**Proceedings of the ASME 2015 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference**
**IDETC/CIE 2015**
**August 2-5, 2015, Boston, Massachusetts, USA**

**DETC2015-46778**

# EXPLORING THE RETENTION OF SUSTAINABLE DESIGN PRINCIPLES IN ENGINEERING PRACTICE THROUGH DESIGN EDUCATION

**Bryony DuPont**
Design Engineering Laboratory
School of Mechanical, Industrial, and Manufacturing Engineering
Oregon State University
Corvallis, OR, USA
bryony.dupont@oregonstate.edu

**Addison Wisthoff**
Design Engineering Laboratory
School of Mechanical, Industrial, and Manufacturing Engineering
Oregon State University
Corvallis, OR, USA
wisthofa@onid.oregonstate.edu

## ABSTRACT

The School of Mechanical, Industrial, and Manufacturing Engineering at Oregon State University is home to one of the largest academic Mechanical Design groups in the country. As a leader in undergraduate design education, we have been able to keep in touch with a large group of mechanical design graduates, and as such are capable of assessing how students retain information learned in undergraduate coursework to see how this understanding is employed in real-world engineering practice. However, the principles governing the design of sustainable products and processes are relatively novel and are only now being integrated into the undergraduate and graduate mechanical design curriculum. It is our hypothesis that particular means of learning and understanding sustainable design - via lectures, homework assignments, design projects, and the use of various sustainability-related LCA tools – will enable the highest retention of sustainable design understanding, and a higher likelihood that this sustainable design knowledge will be propagated into design practice in industry. Multiple curricular studies that explore dissemination and retention of sustainable design skills are being explored, including a junior-level introductory mechanical design course and a graduate level sustainable product development course. In the junior-level course, baseline sustainability knowledge is tested by allowing students to make sustainable design decisions by applying varied skill sets, including general principles, a list of sustainable design guidelines, and an innovative online survey (The GREEn Quiz). The graduate-level course, which employs sustainable design principles within a larger product development architecture, will capitalize on more "expert" knowledge. Future work will also be discussed, including planned validation studies and curriculum improvements, as well as the means of quantifying the retention of sustainable design information.

## INTRODUCTION

The undergraduate program in Mechanical Engineering at Oregon State University is heavily focused in the area of mechanical design, offering four required courses specifically in design (see Table 1) in addition to courses in CAD modeling and machinery, as well as rotating elective design courses.

**TABLE 1: OSU UNDERGRADUATE DESIGN COURSES**

| **Course** | Introduction to Mechanical Design | Machine Component Design | Capstone Design |
|---|---|---|---|
| **Grade Level** | Junior | Junior | Senior |
| **Credits** | 4 | 4 | 8 (two terms) |

These courses walk students through the mechanical design and product design process starting with the junior-level

introductory course, which includes the product design method developed by Ullman [1]. In this class, students learn how to plan and define design projects, perform conceptual design and convergence, and utilize shop facilities to create a finished product. In the second course, Machine Component Design, students build on material in the introductory course by evaluating quality and failure modes in the redesign of an existing mechanical product [2]. Undergraduate design education at OSU culminates with a two-term senior-level capstone design course, in which student teams design and build industry-sponsored products that are showcased at an exposition at the end of the academic year. In all of these courses, fundamental design theory is reinforced, allowing students the ability to apply overarching design knowledge to real-world challenges, in addition to product-specific knowledge. These courses are continually improved over time in order to accommodate modernizing technologies in both existing products and teaching methods.

As students are meant to understand the overarching design process through these courses, it is of interest to introduce material that widens the scope of design such that recent areas of design interest are explored. Of these, various Design for *X* (DFX) principles (where *X* is manufacturing, assembly, quality, etc.) have been integrated into the curriculum. For example, with the advent of additive manufacturing, the junior-level introductory course now covers Design for Manufacturing principles and enforces the design and application of a 3D printed part on each final product. The intent of this integration is to allow our students the opportunity to interface directly with this new technology and be able to take that hands-on experience to their eventual employers, propagating modern techniques in product fabrication.

