Redesign of a Sustainability Experiential Learning Module for Transferability and Portability

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Abstract

In order to teach to the engineering challenges of our global society we have adopted a modular approach to introduce sustainable engineering concepts to traditional civil engineering curricula. This paper highlights lessons learned from the creation, packaging, and distribution of a module that teaches Restore and Improve Urban Infrastructure, one of the fourteen Grand Challenges of Engineering issued by the National Academy of Engineering (NAE). The Sustainable Metrics (SusMet) module is a hands-on activity that engages students in disassembly of a green product and critically reviews the factors that make the product green through the process of discussion and physical disassembly. The SusMet module was packaged for adoption by a wide range of engineering instructors. The complete module package contains: a summary of learning objectives and module activities, lecture slides and notes, recommended readings, detailed description of the experiential learning activity, an assignment, and a pre-and post-module cognitive assessment. The module package was shared through the developers’ networks and within the last year was placed online for free download on our engineering education website (STEMed.engineering.asu.edu). Since then, the module has spread to several classrooms across the country and has been used in two senior-level, interdisciplinary design courses to educate both civil engineers as well as students majoring in sustainability. Since the activity itself requires expensive chairs that can be cumbersome to move around large campuses, the module’s transferability and widespread adoption is slightly hindered. This paper presents the decision matrix used to evaluate replacements for the chair to enhance the transferability and portability of this active and experiential learning module.

Introduction

The next generation of engineering professionals must be prepared to solve complex and multidisciplinary problems in a sustainable and global context. The National Academy of Engineering (NAE) developed and issued the Grand Challenges of Engineering, with five (solar energy, carbon sequestration, nitrogen cycle, clean water, and infrastructure) of the fourteen directly related to sustainability\(^1\). The Grand Challenges offer a framework for exposing engineering students to roles of an engineer in modern society. Adoption of these challenges within engineering curricula engages a diverse array of interested students by establishing contextualized linkages between course content and the contributions an engineer makes to solve global issues through systems-thinking innovation\(^2\). Engineering education can provide students with the tools to approach these grand challenges of the 21\(^{st}\) century while considering aspects that are key for designing sustainable systems\(^3\). Furthermore, according to the National Academy of Science report, *Changing the Conversation*, youth are seeking careers that make a difference\(^4\).\(^5\).

Sustainable engineering offers a solution to pressing challenges, in conjunction with appealing to our youth.
The National Research Council (NRC) provides several recommendations for enhancing education in science, technology, engineering, and mathematics (STEM) disciplines. Recommendations include providing engaging laboratory, classroom and field experiences; teaching large numbers of students from diverse backgrounds; improving assessment of learning outcomes; and informing science faculty about research on effective teaching. NRC recommendations are met with diverse pedagogical approaches. Experiential learning, which involves constructing meaning from direct experience and involves the learner in a real (rather than abstract) experience. Experiential learning, or learning by doing, has been cited to positively impact non-traditional student learning and increase overall student retention and completion of programs of study. In addition, experiential learning provides students with hands-on experience that can give them an edge in the competitive job market today. Research suggests that team based projects can also enhance student learning in STEM fields since it promotes active and collaborative learning while simultaneously promotes individual accountability, personal responsibility, and communication skills. We have adopted an experiential team-based approach in the Sustainable Metrics (SusMet) module.

Incorporating sustainability into traditional engineering courses provides students with a meaningful way to connect more personally to their courses. Through the use of modules, engineering programs can integrate sustainability and experiential learning throughout a host of existing courses by threading individual sets of course skills together in an effort to reach higher levels of intellectual behavior via interdisciplinary concept connection. Modules can be designed to fit into one lecture or over a series of lectures. Modules typically include everything an instructor needs for implementation: a summary of learning objectives and module activities, lecture slides and notes, recommended readings, and an assignment for students. Using modules to teach sustainability concepts reinforces the broader applicability of sustainability to all engineering disciplines by connecting traditional engineering to impacts to, and solutions for, society, economy, and environment. The authors have developed a host of sustainability grand challenge modules available (STEMed.engineering.asu.edu). The SusMet module has been designed such that it can be adopted into any general engineering course from freshman to senior-level undergraduates.

