Using a Sustainable Infrastructure Rating System in the Civil Engineering Capstone Design Course

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Abstract

Sustainability is a key concept for civil engineers. In the past decade a number of efforts have been made to incorporate sustainability knowledge, techniques, and tools into civil engineering education. One approach has been to use professional rating systems as a vehicle in design courses. This paper describes such an approach using the Institute for Sustainable Infrastructure (ISI) Envision™ rating system as part of a learning module in the capstone design course at the University of Utah. In the module, students are first presented fundamental sustainability concepts and tools, and in a separate seminar are introduced to the Envision rating system. Students are exposed at least two more times to brief follow-up discussions applying Envision to their project. It was expected that the use of Envision helps students reinforce underlying sustainability concepts and improve the learning about Envision by applying it to a project. The module effectiveness was assessed for the Fall 2013 semester using three formats: (1) a new civil engineering sustainability literacy questionnaire administered before and after the module, (2) quality of application of the Envision Rating System to the project, and (3) instructor reflection. Results from full assessment in the Fall 2013 semester and partial assessment in the Spring 2014 semester indicate the module helped introduce students to basic sustainability concepts and Envision. However, the assessment suggests a stand-alone course within the civil engineering curriculum would promote a much deeper understanding of sustainability concepts, motivating factors, and broader applications which are beyond the capability of a single capstone design project learning module.

Introduction

The establishment of the term sustainability is most commonly identified to date to the late 1980s, when the release of a United Nations report defined sustainable development as:

“…development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Numerous other operational definitions of sustainability in different contexts followed. In the 1990s the civil engineering profession adopted the term when the American Society of Civil Engineers (ASCE) Board of Direction introduced the concept of sustainability into their Code of Ethics, and shortly thereafter released a formal definition of sustainable development following from the definition above:

“A set of environmental, economic and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the
quantity, quality or availability of natural, economic, and social resources.”

Recently, sustainability concepts have become more engrained in civil engineering practice. ASCE highlighted the importance of sustainability in its publication *The Vision for Civil Engineering in 2025*, where sustainability is mentioned 28 times and sustainable another 22. And the new Institute for Sustainable Infrastructure (ISI) was formed in 2011 to bring a new professional sustainability credentialing and project certification framework to the civil infrastructure engineering profession.

Paralleling the development of sustainability in civil engineering practice, approaches to teach sustainability concepts in the civil engineering curriculum also have been created. Initial interest was partly driven by sustainability being added as part of the ABET accreditation criteria for all baccalaureate level programs, specifically Criterion 3 (Program Outcomes). Criterion 3(c) states that programs must demonstrate their students attain:

> “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.”

In response to ABET and for other reasons, educators have created approaches to introduce sustainable engineering concepts and techniques across departments in Engineering\(^2\), in environmental engineering\(^3\), in civil engineering\(^4,5,6,7,8\), and to address ABET criteria\(^2,9\). In 2011, a special issue of the *Journal of Professional Issues in Engineering Education and Practice* provided a collection of papers on the topic of sustainability in civil and environmental engineering education\(^10\). And very recently implementation of sustainability has been highlighted as a means to realize an important element of the ASCE Body of Knowledge\(^11\). Numerous approaches have been found to be successful through assessment of sustainability knowledge and skills learned in learning activities, modules, and courses and across the civil engineering curriculum\(^7\). More widespread awareness of sustainability in civil engineering education is leading educators to focus on students and their perceptions of sustainability and the profession. For example, Blevins and Burian\(^12\) analyzed the culture of civil engineering students and found many of them to self-identify with sustainability and seek to incorporate sustainability into their education and careers.

Among the approaches to teach sustainability, project rating systems have been used as a platform. For example, the U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED) rating system has served this purpose in capstone design courses\(^13,14\), as well as technical design courses\(^8\). Other studies have met sustainability course objectives using the LEED rating system through projects focused on sustainable energy systems\(^15\) and collaboration of multidisciplinary students on a single project\(^16\). These past applications have found knowledge and student satisfaction to be improved due to the approaches taken to teach sustainability. The ISI Envision\(^\text{TM}^\text{TM}\) Rating System has also found recent use in civil engineering education. Although published works were not found, a post on the ISI LinkedIn Group in December 2013 on the use of Envision in education elicited several
responses of ways educators are using Envision in their civil engineering courses. The responses suggested several educators were using it in project-based courses.