It is the intent of the proposed work to explore the integration of Design for the Environment (DFE) principles into the mechanical design curriculum at OSU. To accomplish this, we will explore both undergraduate- and graduate-level curricular advances, how the principles of sustainability should be taught and utilized in the context of product design, and the means of measuring retention of these principles as students graduate and work in industry.

## PROPOSED METHODOLOGY

The proposed method for integrating DFE principles into mechanical design education at OSU includes the following curricular advances and case studies, followed by detailed description of each method.

**(1) Undergraduate Curricular Advances**

- Two DFE Lectures (Junior Intro Course)
  - Overarching sustainable design guidelines
  - Overview of existing sustainable products
  - Computational tools for DFE
  - Life Cycle Assessment methods
- Sustainable Design Projects (Senior Capstone Course)
  - DFE as Customer Requirements
  - Projects in sustainable redesign of existing consumer goods
  - Projects in innovative sustainable products (new product development)

**(2) Graduate Curricular Advances**

- Development of Sustainable Product Development (SPD) graduate-level course (4 credits)

**(3) Case Studies**

- Survey of DFE for New Product Development methods (Junior Intro Course)
- Studies of sustainable design method usage by experts (Graduate SPD course)
- Use of Eco-QFD (Senior Capstone Course)
- Retention survey (Senior Capstone Course)
- Alumni surveying (all courses)

(1) Undergraduate Curricular Advances

The primary focus of the proposed work is to integrate sustainable design and DFE principles into the undergraduate design curriculum at OSU. It is theorized that the inclusion and effective teaching of these principles will advance the students' design capabilities, and will serve as a conduit to translate sustainable design into the real world once students graduate. To accomplish this, students will be introduced to DFE principles during two lectures in the Junior Intro Course. The first lecture will cover the motivation for studying and applying sustainable design, and will include examples of novel products that have a reduced environmental impact (such as biodegradable coffins, compostable single-serving medicine containers, and uni-material bicycling helmets [3]). For each example, students will explore existing non-sustainable products and map how these new sustainable products are more environmentally friendly. The second lecture will discuss Life Cycle Assessment and various methods for completing LCA, along with an overview of existing sustainable design tools, such as GaBi [4], SolidWorks Sustainability [5], and Eco-Indicator 99 [6]. Students will be able to employ these methods as part of a homework assessment, where they will (a) redesign an existing CAD model using SolidWorks Sustainability to reduce the water and electricity use during manufacturing, and (b) perform an LCA using the Eco-Indicator 99 manual, where they will redesign a water delivery system (i.e. a water cooler) to have a reduced life-cycle environmental impact.

The second undergraduate course where DFE principles will be integrated is the Senior Capstone Course, where students will undertake projects specifically designed by the authors to explore sustainability through the design phase of a product. As a preliminary pilot for this concept, two teams in the Winter-Spring 2015 cycle of Senior Capstone Design are performing DFE-related design projects. The first team is undertaking the redesign of an existing consumer good (a commuting bicycle) using computational sustainable design

tools to inform their design, and the second team is exploring sustainability in new product development by designing a product from a much wider design space (a human-powered lawn mower). Students will first explore DFE principles through the inclusion of customer requirements stemming from sustainable thinking, i.e. "using recyclable materials" and "can be manufactured locally" [7]. These projects will give students valuable hands-on experience with both the theory of sustainable product design and the application of various computational tools that can help distill DFE intent. In the future, more projects of this nature will be explored.