Module Overview

The SusMet module is a hands-on activity that actively engages students through the disassembly of green and traditional products. Early on in the module, students disassemble a green chair and analyze the metrics that contribute to the chair’s greenness. Students critically evaluate the factors that make product’s green through the process of comparison to chairs not labeled green, discussion and disassembly.

The SusMet module has been integrated into over 15 classes over the past five years. It was conceptualized in 2009 as a way to introduce civil engineers to concepts of design for environment, design for disassembly, design for end-of-life, as well as assessing sustainable metrics. The module learning objectives have been updated from Antaya et al 2013 and now cover students’ ability to 1) explain the basics of design evolution, 2)
apply design evolution concepts to analyze the office chairs from recent decades in terms of their “green” quality or design for the environment, 3) determine the feasibility of end-of-life recycling of the materials comprising the chair via disassembly, material categorizing and weighing and 4) examine and assess the green design properties of chairs from mid 1900’s versus a 21st century chair touted as green. Sustainable metrics have been left as an intentional indirect learning objective for this module in order to compare the cognitive outcomes of explicit versus implicit module components across student test groups.

In the activity portion of this module, the instructor begins class with a 10-minute presentation to prepare students for the activity. The presentation introduces the office chair. These chairs represent design evolution; they include a 1950’s chair, early 1990’s chair, late 1990’s chair and a 2000’s chair that was advertised as green based on its ease of disassembly and materials. The “green” chair is designed such that it can be fully disassembled in less than five minutes by the average consumer, has multiple options for recycling at the product’s end of life, and minimizes energy use over materials, production and transportation phases of the chair’s life. All of the chairs used for the SusMet activity are shown in Figure 1. The presentation then uses class discussion to connect the office chair with the history of “design for X” where X is any criteria set for a design, followed up by covering the key module concepts of design for environment, design for end-of-life and design for disassembly. Students are then placed in teams of 4-5 and asked to examine a brochure provided by one of the office chair manufacturers for “green claims” regarding the chair’s disassembly and end-of-life. The instructor holds a brief class discussion on the findings in the brochure; the claims of the brochure indicate that the chair can be dismantled in 5 minutes or less into all of its separate parts using common household tools. The instructor asks students to hypothesize whether or not the claims are true, and how the chairs from other decades will perform compared to the green chair. The students also determine which metrics they will track during the chair disassembly to evaluate their hypothesis.

Each team takes a chair from a different time era and then begins the process of disassembly using common household tools in a timed competition. During disassembly, each team tracks metrics representing design for disassembly and design for end-of-life including, but not limited to, number of parts, number of tools used, number of materials used in the chairs, and recyclability of parts. After 30 to 60 minutes (the time varies based on the length of the class) the instructor stops the disassembly progress and students record the percent of the chair they believe to be disassembled. The teams then switch chairs with another team for reassembly, performing the process in reverse and documenting metrics for their reassembly chair. At the conclusion of the activity, the teams discuss and critically review their hypotheses and evaluation of the sustainability of the chairs based on the metrics collected during the lab. The instructor concludes the class through a 15-minute active discussion on design for environment principles and material selection; this discussion includes how an office chair can be translated to represent many examples of urban infrastructure that require retrofitting and/or redesign. Often, students complete a homework assignment that reflects on the process; the homework assignment varies from class to class. More advanced classes are asked to
complete a lab report, while beginners are asked to respond to a set of module-prompted questions.

