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# A New Framework for Teaching the Triple Bottom Line: The Sustainability Triangle and the Sustainability Index

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## Introduction

Civil engineers are integral to, and ethically bound to, advancing sustainable development (ASCE, 2004). In response to community and industry needs, as well as ABET accreditation requirements, sustainability has been increasingly integrated into civil and environmental engineering curricula (Allen et al., 2008). The American Society of Civil Engineers (ASCE) has recently dedicated two special issues of the *Journal of Professional Issues of Engineering Education and Practice* to sustainability (ASCE, 2011 & 2015). Within these issues are reports of case studies, course modules and entire courses dedicated to sustainability, as well as efforts to integrate sustainability throughout curricula. Cruickshank and Fenner (2012) and Bielefeldt (2013) summarize several pedagogical approaches to teaching sustainability concepts. The following paper presents a single-lesson approach to introduce the concepts of sustainability and sustainable design, at the local infrastructure project scale, to civil and environmental engineering students. The foundation for the lesson was initially developed at the 2nd Infrastructure Education Workshop, sponsored by the Center for Infrastructure Transformation and Education (CIT-E), by five faculty members from four universities for use in a first- or second-year Introduction to Infrastructure course.

## Sustainability and the Triple Bottom Line

The concept of sustainability is often graphically displayed as a venn diagram of natural, economic and social systems (Barbier, 1987; ICLEI, 1996; Mebratu, 1998). These three systems are sometimes referred to as "the three Ps" (3Ps; people, planet and profit) or "the three Es" (equity, environment and economics). This diagram (Figure 1) has become a common symbol for sustainability and it can be found in corporate sustainability reports as well as news and opinion articles. It is also a common starting point for teaching sustainability to civil and environmental engineers (Oswald Beiler and Evans, 2015).

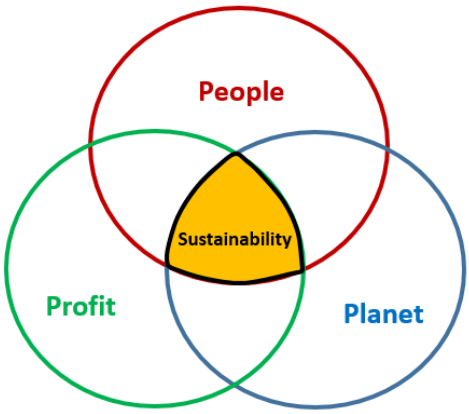


*Figure 1. Sustainability venn diagram*

This diagram serves to demonstrate that the concept that sustainability is achieved by balancing the 3Ps. The term "triple bottom line" is often associated with this effort to balance the 3Ps (Elkington, 1997). The implication is that any point within the outer boundaries of the venn diagram represents an outcome—either sustainable (within the central portion) or not. However, there is no basis for evaluating an engineering project design to determine a point which represents it within the diagram.

**The Sustainability Triangle and Sustainability Index**

The authors and collaborators sought to develop a semi-quantitative methodology to rate a design for each of the 3Ps, to graphically represent the relative balance of the 3Ps, and to evaluate the design on a relative scale of sustainability. A radar chart with three axes, representing people (P1), planet (P2) and price (P3) was the chosen approach. "Price" was chosen as an alternative term to "profit", because the majority of public works are non-revenue generating ventures. For a given project design, each of the 3Ps is given a value from 0 to 100 (Figure 2). The resulting diagram forms a triangle representing the relative values of each P. Ideal sustainability would result in a "full" triangle with values of 100 for all axes.

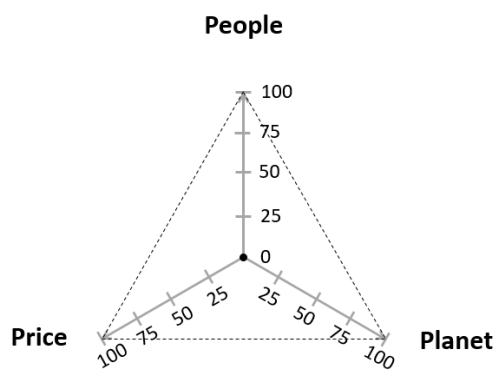


*Figure 2. The Sustainability Triangle*

A benefit of this graphical approach is that any imbalance among the 3Ps is readily apparent. An equilateral triangle (e.g. all Ps equaling 70) is truly balanced, but not ideally sustainable.