(2) Graduate Curricular Advances

While more companies are becoming interested in the design and development of sustainable products, the means of designing these products are still immature. Primarily, it is difficult to employ potentially disparate processes – in this case, the product design process and sustainable design methods – to meet a single goal [8]. To make sustainable product design viable, it is necessary to create a new product design process that is strategically designed to create products that are both innovative and more environmentally friendly. To help test and employ new knowledge in the area of sustainable design theory, a graduate-level Sustainable Product Design course has been developed and is currently being taught (Spring 2015). This course will combine the product innovation methods proposed by Cagan and Vogel [9] and sustainable design methods to guide students through the new product development process. Student teams will establish the need for a new product, brainstorm means of meeting those needs functionally, and employ various sustainable design principles (such as Sustainable Design Guidelines [7] and a novel method developed at OSU called the GREEn Quiz) in order to design a marketable, patent-ready product. Students in this course will become experts in the field of sustainable product design, and their participation in the course will help establish the new product development paradigm - one that inherently incorporates sustainable design thinking – that can be readily be employed in mechanical design work in industry.

(3) Case Studies

Multiple case studies will be conducted throughout these curricular advancements, not only to gauge student understanding and retention, but also to utilize an expert population for various sustainable design tools and methods that will be created in the Design Engineering Laboratory.

(i) Undergraduate Case Study

The first case study was to gauge the baseline knowledge of the students in the Junior Intro Class to better understand what preconceived ideas they have about sustainability and sustainable products. This process involves three groups: a control group (who have been given no lectures or resources about sustainable design), a group that is given a list of sustainable design guidelines, and a group that is given the GREEn quiz (an online questionnaire to aid designers in new sustainable product development). These groups were then asked to generate "more environmentally-friendly" concepts for a redesign of an existing product, and to give their reasoning. Results were analyzed for the number of sustainable design decisions made and other metrics. The results of this case study show how well various sustainable design tools work during the fuzzy front end of product development, and will also give us a baseline for understanding what students already know about sustainability.

Preliminary results from the undergraduate case study are depicted in Figures 1 and 2. Figure 1 displays the average number of sustainable design decisions explicitly stated by each student for all three test groups - control, sustainable design guidelines, and the GREEn Quiz. Students that were provided with sustainability information made more sustainable design decisions compared to the control group, which did not receive supplemental information. Additionally, the GREEn quiz facilitated students' ability to make sustainable design decisions more so than just using a list of sustainable design guidelines alone.

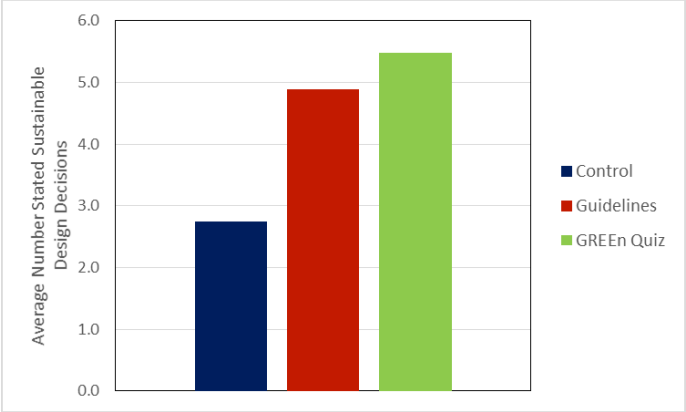


**FIGURE 1: AVERAGE NUMBER OF STATED SUSTAINABLE DESIGN DECISIONS**

The second preliminary result, presented in Figure 2, shows the average number of sketches presented by the students in the study. The control group generated, on average, the highest number of sketches compared to the other groups. There is some uncertainty as to the case of this result, but what is believed is that the students within the control group focused more on visualizing their concepts, rather than writing descriptions of the concepts, compared to the groups who were given written information to guide their design process. Additionally, it is theorized that the current means of including sustainable design information during the conceptual design phase can be constraining to non-expert designers, enabling them to hone in on fewer concept ideas that are more sustainable, rather than more, but less sustainable concepts.