The authors of the present paper have also used the Envision Rating System in several courses. However, their experience indicates that the Rating system by itself may not be sufficient to provide the broad understanding of sustainability concepts in civil engineering practice. Therefore, a module that integrates lessons on fundamental sustainability knowledge, lessons on Envision, and a project-based application of Envision has been adopted by the authors. In this paper, the module is described and its effectiveness is assessed using a new civil engineering sustainability literacy questionnaire, quality of Envision application to the student project, and instructor reflection. The module and the questionnaire are described in the next section followed by presentation of the results of the assessment.

Module Description

The sustainability module described herein builds on a previous set of sustainability curriculum modules by the lead author, which included a lesson on sustainability in the capstone design course. The lead author noted the need for increased application of sustainability knowledge and techniques in the capstone design course to complement the overview lesson. This was accomplished by updating the existing lesson, providing an introductory lesson on the Envision rating system, incorporating periodic student activities to apply Envision, and then to use Envision for the senior design project. Although the module is designed for use in the capstone design course at the University of Utah, it is extensible to most technical design courses that could apply Envision to a project.

The sustainability module learning objectives expect students to be able to

- Define sustainability, sustainable development, triple-bottom line, Cradle-to-Cradle™, life-cycle assessment, and other sustainability terms and concepts
- Explain whole-system thinking and apply to analyze a civil engineering project
- Apply ISI Envision Rating System to a civil engineering infrastructure project

The content of the introductory lesson is delivered using a variety of classroom presentations and learning activities including a reading assignment, a brief video on whole-systems thinking, PowerPoint slides and presentation, small group discussions, and web quests. The topics include coverage of definitions and concepts, discussion of values, systems thinking, and more depth into life-cycle assessment using an example from urban water supply infrastructure. The introductory lesson is presented approximately six weeks into the semester length course.

The sustainability rating system seminar is delivered approximately three weeks after the introductory sustainability lesson. The rating system lesson includes coverage of LEED and Envision, which is delivered with a PowerPoint presentation using some of the slides available at the ISI web site (www.sustainableinfrastructure.org) and an example the authors create for the class design project (specific for each semester to adjust to the project). Envision was developed by the American Council of Engineering companies (ACEC), American Public Works Association (APWA), and ASCE to promote sustainability concepts in infrastructure design. After its conception in 2011, ISI Envision partnered with the Zofnass Program for Sustainable
The fundamental objective of the ISI Envision partnership is to aide multi-discipline professionals, from both public and private sectors, in creating infrastructure plans using sustainability metrics as a guiding principle. ISI Envision uses a life-cycle assessment approach to measure the sustainability of each project. This includes evaluating the project for its environmental impacts, life-cycle costs, and socio-economic influences and priorities. Specifically, the rating system is divided into the following five categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk. Each ISI Envision category has a list of criteria where sustainability credits are accumulated if applicable to a specific infrastructure design. These criteria can also provide guidance into improving a design to make it increasingly more sustainable.

The ISI Envision toolbox provides more than a checklist of sustainability criteria and metrics for professionals in the industry. ISI Envision includes a large collection of sustainability professionals credentialed in the ISI Envision rating system who are available to review and verify results when applied to a project. The credentialing protocol can be completed by students as well as industry professionals. The cost for credentialing as a student is provided at a reduced cost to facilitate the learning and use of sustainability concepts in young professionals through the use of the system. Furthermore, consulting companies can be certified as ISI Envision specialty firms that commit to applying ISI Envision standards in all infrastructure designs and plans. In terms of functionality, ISI Envision is not limited in application to the size, type, location or intricacy of a project, making it a practical tool for the Civil Engineering industry.

After being introduced to Envision, the students revisit sustainability concepts and Envision approximately once every two weeks. The check-ups are specifically designed to be a team application of Envision to the project, and they revolve around exploration of Envision and linking Envision elements to sustainability concepts in the project. When students are initially engaged in the Envision application, the project development is in the feasibility study stage which helps them to explore some of the key concepts associated with planning and designing the project. The application of Envision continues to conclusion of the course, with submittal of preliminary design documents. There are limitations to the amount of Envision content student teams can apply because parts of Envision focus on community involvement and leadership, and other aspects that are not possible to achieve in a class project setting. These elements are still discussed, but hypothetically incorporated into the project rating developed in Envision.