Summing the scores of the 3Ps would potentially lead to a sustainability score, with 300 being ideal. However, this does not take into account the imbalance among Ps. For example, if design alternative #1 was determined to have disregard for social impacts, but excellent scores for price and planet, the 3P sum would be 30 + 90 + 90 = 210. In contrast, design alternative #2 may score higher for social aspects, but lower for both price and planet--for example 70 for each resulting in an identical sum of 210. With a goal of the triple bottom line to strive for balance of the 3Ps, it is clear that alternative #2 is balanced while alternative #1 is not, as shown in the Sustainability Triangles of Figure 3.

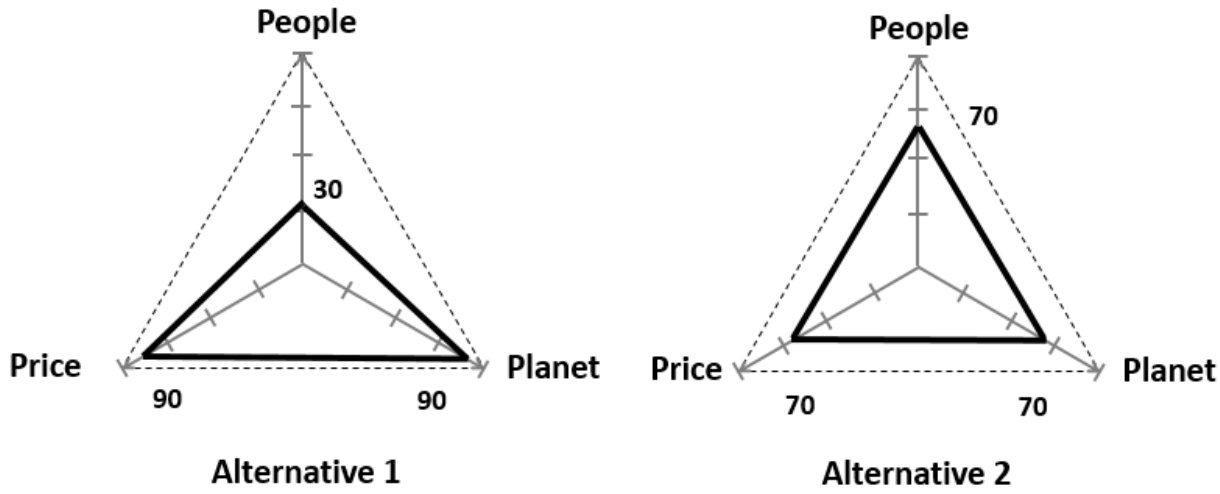


*Figure 3. Sustainability Triangles for two alternatives with three P sums of 210.*

After full development of this approach, the authors became aware of a similar methodology previously developed to assess the sustainability of event (e.g. festival) tourism (Fredline et al. 2005) in which the area enclosed within the three P triangle, termed a Synthesis Diagram, was calculated as a percentage of the theoretical maximum area (P1=P2=P3=100). The higher the percentage, the higher the performance rating. No evidence was found of transfer of the approach for application outside of the tourism industry.

As an alternative approach, to account for the relative imbalance among P scores, the authors and collaborators developed a Sustainability Index (SI):

SI = [sum of 3Ps – (maximum of 3Ps – minimum of 3Ps)], or

$$\text{SI} = [\sum_{i=1}^{3} Pi - ((max\ (\text{P1}\ldots\text{P3}) - min\ (\text{P1}\ldots\text{P3}))]$$

Table 1 summarizes SI calculations for the two alternatives shown in Figure 3. The SI can then be evaluated on a proposed sustainability scale shown in Table 2, or graphically in Figure 4.

