 acre-feet of stormwater. It is in your best interest to relate as many elements as possible to the combined sewer overflow so that Atlanta's Department of Watershed will fund it. And of course, the facility must be completed on time and within budget.

Student 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. You may choose to draw on the blank map from Appendix C and/or incorporate elements from the draft concepts shown in Appendices D-F.

*NOTE: Appendices A-F of the case study are not included in this paper.

Case Study References

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Appendix 2: Samples of Student Assignments

Atlanta Fourth Ward Park, Case Study Assignment 1:

"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. You may choose to trace the dark green area from Appendix C and/or incorporate elements from the draft concepts shown in Appendices D-F."

The following design (Figure 2) and description are from a student in the BC 4334 class:

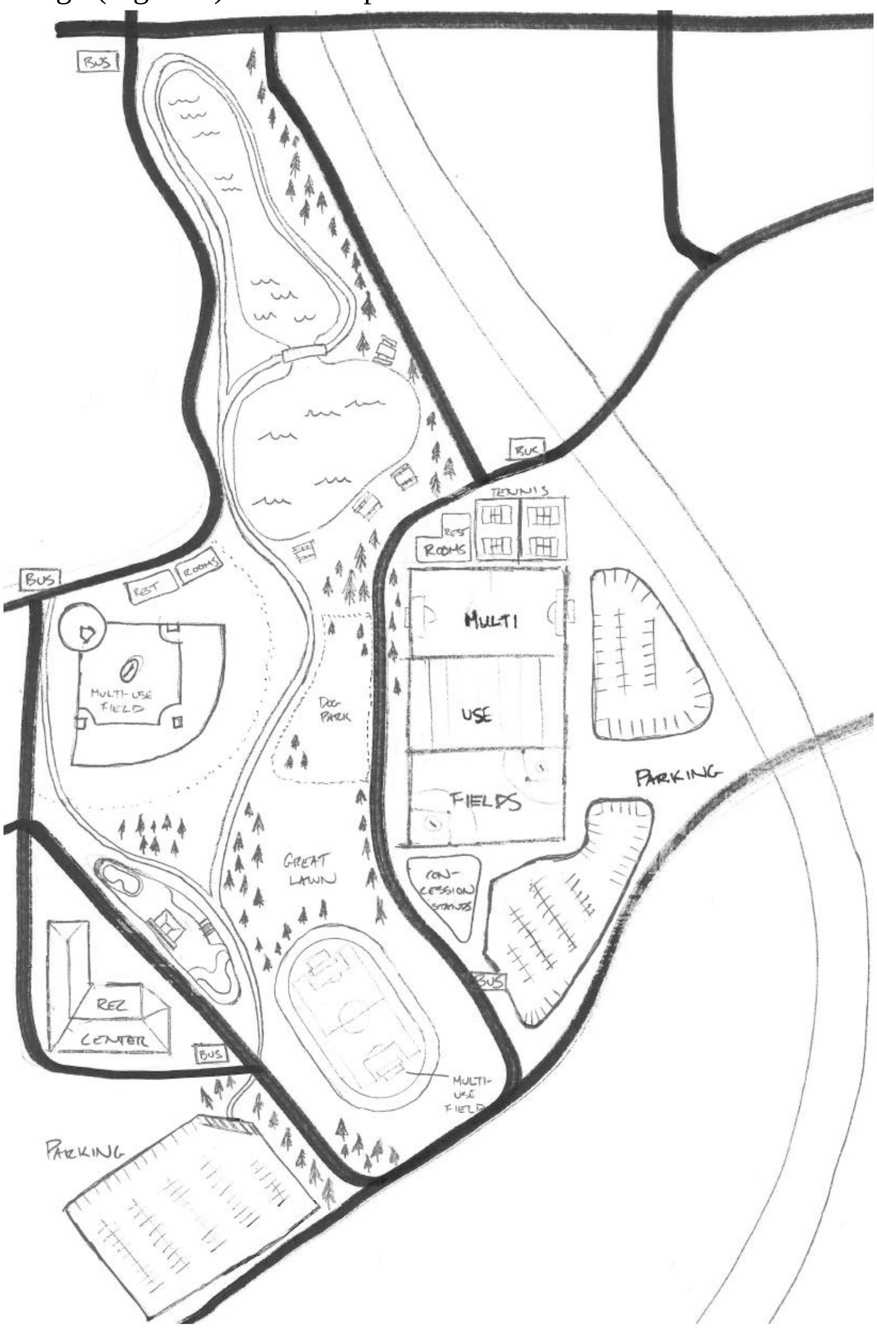

Figure 2: Sample of student park design

This design for the park incorporates features from different options located in Appendices D-F. We have two large parking areas that services two multi-use fields and a skate park. The parking lots are complete with required handicap parking, fire/emergency lanes, and are large enough to service the entire park should there be events or games on more than one of the fields.