The application of Envision is guided as if the student team was seeking project certification. The students review the Envision categories, discuss ones that relate to their project, identify ways to modify the project (for the semester deliverables or hypothetically), insert rating score and reasoning, and for some identified criteria to provide documentation that becomes part of the final report. The students consider as many of the relevant criteria as possible across each of the five categories of Envision. A summary of the criteria included, credits earned, and overall Envision rating is included as part of the class deliverable products.
Module Assessment

The module was applied and assessed in the Fall 2013 and Spring 2014 capstone civil engineering course (complete assessment results from Fall 2013 are included in this paper). Both course offerings had 24 senior level civil engineering students. The lead author was the instructor of the Fall 2013 course, with the second author serving as a Teaching Assistant for both semesters. To assess student learning, the authors sought a sustainability literacy assessment instrument specific to civil engineering. One of sufficient breadth and depth and relevance to the course could not be found. Therefore, the authors created one. Using literacy documents for environment, sustainability, and other related topics the authors compiled a list of appropriate questions and combined with ones they created. For the questionnaire, the authors defined sustainability literacy to include knowledge of: 1) how humans affect the environment (through design conception, construction, and deconstruction, energy sources and consumption, waste disposal, etc.); 2) what the definition of sustainability means with respect to the civil engineering discipline (defining sustainable development practices, components, and key considerations); and 3) why these considerations are important (environmental, social, and economic impacts, future generations, resource depletion, etc.). The questionnaire used in the Fall 2013 semester is included as Appendix A with answers and explanations and reflections of the authors. Continued improvement of the questionnaire was conducted with the help of sustainability teaching colleagues across the U.S. leading to an improved questionnaire included as Appendix B, but not used in the assessment. The assessment was conducted by having students complete the questionnaire prior to AND after completing all the module elements. The results from the Fall 2013 semester are reported next.

Results

Of the 24 students invited to complete the literacy questionnaire in the Fall 2013 semester, 17 submitted full responses for both the pre- and post-module instances. The average score on the pre-module questionnaire was 6.2 out of 17 possible points. The average score on the post-module questionnaire was 9.2.

The summary of the scoring by each question is shown in Figure 1. Question 11 clearly illustrates the effectiveness of the Envision exercise in helping students to learn the credit categories of Envision. Only two students were able to correctly answer the question on the pre-module questionnaire, but 13 of 17 were able to correctly answer it after the module was completed. The students worked with these credit categories twice in the semester during class and several other times outside of class.

The responses to question 16 further supports the student learning from the Envision exercise. This question was more challenging as it was not a multiple choice question. Students were asked to identify one specific credit that could be acquired for Envision. Similar to question 11, only two students were able to correctly answer the question on the pre-module questionnaire, but 13 of 17 were able to correctly answer it after the module was completed. The students worked with these credit categories twice in the semester during class and several other times outside of class.

The responses to question 16 further supports the student learning from the Envision exercise. This question was more challenging as it was not a multiple choice question. Students were asked to identify one specific credit that could be acquired for Envision. Similar to question 11, only two students were able to correctly answer the question on the pre-module questionnaire. But, for the post-module the question was correctly answered by nine students. This was expected to be a question that is well addressed with the lesson. The most popular answer was “Use Recycled Materials”, which is Envision RA Credit 1.3 (listed by seven students). This particular credit was not stressed in the exercises more than others. It must be assumed that the
students fixated on this because of the heavy emphasis on recycling and use of recycled materials for sustainability of civil engineering projects as a best practice. Other credits highlighted more than once were to involve stakeholders (Envision LD Credit 1.4, mentioned by three students) and use renewable energy (Envision RA Credit 2.2, mentioned by two students). These were not parts of the student project in class, but similar to Use of Recycled Materials, they are common goals for broad sustainability of civil engineering projects – they are mainstream concepts. And all three were at least discussed in the class review of Envision and its application to the class project.

Further details for each question are included in the Appendix A as part of the instructor reflection on the question, answer, and response success.

Figure 1. Pre- and post-module questionnaire scores.

Overall, the module helped to improve the civil engineering sustainability literacy of the students, by 50% (6.2 correct on the pre to 9.2 correct on the post). But the post-module score remains at 55% correct, which suggests there is room for improvement in effectiveness of the module. The student responses indicated retention of definitions, but higher level learning outcomes related to comprehension that expected students to explain were not well achieved. For example, many students answered vaguely on pre-module questionnaire for question 4, a definition of sustainable development. Post-module, significantly more students were able to
correctly paraphrase the Brundtland definition. And the majority of students showed greater command of the definition using more precise and appropriate terms in post-module responses compared to pre-module responses. But it was a slight majority of students.