*Table 1. Three P scores and Sustainability Indices of two alternatives.*

| | People | Planet | Price | Sum | Max P | Min P | Difference | **SI** |
|---|---|---|---|---|---|---|---|---|
| Alt #1 | 30 | 90 | 90 | 210 | 90 | 30 | 60 | **150** |
| Alt #2 | 70 | 70 | 70 | 210 | 70 | 70 | 0 | **210** |

*Table 2. Scale of sustainability*

| SI scale | 0 | 100 | 200 | 300 |
|---|---|---|---|---|
| Rating | Completely unsustainable | Moderately unsustainable | Moderately sustainable | Fully sustainable |

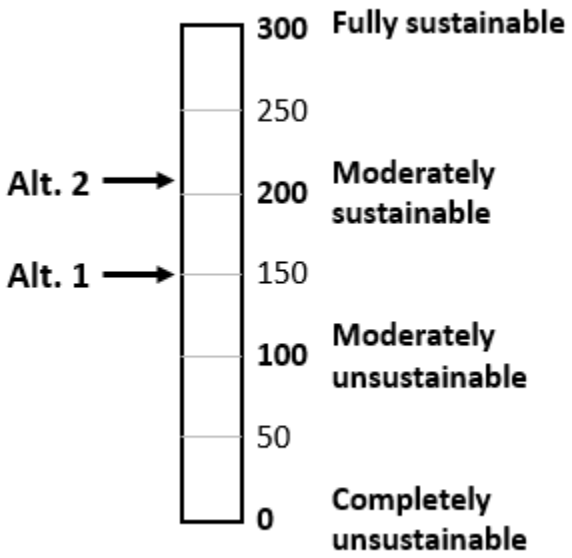


*Figure 4. The Sustainability Index of two alternatives on the scale of sustainability.*

The advantage of this approach is that a larger imbalance among the 3Ps results in a greater deduction from the sum of the 3Ps, thus embracing the spirit of sustainability and the triple bottom line. As demonstrated above, two alternatives with identical 3P sums may have substantially different SI values.

A limitation to this approach is the lack of a unified method for determining individual P values from 0 to 100. Slaper and Hall (2011) acknowledge the challenges faced by businesses when performing triple bottom line analyses. However, it is possible to normalize to a 0 to 100 scale, values for each P from established methodologies such as the rating systems of Leadership in Energy and Environmental Design (LEED, U.S. Green Building Council) or ENVISION (Institute for Sustainable Infrastructure). The use of such systems would require substantial student training and is beyond the scope of typical introductory courses. Even without an accepted rating system for each P, this methodology serves as a useful *screening tool* for comparing design alternatives, and an effective approach to introducing the concepts of sustainability and the triple bottom line to students as is described below.

## The Triple Bottom Line Lesson

Once the methodology was fully developed, the Sustainability Triangle and Index were integrated into a single lesson to introduce civil and environmental engineering (CEE) students at the University of Wisconsin-Platteville to the concepts of sustainability and the triple bottom line as a means of evaluating engineering design alternatives. By providing a framework for evaluating alternatives, students learn that sustainability is integral to the design process. The

lesson is scheduled within the first two weeks of a three credit Introduction to Infrastructure course which:

- introduces civil infrastructure; social, political, historical, sustainability, and planning implications of infrastructure
- introduces each of the subdiscipline areas of civil and environmental engineering (transportation, environmental, construction, structural, and geotechnical), and
- develops professional skills (e.g. report writing, oral communication, teamwork).

This course is required of all CEE majors and is one of the first courses taken once students matriculate into CEE programs from General Engineering, typically in their second year. The course is one of three fundamentals courses (along with Surveying and Computer Applications) that students take before advancing to first courses in each of the CEE subdisciplines. Five sections, with approximate enrollments of 30 students each, are offered each academic year in a three lecture hour per week format.