A pedestrian (foot/bicycle) pathway starts at the parking lot and continues north between the multi-use fields and the skate park, where it splits around two scenic ponds with picnic tables and trees. All entrances and exits to this path are ADA compliant and complete with intermittent trash and recycling containers, as well as an emergency notification system.

Bus stops and other public transit locations are placed around the pedestrian pathway. The two proposed parking areas include bus stop destinations and possible integration with a city shuttle as well. Two other bus stops exist on this beltline; one to the north of the rec center near the baseball diamond and restrooms, and one at the northmost area of the map, above the pond. The 4 bus stops are spaced evenly throughout the park so every park feature is reasonably accessible.

The dog park is located in the center of the area, between the ponds and the southmost multi-use field. Pet waste containers are provided at the corners of the dog park, as well as intermittently along the pedestrian pathway.

The largest multi-use field area is located in the eastmost part of the park. These fields are equipped to simultaneously host 3 football, soccer, lacrosse, baseball, or softball games. Sufficient parking exists adjacent to these fields as well as concession stands, bus stops, and restrooms. Across the street to the west, an olympic track that contains an additional multi-use field exists. As we continue west, we cross the pedestrian pathway and realize a full recreational center, cast in place concrete skate park, and parking lot with bus stop. The skate park is located next to the recreation center which is to include a first aid facility.

Throughout the park is a large amount of trees. Trees provide many benefits to the public and social health of a community. Not only do trees produce oxygen and help combat smog, a canopy can reinforce the ability to meet clean air regulations. According to canopy.org, "Access to trees, green spaces, and parks promotes greater physical activity, and reduces stress, while improving the quality of life in our cities and towns." Also important to water filtration and retention, trees and urban forests can help reduce needs for stormwater management. Additionally, trees are home to a number of species of birds, insects, and other animals. Again from canopy.org, "where a canopy of trees exists, apartments and offices rent more quickly and have a higher occupancy rate; workers report more productivity and less absenteeism.

The two ponds located at the northmost area of the map are beneficial for several reasons. The first benefit is water conservation. Lawns and plants need a lot of water. According to tetra-fish.com, "ponds can be filled with rainwater, virtually watering themselves." Pond water also directly keeps the lawns and trees watered. By incorporating the two ponds, we can realize all the benefits from our trees without the full cost of watering or hydrating them. Other benefits include reduced mowing, less pesticides, less fertilizers, and increased level of environmental awareness. These ponds also do a considerable job of supporting wildlife.

Aeration in ponds is also a good idea to reduce algae. Through the process of aeration (small fountain-like bubbles), algae spores are mixed up and sent deeper, limiting the time they are exposed to sunlight. This also can help with mosquito breeding problems, nasty bacteria, and bad smells. These ponds can double as stormwater detention ponds.

In summary, this design aims to bring to the community a sustainable park area that realizes multiple health and social benefits. Through the use of multi-use recreation fields, a rec center, skate park, scenic ponds, and other amenities, this design will bring vibrancy and color (green!) to an already historic area.

Atlanta Fourth Ward Park, Follow-up Assignment 2:

"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 following is a sample from a student in the CEE 4134 class:

Quality of Life:
In order to improve my design's sustainability pertaining to this category I would not only increase the size of the interconnecting paths, but also add more of them. This would cover both the "Encourage Alternative Modes of Transportation" (QL2.5) and "Improve Site Accessibility, Safety & Wayfinding" (QL2.6) credits. Between the two I would focus on attaining better accessibility because if it easier to utilize the Beltline Trail then more people will be encouraged to use it for travel. Originally, I only mapped a few connecting streets on either side of Ralph McGill Boulevard, but after looking at the priorities given by the stakeholders, I will be adding more connections across it to fulfill its request to have "Future street connections across the beltline." In doing so, I believe this will reach the Conserving level of achievement because the only negative impact could be the inability to create more multi-use fields if these connecting streets become too intertwined.

Leadership:
To receive credits for "Stakeholder Involvement" (LD1.4) and "Foster Collaboration and Teamwork" (LD1.3) monthly or bi-weekly meetings should be in place. The beginning planning stages of the project are crucial because if something is not communicated correctly in this period it could become a costly change order towards the end of the project. Having the meetings will ensure that the right aspects of the project will be implemented to improve sustainability. Further down the line during the construction phases the meetings can be less frequent as they can be held to review progress and confirm all jobs are on schedule and done to the owners' satisfaction. Once completed, this can reach the Restorative level of achievement because this does not have any

negative effects as it only ameliorates the overall sustainability of the project. It will even help break any cognitive barrier due to the large input of all the stakeholders inputting all the ideas.