A reduction in score was noted for question 9, which asked for students to identify the objective of life-cycle assessment. The reason for this reduction is not known. The authors guess based on reflection that the introductory sustainability lesson reviewed concepts of green building that included coverage of building performance monitoring and adaptation. The concept of life-cycle of the building was stressed in this segment of the lesson. This may have led to students choosing to select (a) and (b) in the post-module questionnaire after having selected the correct answer in the pre-module questionnaire. The reduction in score highlighted the need to review the questionnaire and revise for future use, which is described in the conclusions section.

The effectiveness of the module, specifically the Envision component, was also assessed based on the quality and depth of the application of Envision to the class project. The Fall 2013 class project was the design of a water storage reservoir at an existing water treatment facility. Envision was appropriate to apply in this case because of the proximity of the project site to people, outdoor recreational sites, and a protected environmental corridor. All of these elements required students to consider if this was the right project and then how to do the project right (the foci of Envision). The student team completed a review and inserted comments for all Envision credits as they related to their project. In the end the team not only provided a hypothetical rating, and summary documentation to the client, but also recommendations on how to achieve higher levels of Envision rating for relatively small increase in resources from the client. Overall, the quality of the Envision application was noted by the instructors/authors to be a demonstration of an effective application of the tool.

An unexpected outcome of the student application of Envision in the Fall 2013 and Spring 2014 module delivery was the desire of students to acquire the Envision Sustainability Professional (ENV SP) credential. Although no students (to the authors’ knowledge) pursued the credential following the fall semester, several expressed interest. In the spring semester at least four students have expressed interest and are preparing to take the examination. The first author has acquired an ENV SP credential and has helped to encourage students to acquire the credential. The second author is working towards the credential and should have it this spring. This momentum towards credentialing is partly a result of the module development and application.

A summary review of our results suggests incorporating a learning module and assessment within a capstone design project can motivate students to engage in credentialing themselves with sustainable development rating systems and increases their fundamental understanding of sustainability concepts. It can ignite a sense to learn more or pursue a future oriented toward sustainable development. Our results point to an inability to instill an inherent grasp of the concepts and to establish confidence in their knowledge of the concepts (e.g. responses to question 9). This can be attributed to the limited time provided for presenting, discussing, and interacting with the concepts during the design project. Due to the lack of introductory courses prior to the capstone project on the subject matter, the students are forced to apply concepts before they are comfortable with the material or fully understand the purpose or need. It can be
expected that allowing for a holistic sustainability curriculum within the engineering program that introduces sustainability concepts early on and carries the concepts throughout their educational tenure will produce an increasingly grounded understanding and confidence in the subject. Thus, introducing sustainable development within the capstone project is a good beginning, but without a strong foundation in sustainability concepts with a comprehensive course its impact on deeper learning and competency is constrained.

Conclusion

This paper presented a sustainability module for civil engineering education that incorporated the use of the ISI Envision Rating System. The module integrates lessons on fundamental sustainability concepts and tools with lessons on Envision, and combines those lessons with the application of Envision to the students’ capstone design project. It was delivered in the Fall 2013 and Spring 2014 semesters in the capstone design course at the University of Utah.

The module was assessed using a new Civil Engineering Sustainability Literacy questionnaire created by the authors. The sustainability literacy assessment instrument was a combination of questions on general sustainability knowledge, civil engineering specific sustainability knowledge, and techniques including life-cycle assessment and the use of rating systems. Achievement of student learning was assessed by administering the questionnaire instrument before and after the module was delivered.

The student responses to the questionnaire indicate the Envision exercises and exploration helped students learn basic elements of Envision, as noted by the improvement from the pre- to post-module questionnaire questions specific to Envision. The general sustainability literacy of students was improved, but not significantly. This leads to an important conclusion of the effectiveness of the module. Applying a rating system, such as Envision, to a project is a useful exercise to help students learn about the rating system, but is not providing deeper learning of general sustainability knowledge. The assessment of this module is preliminary, and improvements are needed to module activities and to the assessment questionnaire. The instructor reflection leads to the recommendation that more active exercises similar to the application of Envision are needed to improve the effectiveness of the module for enhancing sustainability knowledge. This finding and conclusion follows from the well-known effectiveness of active learning and the use of project-based learning, both of which are elements of the Envision application of the module.