The authors developed a "screencast" (voice-over PowerPoint presentation) which defines sustainability and the triple bottom line, and explains the Sustainability Triangle and the Sustainability Index as described above. The screencast also provides an infrastructure context for triple bottom line considerations by reviewing several large-scale infrastructure projects from various sectors (e.g. transportation, wastewater treatment). Students are instructed to watch the screencast prior to the in-class activity and are assigned pre-lesson homework.

The in-classroom (50 minutes) portion of the Triple Bottom Line lesson includes a brief review of the pre-lesson screencast, a discussion of their pre-lesson homework within small groups and collectively as a class, and focuses on the following lesson objectives:

- Ability to identify criteria that help determine the sustainability of project alternatives.
- Use the Sustainability Triangle and Sustainability Index to evaluate project alternatives.
- Explain the complexity of assessing the sustainability of project alternatives.

Finally, a post-lesson homework is assigned to students.

At the beginning of the class period, a brief, two-minute review of pre-lesson screencast restates the lesson objectives and summarizes the concept of the triple bottom line. The instructor poses two questions to the class: "What is sustainability?" and "What are the three Ps?". Students volunteer answers and the instructor coaches correct responses by asking questions of the class. The sustainability venn diagram is then reviewed.

Next, the instructor assembles students together in groups of 3-4 to discuss their pre-class homework—identifying potential positive and negative impacts of general infrastructure with respect to People, Planet and Price (see Table 3). Each group summarizes and compiles a new 3P impact table. Next, the instructor rotates between groups to prepare a "master" table of 3P impacts for the class. The idea is not to make an exhaustive list, but to help students identify that there are many potential positive and negative impacts within each of the 3Ps, and that these impacts will support a rating of any project with respect to each of the 3Ps. The social,

environmental and economic impacts of infrastructure are each covered in more detail later in the semester. Global aspects of sustainability are addressed in other courses in the curriculum. It is important to keep track of time during this exercise, as it could become a lengthy discussion and take up a significant portion of the class period. Five minutes is recommended for this exercise.

*Table 3. Pre-Lesson Homework table to be completed by students, with sample responses included.*

| | **People**<br><br>**(Equity)** | **Planet**<br><br>**(Environment)** | **Price**<br><br>**(Economics)** |
|---|---|---|---|
| **Positive impacts** | *Increased accessibility*<br><br>*Increased safety* | *Treatment (removal) of contaminants*<br><br>*Provides wildlife habitat* | *Economic growth*<br><br>*Construction employment* |
| **Negative impacts** | *Aesthetically unpleasant*<br><br>*Displacement of homes/businesses* | *Increased runoff and flooding*<br><br>*Loss of wildlife habitat* | *Increased user fees*<br><br>*High capital cost* |

Once potential positive and negative impacts are identified with respect to the 3Ps (the first lesson objective), the next step is to apply those impacts to a specific example. Campus parking was chosen because it is a very common problem on university campuses with which most students and faculty have familiarity. Student groups are asked, “Which of the listed impacts are most likely to be important when considering campus parking solution alternatives?” Each student group is asked to review the “master list” and identify impacts that they believe are relevant to the campus parking example. The instructor then solicits relevant impacts from each group, highlighting these on the master list and finally asks “Are there other impacts that could be expected from parking solution alternatives that aren’t on the list?” Again, the instructor must keep track of time and not spend more than a few minutes on this exercise.

The second lesson objective is addressed by a PowerPoint presentation that is used to guide students through four alternatives to alleviate the campus parking shortage: a new gravel or paved surface lot, a new parking deck, a new underground parking facility, and improving on-street parking adjacent to campus. Approximate costs per parking stall for each option are provided. Next, for each alternative a representative picture of the alternative is provided and a location is identified on an aerial photo of campus. Positive and negative impacts for each of the 3Ps are identified, a score is given for each of the 3Ps, a Sustainability Triangle is drawn, and the Sustainability Index is calculated. During the discussion of the examples, emphasis is given to the *relative* scores of the 3Ps. The goal is not to provide students with a means for determining definitive scores, but rather to understand that any reasonable approach to developing relative scores will assist in evaluating design options. By intentional design, each alternative has strengths and weaknesses with regard to the 3Ps. A comparison of the Sustainability Indices for all four parking solution alternatives results in similar values—thus there is no clear “best” solution.