Resource Allocation:
Credit RA2.2 “Use Renewable Energy,” is a credit that has a myriad of possibilities with this project. Solar energy is an easy energy source to harvest to all the lighting across the Beltline. Using solar powered LED light fixtures will not only be self-sustaining, so no maintenance is required, but it will also reduce the amount of light pollution, another credit in the Quality of Life category. And, although sufficient design would be needed, it could be a possibility to implement a sprinkler system for the multi-use fields that incorporates the storm water runoff in the already planned retention basins. That way an outside source wouldn’t be needed to supply extra water and be wasteful. If this credit is fulfilled, then I believe it can achieve the Conserving level of achievement because there will be no negative effects.

Natural World:
The plan for the Beltline Trail already considers the construction of a basin to “detain stormwater runoff to offer capacity relief to the CSO system.” In doing so, it will decrease its flooding problem from this inefficient system and receive credit for NW2.1 “Manage Stormwater.” Previous flooding problems will be alleviated because any surplus flow will be diverted into these basins. It will reduce costs that were once directed to property damage. This should achieve the Restorative level because it is not only restoring the environment surrounding the basins, but also preventing any future damage with its capacity being designed to withstand a 100-year flood.

Climate and Risk:
One goal for the park design is to minimize the urban heat effect. Credit CR2.5 “Manage Heat Island Effects” will be satisfied if this goal is met. The objective to reduce the amount of heat being retained and released during the day in the city, mainly from the asphalt. If materials such as concrete are used for all pathways, less heat will be absorbed therefore reducing the residual heat that will be emitted. Also, asphalt is more expensive to install. So by using concrete it not only efficient in combating the heat island effect, but also less expensive. It is because of these long-lasting results that the overall effects can be diminished and allow this credit to be given the Restorative level of achievement.

Appendix 3: Student Surveys

Pre-module survey

This is a preliminary student survey for an educational case study you will be given on Atlanta's Fourth Ward Park. The assignments and instruction will be used to teach you about decision making for sustainable infrastructure using the Envision rating system. Please answer all the questions in the following sections.

Skills

Select your confidence level to:

Low confidence (1) (2) (3) (4) (5) High confidence

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

Perceptions

Rate how much you agree with the following:

Strongly disagree (1) (2) (3) (4) (5) Strongly agree

Sustainability is an abstract concept that cannot be easily measured.
Sustainability is too broad and complicated to integrate into everyday construction projects
Achieving a sustainable project often requires major trade-offs with other stakeholder priorities.
Achieving some degree of sustainability in construction projects is good enough.

Sustainable Design and Envision

How proficient are you in using the Envision rating system for sustainable infrastructure?

Not at all / never heard of it (1) (2) (3) (4) (5) Extremely proficient (ENV SP)

List as many characteristics of sustainable design as you can think of.
List as many barriers to sustainable design (factors that prevent it) as you can think of.

Experience

In how many classes have you experienced these topics?

0 1 2 3-4 5+

How many years of industry experience do you have working with these topics?

0 1 2 3-4 5+

Post-module survey

This is a follow-up student survey to assess your learning from the case study exercises and in-class instruction on cognitive barriers and Envision. Please answer all the questions in the following sections.

Skills

Select your confidence level to:

Low confidence (1) (2) (3) (4) (5) High confidence

Assess and evaluate multiple stakeholders' requirements and priorities for a design

Synthesize multiple stakeholders' requirements and priorities into an appropriate and unified design

Make design decisions creating a solution to a complex and open-ended design problem

Assess the social, environmental, and economic sustainability of a design

Recognize mental barriers that may prevent more sustainable outcomes

Perceptions

Rate how much you agree with the following:

Strongly disagree (1) (2) (3) (4) (5) Strongly agree

Sustainability is an abstract concept that cannot be easily measured.

Sustainability is too broad and complicated to integrate into everyday construction projects

Achieving a sustainable project often requires major trade-offs with other stakeholder priorities.

Achieving some degree of sustainability in construction projects is good enough.

Sustainable Design and Envision

How proficient are you now in using the Envision rating system for sustainable infrastructure?

Not at all / never heard of it (1) (2) (3) (4) (5) Extremely proficient (ENV SP)

In general, how helpful did you find the Envision manual and credits in…

Extremely harmful (1) (2) (3) (4) (5) Extremely helpful

...helping you make informed design decisions?

...improving your design's sustainability outcomes?

...reducing the effects of choice overload, bounded rationality, and/or satisficing?

List any new characteristics of sustainable design that you learned about.

List any new barriers to sustainable design that you learned about.

Cognitive Barriers

Define "choice overload" and list at least one way that it can be overcome.

Define "bounded rationality" and list at least one way that it can be overcome.

Define "satisficing" and list at least one way that it can be overcome.

Choose the option you most agree with: "Cognitive barriers to sustainable decision making…"

...do not exist.

...exist but *do not significantly affect* decision making.

...exist and influence decision making, but *do not seriously affect* a project's outcome.

...exist, influence decision making, and *can seriously affect* a project's outcome.

Additional Comments

Please provide any comments you have on this Envision case study and module, and list any ways it might be improved.