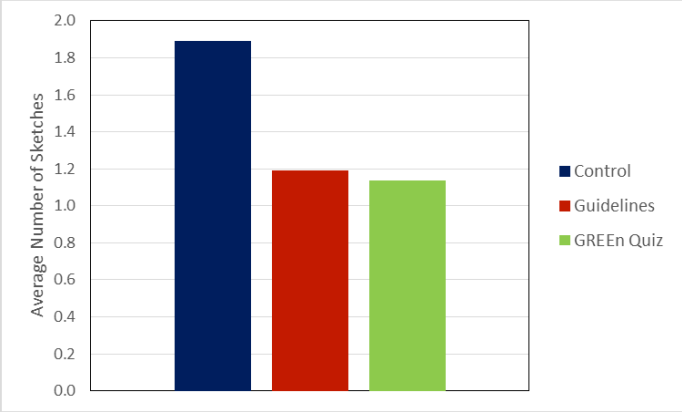


**FIGURE 2: AVERAGE NUMBER OF SKETCHES**

(ii) Graduate Case Studies

Two case studies will be conducted in the graduate level sustainable product design course. The first study will investigate how users of the GREEn Quiz determine relevance and applicability of sustainable design guidelines. Students will be asked to take the GREEn Quiz with respect to a generic product within their product scope, and throughout the use of this method, will be writing done the guidelines that are deemed most relevant. This will provide clues as to what experts view as relevant and will provide further information to improve the effectiveness of the GREEn Quiz.

The second study focuses on how informing the product designer about sustainability during conceptual generation can improve the environmental friendliness of a design. In this study, which will occur during the concept generation phase of the course, individual students will be asked to generate a concept within their project scope, including sketches and text call-outs. Once the concept is completed, they will be asked to use the GREEn Quiz to inform them on how they can improve the sustainability of their concept. After the completion of the quiz, the students will be asked to revise their original concept such that it improves the environmental impact. These results will indicate how a designer may use the GREEn quiz in a real-world design setting, and will inform improvements to the method to that end.

There are other future case studies we've postulated that will further explore how students understand and perpetuate sustainable design. In a future case study, we want to explore adding an Environmentally Conscious Quality Functional Deployment [10] to the Senior Capstone Course, and compare how this QFD model perpetuates sustainable design principles throughout the design process. We'd also like to create a survey that explores the retention of sustainable design principles from the Junior-level classes to the Senior Capstone Course, to see if students were able to apply sustainable design thinking as part of their larger design method. Lastly, we are interested in surveying recent alumni to better understand how sustainable design ideas are used in industry, and if they students were able to make positive changes in the industrial product development process.

## REFERENCES

[1] Ullman, D., 2009, The Mechanical Design Process, Mcgraw-Hill, New York, New York, USA.

[2] Budynas, R., and Nisbett, K., 2014, Shigley's Mechanical Engineering Design, Mcgraw-Hill, New York, New York, USA.

[3] Reis, D., 2010, Product Design in the Sustainable Era, Taschen, Cologne, Germany.

[4] "GaBi Life Cycle Assessment Software," PE Int. [Online]. Available: http://www.gabi-software.com/software/.

[5] Dassault Systems, 2015, "SolidWorks Sustainability."

[6] Ministry of Housing, and Spatial Planning and the Environment, 2000, Eco-indicator 99 Manual for Designers.

[7] Telenko, C., Seepersad, C. C., and Webber, M. E., 2008, "A Compilation of Design for Environment Principles and Guidelines," ASME Internation Design Engineering Technical Conferences and Computers and Information in Engineering Conference, New York, NY, pp. 1–13.

[8] Newcomer, J. L., and Steif, P. S., 2008, "Student thinking about static equilibrium: Insights from written explanations to a concept question," J. Eng. Educ., **97**(4), pp. 481–490.

[9] Cagan, J., and Vogel, C., 2013, Creating Breakthrough Products, Pearson Education, Inc., Upper Saddle River, NJ, USA.

[10] Romli, A., Prickett, P., Setchi, R., and Shoe, S., 2014, "A Conceptual Model for Sustainable Product Design," Key Eng. Mater., **572**, pp. 3–6.