It is key to point out to students that the Sustainability Triangle and Index are best used as a basic screening level tool to compare alternatives. If no clear, best alternative exists, one might have to re-evaluate the 0-100 values for each P, or even develop additional alternatives for evaluation. To help demonstrate these challenges (the third lesson objective), two more detailed alternatives are provided to students: Alternative A is a paved surface lot adjacent to campus on purchased private land after the removal of residential homes, and Alternative B is a paved surface lot on campus (directly across the street from Alternative A) which displaces an athletic soccer practice field and recreation area. Students are individually asked to "Take a few minutes to consider if/why these new alternatives are *more balanced with respect to the 3Ps* than the extreme examples shown previously. Write down your thoughts and give them to the instructor." Collecting and reviewing this work after class gives the instructor an immediate idea of how well the students learned to evaluate alternatives using the methodology described. However, this puts the students "on the spot", without time to reflect.

A "game changer" scenario is then presented to add complexity to solving the campus parking problem. This focuses not on adding infrastructure to accommodate more parking, but rather on how to manage the demand for parking:

- "What if the campus goal is to reduce the number of cars coming to campus (parking "demand") rather than adding more stalls (parking "supply")?"
- "How could this be accomplished?"
- "How does this change perspective?"

Undergraduate students without prior exposure to this concept typically do not consider such an approach to parking problems. Their typical approach is to construct more capacity. It is important to ask these questions, because in actuality, modifying behavior may likely lead to more sustainable solutions. The addition of this segment to the lesson foreshadows infrastructure planning discussions later in the semester.

Finally, students are asked to consider the positive and negative impacts of two large-scale projects highlighted in the pre-class screencast: Central Delaware Waterfront Development in Philadelphia, PA and Newtown Creek Wastewater Treatment Facility in Brooklyn, NY. Students are asked to reflect upon the "master list" of 3P impacts. For the campus parking examples covered in class (small-scale projects) only a few impacts are likely to be significant. It becomes readily apparent that many more will apply to these larger projects, making sustainability evaluations more challenging which further addresses the third lesson objective.

When concluding the in-class lesson, it is important to re-state for students that quantifying the 3Ps is difficult, especially considering multiple perspectives. As is commonly done with alternatives analysis for large-scale infrastructure projects, meetings with stakeholders can be conducted to gather input. Sustainability Index scores are not absolute – there is inherent uncertainty in the scores. It is hard to say that an alternative with an index score of 160 is really better than one with a score of 150. However, it should be easier to say that an alternative with an index of 200 is better than one with 150, and with near certainty that score of 250 is better than 150. Identifying the 3P scores, and using the Sustainability Triangle and Index is a

framework that can be useful when evaluating alternatives from the perspectives of their positive and negative impacts for people, planet, and price.

At the conclusion of the in-class lesson a homework assignment is given to help instructors assess student understanding of the concept of the triple bottom line and how to evaluate project alternatives from a 3P perspective. The in-class presentation of alternatives is made available as a PowerPoint presentation to students to review after class. The assignment is:

> With more time to reflect, and the previous slides to review, for both Alternatives A (paved surface lot next to campus, residential lots purchased, houses relocated) and B (paved surface lot on campus displacing soccer practice field/recreation area):
> 1. Identify the positive and negative impacts on each of the 3Ps
> 2. Make reasonable estimates of the 0-100 score for each P
> 3. Draw a sustainability triangle
> 4. Document which alternative is more sustainable, and why.

Note that this assignment does not specifically ask students to calculate the Sustainability Index. This is intentional. If they understand the tool and its purpose, they will calculate a Sustainability Index. If they do not fully understand it, they may simply draw a triangle and generate a generalized opinion of which alternative is best.