Overall, the poor performance on the pre-module questionnaire and the lack of substantial improvement in sustainability knowledge following the module was discouraging for the first author that has worked to implement sustainability elements across the entire civil engineering curriculum at the University of Utah. In fact, the finding from this questionnaire was contrary to previous assessment surveys used to assess the effectiveness of the sustainability elements in the curriculum. One explanation concluded by the authors is the need to review and improve the newly created Civil Engineering Sustainability Literacy Questionnaire. Specifically, review of the questionnaire identified question 10 as poorly stated, and with relatively limited coverage in the module. Also, questions 13-15 expected students to be synthesizing material without adequate exercises to support their learning. The questionnaire was revised and then circulated to
more than a dozen colleagues at the University of Utah and other institutions across the country for input and suggestions. The resulting questionnaire is attached as Appendix B. Further refinement of the questionnaire and the module will continue and readers are encouraged to contact the first author for copies of the most current materials.

One final conclusion from the assessment and reflection of the authors is the limited ability to use modules to accomplish deeper learning of sustainability concepts. The first author has attempted this with modules introduced at different parts of the curriculum, and past surveys of students indicated it was having a modest positive impact. But the questionnaire administered for this paper identified the lack of knowledge of senior level students after being exposed to sustainability modules in previous coursework, suggesting that deeper learning was not taking place in the previous modules. The authors conclude to achieve a strong grasp of sustainability concepts and knowledge a dedicated sustainability engineering course is needed in the curriculum following by repeated applications and extension of knowledge and skills.

References


Appendix A. Civil Engineering Sustainability Literacy Questionnaire
(used to assess Fall 2013 course offering)

Name: ____________________________________

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

   Answer: B

   Explanation/Reflection: The question assesses student comprehension of a life-cycle
   assessment (LCA) application. LCA is presented in class with an example. Specific tools
   are introduced, but training or exercises are not part of the module.

2. Define sustainability using one sentence.

   Answer: Capacity to endure (Wikipedia), ability to sustain (dictionary)

   Explanation/Reflection: Sustainability is defined in the introductory lesson and students
   are engaged in a discussion about basic needs versus quality of life.

3. Which of the following sustainability rating systems are applicable to civil engineering?
   (Circle all correct answers)
   a. ESRB
   b. LEED
   c. Envision
   d. SUSTAIN

   Answer: B & C

   Explanation: Both LEED and Envision are described in the introductory lesson, with
   much greater attention (to application level) given to Envision.

4. Define sustainable development using one sentence.

   Answer: Meeting the needs of the present without impacting the ability for future
   generations to meet their needs

   Explanation/Reflection: The lesson introduces the class to the Brundtland definition
   above, plus definitions from ASCE and other organizations. Students are engaged in a
   web quest activity during the lesson to explore definitions and report back to the class.
5. Are natural hazards a factor for consideration in sustainability of civil infrastructure projects? Explain why or why not?

Answer: Yes, with many possible explanations. Seeking descriptions that relate to risk, long-lasting, durable, resilient to external factors, and so on – ideas discussed during the lesson.

Explanation/Reflection: Students did poorly on this question, and it is attributed to lack of reinforcement in the Envision exercises and application to the particular project for this class. Envision does contain a Risk element, but it was not carefully considered. This is an area for improvement in the future. Some students made appropriate (and high level) observations that designing to mitigate hazards may be life-cycle best approach instead of designing to not withstand, saving money, and then having to rebuild.

6. What is Envision from the Institute for Sustainable Infrastructure?
   a. long-term view of what the civil engineer will be in 2025
   b. document that highlights the key aspects of sustainable infrastructure
   c. training course to educate engineers about sustainability
   d. a sustainability rating system for infrastructure

Answer: D

Explanation/Reflection: The module made students aware of Envision such that they could describe what it is. Interestingly (in a positive way), a fair number of students knew about Envision before the module, but they could not describe its element and likely did not know how to apply.