Module Evolution and Transferability

The SusMet module was first packaged in 2012 and its transferability was tested. Due to high demand, in 2013 the module package was updated with a module description, activity description and readings, sample slides with notes sample assignment for students to exercise research and communication skills, and a pre/post cognitive assessment of the learning objectives to enable additional instructors to adopt it in their classes. In 2014, through sustained interest, we made the entire SusMet module package available at free download on our engineering education website (STEMed.engineering.asu.edu). The digital availability of the module presented new, unanticipated challenges. Despite the success of creating modifications for the module and its contents, many faculty at other institutions are unable to use the module because they do not have the resources to purchase the $900 green chair. The chairs are not easily transported, so it is difficult to share the modules with the teams’ local community college collaborators. However, there was no obvious product with which to replace the chair. There are many key elements that make the chairs in the SusMet module successful, and it was difficult to find all of these elements in one product. Thus, the aim of this paper is to evaluate the factors for module success and update the module with alternative objects to the chairs using a decision matrix, described in the following section.

Analysis of Module Key Elements

We began our search for objects to replace the chair by breaking down the key elements of the chair that make it the object of choice for the SusMet module. We have determined five key elements, including 1) object access, 2) design evolution, 3) sustainable metrics, 4) design for disassembly and 5) design for end-of-life shown in Figure 1, that need to be met by an alternative object in order to uphold the learning objectives of the module.
Figure 1. Key chair elements representing object of choice for the SM module.

Element 1: Object access

The success of the SusMet module is due, in part, to the office chair through which sustainability and engineering grand challenge topics are explored. The office chair is recognizable object; instructors and students alike have been able to relate to this object through personal experiences. In addition, the office chair is somewhat portable within a campus. Most office chairs are made with casters, rolling the office chair between and around classrooms presents an easy way to transport; however the chairs are not portable outside of a campus. While the chair lab is capable of being used in many classes across a campus, there are scalability issues for larger classes that require more chairs. Typically, the SusMet module needs approximately one chair per five students. The most limiting factor in the object access element is the affordability of the office chair. While we have reclaimed our 1950s, early1990s and late 1990s office chairs from university surplus, the “green” chair was purchased at $1000 per chair, limiting the instructors that can purchase these as supplies. Choosing an affordable object will be the most challenging objective to ensure module transferability.

Element 2: Design evolution

While design evolution is a subtle component of the module, it is critical to showcasing the changes that occur over time for one object. Some of the office chair evolutions include changes in chair structure, manufacturing, material usage and application, chair
functions and core movements and ergonomics present in designs. While all of these aspects are present in the chairs we use everyday we have found that presenting students with hands-on accounts of design evolution has a significant impact on the experience as opposed to having one example of an office chair design. For example, the 1950s chair was simple in its design with only a few parts and a few different materials. The design evolution engages students in discussions of increased functionality at the expense of simplicity and in some cases sustainability. Finding an object with design evolution examples will be easy; most objects have gone through several evolutions in order to appeal to consumers.

Element 3: Sustainable metrics

Sustainable metrics and green claims also make the SusMet module successful. While the 1950s, early 1990s and late 1990s office chairs do not come with brochure material outlining some of the “green” features of the chair, the “green” chair brochure shares these features (e.g., material selection, energy reductions, and emissions reduction procedures). The claims of the “green” chair present a unique case for students to use reasoning supported by evidence to challenge these marketing claims. The claims also enable students to think through what constitutes a “sustainable metric” and how would they apply the metrics to assess the other office chairs present in the module. Locating an object that makes “green” claims will narrow possible alternative to the office chair though it will not be a limiting factor in object selection.

Element 4: Design for disassembly

Design for disassembly is a key-learning objective for the SusMet module. In discovering whether an object has been designed for disassembly students take an active, experiential role as object disassemblers during the module. In addition, the timed competition makes the module fun for students. Because the object is disassembled every time this module is conducted, it is important to consider the size of the object, sections that can be disassembled, and tools required for disassembly. The chair is ideal for teams of 4-5 students since it allows for multiple students to work on disassembling the chair at once. The chair can be broken down into sections, such as the arms or back, and then students can continue to disassemble the sections individually while contributing to their team. In addition, the smallest parts of the chair are visible and while some screws are very little, the smallest parts compare favorably to that of a smaller objects whose parts become unidentifiable when disassembled. The chairs typically require common household tools for disassembly, which are more readily available to the average instructor. The chair can also be disassembled and reassembled without deconstruction; the alternative object will need to have reassembly capabilities in order to ensure use of the object in multiple classes.