**Assessment Results**

Students are given five days to complete the homework assignment. Assignments are scored using the following 3-point rubric:

> +1 thorough explanations for identifying the positive and negative impacts of each of the 3Ps
>
> +1 making reasonable estimates of the 0-100 scores for each P and creating Sustainability Triangles for each alternative
>
> +0.5 for calculating both Sustainability Indices
>
> +0.5 for comparing alternatives A and B by using the Sustainability Indices

Student performance with regard to understanding and utilizing the Sustainability Triangle and Sustainability Index was assessed in the Fall 2016 semester.

The results for the homework assignment assessment are presented in Table 4.

*Table 4. Results from submitted TBL post-lesson homework*

| Score | Results (n=84) |
|---|---|
| 3 | 29 (34%) |
| 2.5 ≤ 2 | 51 (61%) |
| 1.5 ≤ 1 | 4 (5%) |

The instructors were surprised that only 34% of students used the method completely in that they identified the positive and negative impacts of each P, created the Sustainability Triangles for both alternatives, calculated both Sustainability Indices, and used the results of the indices to compare alternatives A and B. Approximately two-thirds (66%) of students did not compare the alternatives using the Sustainability Index, and limited their evaluations to Sustainability Triangles and generalized discussions of 3P values and relative imbalances. While the majority of these evaluations were correct, they were incomplete. These results seem to demonstrate that many students are "reactive" in their approach to doing homework (i.e. responsive only to clear prompting). However, these results also suggest that the presentation of material leads students to focus on the Sustainability Triangle more than the Sustainability Index. Students are successful in reasonably rating the 3Ps for the alternatives, using the in-class examples for reference.

The following questions were posed on the final examination:

**Q1**: Calculate the sustainability index, and recommend the best option given the following options for an infrastructure project:

| | Option 1 | Option 2 |
|---|---|---|
| Project life cycle cost score | 90 | 85 |
| Environmental impact score | 80 | 76 |
| Social impact score | 73 | 83 |

**Q2**: Given the following analysis of four potential locations of a new power generating facility, which is the most sustainable design? Show work and explain.

| | Land cost | Displacement | Construction cost | Impact on lake | Paving of greenspace | Annoyance to neighbors |
|---|---|---|---|---|---|---|
| Location 1 | 5 | 1 | 4 | 4 | 5 | 2 |
| Location 2 | 5 | 2 | 4 | 3 | 5 | 1 |
| Location 3 | 2 | 3 | 3 | 3 | 2 | 5 |
| Location 4 | 1 | 4 | 1 | 5 | 1 | 3 |

For each criterion, locations were given a score from 1 (worst) to 5 (best).

Student performance is summarized in Figures 5 and 6.