7. The term “Triple-Bottom Line” refers to:
   a. The balance of cash-flow, investments, and accounts payable
   b. The three pillars of people, planet and profit
   c. Investments that have a payback period less than 5 years
   d. Extra emphasis on safety for civil engineering projects involving the public

Answer: B

Explanation/Reflection: This was the most correctly answered question before the module. Students know this concept fairly well, and have it reinforced in the context of civil engineering projects and multi-criteria decision making (MCDM) during the module. The expectation for greater learning related to MCDM will be expected in the future and incorporated into the assessment.
8. How is durability important for making a civil engineering project more sustainable? Explain with specific examples

Answer: Yes, long-lasting leads to less material need, less environmental impact, etc. over time. This assumes durability is not at the expense of life cycle cost, environmental, or community impact.

Explanation/Reflection: Few students connected durability to possible reduced material need over the long term. This was not well articulated by the instructors and is noted as an important point to make in the future, with an example.

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

Answer: C

Explanation/Reflection: Students were introduced to an example applying LCA.

10. Give an example of environmental justice consideration in a civil engineering project.

Answer: seeking identification of a social impact – a party being inequitably affected by a project.

Explanation/reflection: Student responses indicated that the module did not adequately cover Environmental Justice. No student correctly stated an example or any example that indicated a social impact related to equity. This actually was something that was anticipated would be part of the Envision experience, but the approach we used to apply Envision did not highlight environmental justice and social equity issues. This was identified as an area to include explicitly in the introductory lessons to the module and then reinforced during the Envision application.

11. What are the five categories of Envision?
   a. Natural World, Climate & Risk, Resource Allocation, Leadership, Quality of Life
   b. Community, Economy, Environment, Durability, Reusability
   c. Sustainable Sites, Indoor Environmental Quality, Water Efficiency, Energy and Atmosphere, Materials and Resources
   d. People, Planet, Profit, Performance, Preservation

Answer: A

Explanation/Reflection: This question assessed student recall of the details of Envision. The student responses showed a significant improvement from pre-module to post-module applications of the questionnaire.
12. Briefly relate the concept of Cradle to Crave™ in terms of your class civil engineering design project.

Answer: Students should highlight inception of project to decommissioning or demolition or reuse. Students should also highlight materials and use and implications for environmental impacts across the life cycle of the materials (extraction to disposal).

Explanation/Reflection: Module (foundation lesson that described C2C) helped students to answer this question. Generally, those that answered the question incorrectly on the pre-module questionnaire performed better or answered entirely correctly on the post-module questionnaire.

13. In what way do risk-based design criteria relate to sustainability of a civil engineering project?

Answer: seeking recognition of importance of lowering risk of failure of project and protecting safety of people.

Explanation/Reflection: Module does not effectively address this concept and Envision does not highlight safety and long-lasting (minimizing failure) project sufficiently (and we did not highlight it sufficiently in the exercises with / application of Envision). No students adequately made connection to safety or reduced risk of failure of project.

14. Use an example to describe the concept of systems thinking and relate it to a civil engineering project.

Answer: seeking recognition of importance of linking project at hand with larger system to improve design, limit risk of failure, enhance community, reduce cost, etc.

Explanation/Reflection: Module includes a 6-minute video on systems thinking, but it focuses on mechanical clothes dryers. The responses of the students suggest they are not adequately able to take the concept and apply it to their project (or any civil engineering project). Some students did display the ability to at least note an example on the post module quiz, but most could not adequately relate. Decided we need to add exercise to module that helps students make this connection.

15. Explain importance of climate change and variability for sustainability of civil engineering projects?

Answer: seeking recognition of concept of climate change impacts – changes to temperature, precipitation, and other climate variables that affect civil engineering projects. Importance for project is to design to be able to handle changes in climate conditions or other factors that may change in response to climate variation (i.e., resource availability).
Explanation/Reflection: The module introductory lesson does not include coverage of climate change or adaptation. Climate is a major part of Envision (one of the five credit categories); thus it was anticipated that this topic would be adequately covered in the Envision application to the project. But, the student responses indicate this to be an area for improvement in the future. It was concluded that in the future the module lessons will need to mention climate change concepts and adaptation and then reinforce during the Envision application.

16. Give one example of a specific action/aspect of project that could earn Envision credits.

   Answer: many answers possible

   Explanation/Reflection: Envision exercise that lasts for several weeks has students exploring Envision, considering particular credits, and identifying how to achieve for their project.

17. List three specific actions civil engineers can take to reduce greenhouse gas emissions (Note: there are many possible actions).