Element 5: Design for end-of-life

The final element of significance to the SusMet module is design for end-of-life. Design for end-of-life, while a key-learning objective, will help to further define the possible
objects that will work as alternatives to the office chair. The green office chair is unique because its particular green claims relate to design for end-of-life; it is supposed to be easily disassembled for recycle or remanufacture. The chair parts are easy to distinguish as recyclable and it is possible to group the materials by type. Afterwards, students can explore the various end-of-life avenues for the different materials, from recycle to landfill. In order for this to continue to be a part of the module the alternative object must not be of singular material by nature and must have a minimum of two different options for its end-of-life for students to explore.

Decision Matrix

We identified new objects with the potential to replace the chairs in the SusMet module by brainstorming with researchers, instructors and students. The objects we identified as possible alternatives to the chair include a fan, cell phone, monitor, printer, coffee maker and clock radio. We analyzed these objects with a decision matrix format presented in Table 1. The objects were scored against each of the five chair elements discussed in the previous section using a ternary scale; a score of -1 meant not all design evolutions of the alternative object fit the element, a score of 0 meant some but not all evolutions of the alternative object fit the element and a score of 1 meant that all evolutions of alternative object fit the element present in the chairs. An object can score a maximum of 9 points. The decision matrix revealed that the highly weighted elements of this module are 1: object access, 3: sustainable metrics, and 4: design for disassembly as these elements determine whether the object will work for both instructor access and student group disassembly. Cell phones totaled 0 points; they satisfied elements 1-3 however are not suitable objects to replace the chair due to their small overall size and the size of parts as they are disassembled, which presents a challenge with more than one student to working on them at a time. Monitors performed similarity to cell phones at 4 points; though larger in size they are inherently less affordable. Printers, coffee makers and clock radios, all scoring 8 points, satisfy elements 1-3 and 5, fully satisfying element 4: design for disassembly, however, is difficult with appliances that are inherently small in design. A fan was the only object to satisfy all the elements and score 9 out of 9 points. Fan sizes falls between cell phones and chairs meaning that many students can disassemble a fan at once and fans are also more affordable to purchase, more portable for an instructor to move around campus, and can also be distinguished by ‘green’ features such as energy and material sourcing.
Table 1. Decision matrix for alternative object to replace office chair.

<table>
<thead>
<tr>
<th>Alternative Object</th>
<th>Key Object Elements</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Element 1: Object access</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recognizable</td>
<td>Portable</td>
</tr>
<tr>
<td>Fan</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cell phone</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Monitor</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Printer</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Coffee maker</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Clock radio</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Key: -1= not all evolutions of alternative object fit element, 0= some but not all evolutions of alternative object fit element, 1= all evolutions of alternative object fit element

Conclusion

While it might seem simple to replace the office chair with any product that can be disassembled, the multiple layers of learning outcomes achieved from this particular mix of chairs is quite difficult to replicate. Analysis of five elements present in the office chairs that make them ideal objects for this module, including object access, design evolution, sustainable metrics, design for disassembly and design for end-of-life, revealed that substituting an alternative object is not a simple task. We utilized a decision matrix to assess alternatives objects of fan, cell phone, monitor, printer, coffeemaker and clock radio against the five elements. Through this process we recognized that the highly weighted elements of this module are object access, sustainable metrics, and design for disassembly; objects need to be affordable, have a “green claim” to test and capable of being disassembled by multiple students at once. Cell phones, monitors, printers, coffee makers and clock radios are all too small despite their affordability and “green claims”. Fans, however, appeal to all elements present in the chair, including size, and could be utilized as an alternative object to replace the chair. Additional object suggestions will be made available via our engineering education website (STEMed.engineering.asu.edu).
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References