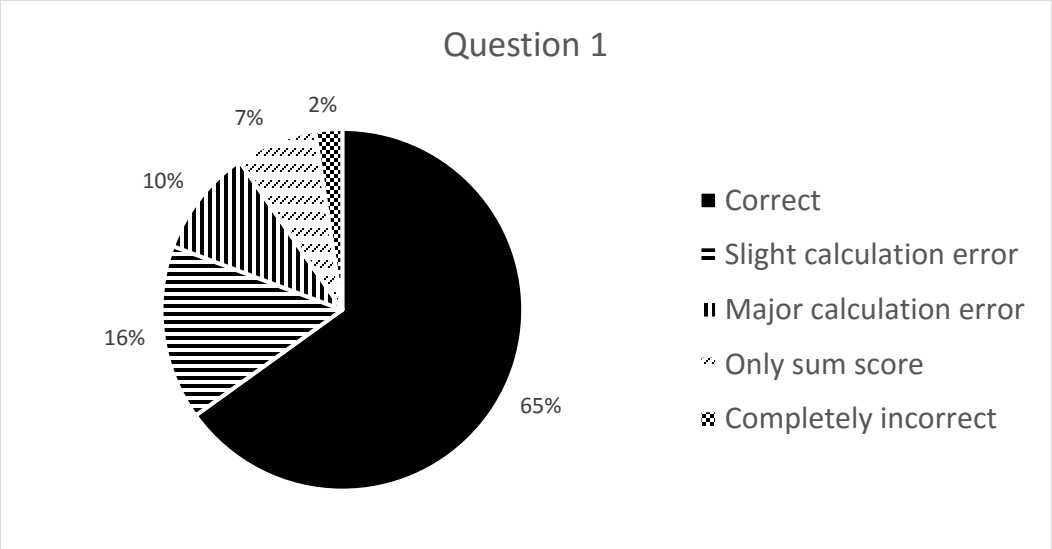


*Figure 5. Percentage of student responses to Question 1.*

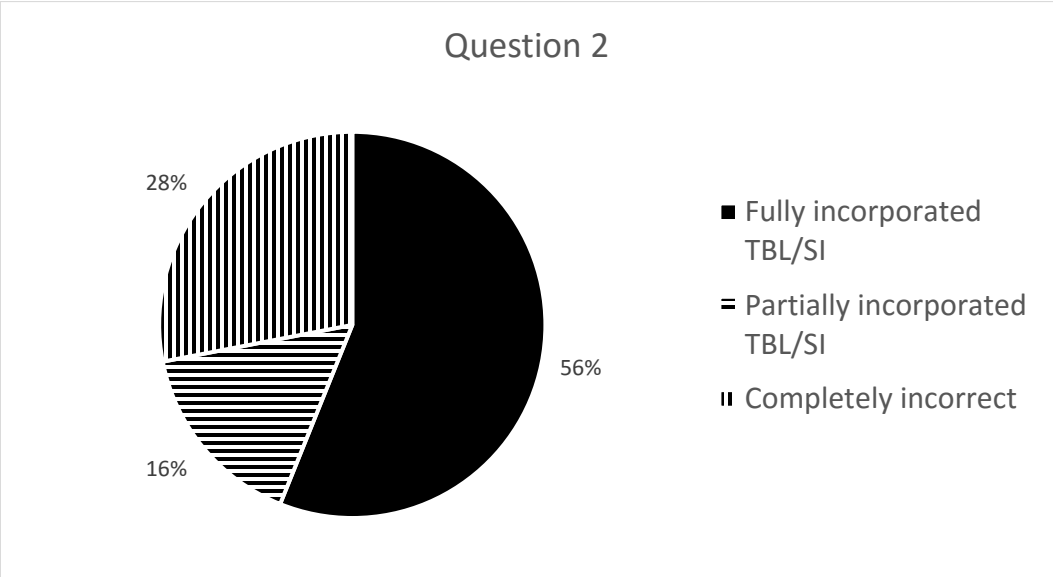


*Figure 6. Percentage of student responses to Question 2.*

In general, student performance on Question 1 was quite good. Common calculation errors included subtracting the difference of the P scores from 100 rather than the difference between the maximum and minimum, subtracting the minimum score from the sum rather than the difference between the maximum and minimum, and dividing the sum by the imbalance rather than subtracting it. Note that no equations were provided for the students, nor note cards allowed for this exam. Providing the equations would undoubtedly improve performance, but the authors purposefully did not supply equations in order to assess students' true understanding of the methodology.