   Answer: Many answers possible --- but several main themes (materials, construction, operation, decommission, personal lives) --- specify materials with lower GHG life cycle emissions, design to reduce long-term emissions during operation of a project (1, do not use pumps if possible), seek to reduce GHG emissions in personal lives, planting trees as solution

   Explanation/Reflection: Approximately half of the students got this question correct in pre- and post-module questionnaires. It was encouraging to see most students had responses (more than ¼ did not have a response in the pre-module questionnaire) or improved their response in the post-module questionnaire. The module was not designed to include information explicitly describing ways to reduce GHG emissions. It is of course part of Envision and part of sustainability discussions. Personal actions were not mentioned in the module, but it was positive to see several students respond with this action. Another positive observation of student responses was several students identifying Envision Credits (not explicitly by number, but by name) and stating how it could reduce GHG – for example using locally sourced materials. This suggested a way to in the future improve the lesson by tying this learning outcome to Envision.
Appendix B. Civil Engineering Sustainability Literacy Questionnaire
(current draft, after revisions)

Name: ____________________________________

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

Answer: B

2. Define sustainability using one sentence.

   Answer: Capacity to endure (Wikipedia), ability to sustain (dictionary)

3. Identify the rating system used to rate the sustainability of building design projects (circle all correct answers)
   a. ESRB
   b. LEED
   c. Envision
   d. SUSTAIN

Answer: B

4. Identify the rating system used to rate the sustainability of non-building infrastructure design projects (circle all correct answers)
   a. ESRB
   b. LEED
   c. Envision
   d. SUSTAIN

Answer: C

5. In which phase of a civil engineering project should sustainability be addressed?
   a. pre-planning
   b. design
   c. construction
   d. all of the above
   e. none of the above

Answer: D
6. Define sustainable development using one sentence.

   Answer: Meeting the needs of the present without impacting the ability for future generations to meet their needs

7. In one sentence, describe why natural hazards are a sustainability consideration of civil engineering projects?

   Answer: Looking for descriptions that mention reducing risk, long-lasting, durable, resilient to external factors, etc.

8. Is climate change important for sustainability of civil engineering projects? If yes, describe in one sentence why climate change is a sustainability consideration of civil engineering projects?

   Answer: Yes. Looking for descriptions that mention reducing risk, resilient to external factors, adaptable, etc.

9. The term “Triple-Bottom Line” refers to:
   a. the balance of cash-flow, investments, and accounts payable
   b. the three pillars of people, planet and profit
   c. investments that have a payback period less than 5 years
   d. extra emphasis on safety for civil engineering projects involving the public

   Answer: B

10. What are the sustainability tradeoffs associated with increasing the durability of a civil engineering project? (circle all that apply)
    a. it may increase cost
    b. it may make a project less safe
    c. it may cause more environmental impacts
    d. all of the above

    Answer: A & C – increasing durability may be linked to cost and life-cycle environmental impacts

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

    Answer: C
12. Give an example of environmental justice consideration in a civil engineering project.

Answer: seeking identification of a social impact – a party being inequitably affected by a project.

13. What are the five categories of Envision?
   a. Natural World, Climate & Risk, Resource Allocation, Leadership, Quality of Life
   b. Community, Economy, Environment, Durability, Reusability
   c. Sustainable Sites, Indoor Environmental Quality, Water Efficiency, Energy and Atmosphere, Materials and Resources
   d. People, Planet, Profit, Performance, Preservation

Answer: A

14. Give one example of a specific part of a civil engineering project that could earn Envision credits.

Answer: many answers possible

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

Answer: B.

16. Which of the following are principles of systems thinking?
   a. it views the measured outcome within the larger, more complex system
   b. it addresses problems in a way that does not create new problems in the future
   c. it considers the impact of actions beyond environmental, economic and social to also include time and space
   d. it can be thought of as the three dimensional ripple effect of your actions where nearly everything is somehow interrelated and interconnected
   e. all of the above

Answer: E. All of the above

17. Considering systems thinking in the context of a roadway design project, what other interconnected systems should also be considered in the design? Give two specific examples.

Note: “roadway project” is changed in the question to best fit the class project.
Answer: seeking recognition of economic, environment, social, and also the importance of linking project at hand with other systems to improve design, limit risk of failure, enhance community, reduce cost, etc. (water project is connected to natural systems, wastewater, etc.)

18. Give one example each of how you would apply the economic, social, and environmental dimensions of sustainability to the design of a roadway project.

Note: “roadway project” is changed in the question to best fit the class project.

Answer: seeking recognition of connection among economic, social, and environmental dimensions in CE projects - many answers possible