Question 2 was purposely separated from Question 1 in the exam, with several other questions not related to the triple bottom line. This question was also specifically designed to assess the students' ability to synthesize information. This was not an explicit learning outcome of the Triple Bottom Line lesson. As such, the question provides instructors with an indirect measure of the ability of students to perform beyond basic expectations. In the course, students are also introduced to *alternatives analysis* through a matrix such as that provided in Question 2. By intentional design, there are six criteria—two representing each of the 3Ps (People: displacement, annoyance; Planet: lake impact, paving greenspace; Price: land cost, construction cost). Since each criterion had equal maximum weighting (5 points each), there were 10 possible points for each P. Summing the two criteria scores in each category and multiplying by 10 gives a score out of 100 (Table 5) suitable for utilizing in the Sustainability Index (Table 6). More than half (56%) of students fully incorporated the Sustainability Index in their solutions. A smaller percentage (16%) integrated the triple bottom line concept (i.e. the imbalance among the criteria) but failed to calculate the Sustainability Index. Approximately one-quarter (28%) of students did not fully, or partially, integrate the triple bottom line concept or the sustainability index. In a few cases, this was due to students' complete misunderstanding of sustainability (e.g. confusing sustainability and *durability*) and the triple bottom line. More common however, was that students did not "see the forest through the trees"—without prompting, they did not recognize that the criteria were representative of the 3Ps. They simply summed the scores of all criteria and assumed that the highest score was the best (and thus most sustainable).

*Table 5. Grouping of criteria from Question 2 into the 3P categories.*

| | People (P1) | | | Planet (P2) | | | Price (P3) | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | Displacement | Annoyance to neighbors | **P1 sum x 10** | Impact on lake | Paving of greenspace | **P2 sum x 10** | Land cost | Construction cost | **P3 sum x 10** |
| 1 | 1 | 2 | **30** | 4 | 5 | **90** | 5 | 4 | **90** |
| 2 | 2 | 1 | **30** | 3 | 5 | **80** | 5 | 4 | **90** |
| 3 | 3 | 5 | **80** | 3 | 2 | **50** | 2 | 3 | **50** |
| 4 | 4 | 3 | **70** | 5 | 1 | **60** | 1 | 1 | **20** |

*Table 6. Determination of Sustainability Indices for Question 2.*

| Location | People | Planet | Price | Sum | Max P | Min P | Difference | **SI** |
|---|---|---|---|---|---|---|---|---|
| 1 | 30 | 90 | 90 | 210 | 90 | 30 | 60 | **150** |
| 2 | 30 | 80 | 90 | 200 | 90 | 30 | 60 | **140** |
| 3 | 80 | 50 | 50 | 180 | 80 | 50 | 30 | **150** |
| 4 | 70 | 60 | 20 | 150 | 70 | 20 | 50 | **100** |

Given the indirect nature of this question, the authors believe that it was quite challenging for second-year students. As such, their performance overall is considered to be good and serves as

reinforcement that the Triple Bottom Line/Sustainability Index lesson is an effective tool for introducing civil and environmental engineering students to these important concepts.

**Availability of Lesson Materials**

The entire Triple Bottom Line lesson, including:

- Lesson outline
- Pre-class screencast
- In-class presentation
- Homework assignment and answer key

is available for download and use from the Center for Infrastructure Transformation and Education at www.cit-e.org under the "Course Materials" tab. This lesson is a component of the Fundamentals module of the Model Introductory Infrastructure Course that is under development. All lessons are peer reviewed.

**Conclusion**

The Sustainability Triangle and Index are effective tools for introducing first- or second-year students to sustainable engineering design. The Triple Bottom Line lesson described above provides students a framework to perform *preliminary* evaluation of engineering design alternatives through consideration of basic social, environmental and economic impacts. This approach goes beyond identifying the impacts of a single design and emphasizes to students that sustainability is integral to client and community acceptance. Five CEE faculty members representing the structural, environmental and transportation subdisciplines have utilized this lesson in the second-year Introduction to Infrastructure course. While direct assessment has not been conducted, indirect assessments suggest that the lesson prepares students well for more detailed evaluations in upper-level courses. For example, with this basic framework as a foundation, it is easier to address sustainable engineering design with respect to:

- the materials used for construction of a bridge,
- the location of a roadway to by-pass a community, or
- the selection of a secondary source water supply to meet increasing demand.

In order to use the Sustainability Triangle and Index beyond preliminary evaluation, methods for quantifying impacts of designs on each of the 3Ps must be adapted from other sources (e.g. LEED) or developed.

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