120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7532

Teaching Sustainability in an Engineering Graphics Class with Solid Modeling Tool

Dr. Ananda Mani Paudel, Colorado State University, Pueblo
Dr. Jane M. Fraser, Colorado State University, Pueblo

Jane M. Fraser is Chair of the Department of Engineering at Colorado State University, Pueblo. She was formerly on the faculty at the Ohio State University and Purdue University. She has a B.A in mathematics from Swarthmore College and a M.S. and a Ph.D. in industrial engineering and operations research from the University of California, Berkeley.

Teaching Sustainability in an Engineering Graphics Class with Solid Modeling Tool

Abstract

There is consensus about the need to teach sustainability, but also concern about how to accommodate these concepts into a crowded curriculum. Offering a separate course may not be a realistic choice due to resource or credit hour constraints. This paper investigates the capability of the sustainability component recently added to SolidWorks, which many universities use as a main Computer Aided Design (CAD) tool. We studied its usefulness in teaching sustainability concepts to engineering students.

The study was performed in a Southern Colorado regional university over a period of two years involving eight sections of a first-year engineering graphics class consisting twenty four students each. In one course module, Life Cycle Assessment (LCA) was used to analyze the environmental impact of a cup holder. A sustainability report generated in SolidWorks accounts for the amount of Carbon Footprint, Water Eutrophication, Air Acidification and Total Energy Consumption. The base design scenario along with alternative options was evaluated to identify the environmental impacts and was compared to determine the most environmentally friendly options.

To study the impact of this module on students, pre and post surveys were administered and the results suggested a significant improvement in sustainability learning and an increase in interest in sustainability. A similar approach could be used in other engineering programs with modifications depending upon the students' learning styles and educational background.

1. Sustainability, Design and Engineering Education

The World Commission on Environment and Development defines sustainable development as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[1]. The US Environmental Protection Agency proposed a P3 Model: People, Planet and Prosperity[2], which gives the engineering professionals a major responsibility in promoting the well being of the planet by maintaining the ecology and environment. David Orr described sustainable design as an activity that needs the careful nesting of human purposes with the larger patterns and flows of the natural world. The scope of sustainable design includes economic profitability, social acceptance, minimum energy and material use with minimal impact to the environment, and production of no hazardous waste.

The current design philosophy and approach in the engineering profession embrace the functional purpose – derived from the customer needs – and the economic requirement – the producer's basic business motivation – with little consideration of sustainability. With the growing consensus in industry and in academia about the importance of sustainability, engineering professionals must understand and incorporate sustainability concepts in their professional endeavors. Engineering educators need to prepare engineers with proper knowledge, skills and ability to accomplish sustainable design.

Specific industries have developed practices to incorporate sustainability into their design. In the automotive industry sustainability research is performed through a comprehensive review of a vehicle's life cycle, disposal and end of life analyses using different sustainability metrics and models to quantify the environmental impact[3]. However, application research literature points to the need for the whole design process to be reconsidered to integrate sustainability and to incorporate social responsibility into the product design[4].

1.1 Approaches in Teaching Sustainability in Engineering Education

Efforts to teach sustainability in the undergraduate engineering curriculum are assessed in Vanderburg[5], where engineering education is described as composed of technical core courses and complementary courses on humanity subjects. However, technical core courses are taught in isolation from the human life context and humanities courses are very general in nature with no direct link to modern science and technology. Closer connections between the technical courses and the humanities courses can help engineering students understand the holistic nature of sustainability and the world; an alteration to any component may impact the entire system. Such education will help to prepare students as a global responsible citizen. This broader multidisciplinary knowledge is essential for seamless integration of sustainability into engineering education.

Other approaches include an interdisciplinary seminar on environment and sustainability as a summer research program[6], developmental and systems approach[7], etc. The developmental and systems methodology utilizes Bloom's Taxonomy and demonstrated a cognitive progression in learning sustainability via reading case studies throughout the six sequential design courses. Reading assignments are a good way to familiarize students with the topic. Such familiarization could be enhanced by simulation or hands-on activities, using visualization tools and databases, but it should be incorporated from very beginning of the engineering design process. In addition, various methods and pedagogies are available in literature incorporating sustainability in design education to enhance skills, awareness, learning in context, ethical responsibilities, synergy and co-creating principles[8].

1.2 Standalone and integration

Currently sustainability is taught more in some engineering disciplines such as environmental, chemical and civil engineering[9], but since sustainability needs to be considered in every activity that any engineer performs, it is imperative that all engineering students should have a strong background in sustainability, which makes it necessary to integrate sustainability into the existing courses throughout the engineering programs[10]. Integration of sustainability in engineering education is vital to understand the social and environmental implications of a modern technology that makes engineers to incorporate sustainability into their design[11]. Some improvements in sustainability awareness among the engineering students have been reported in the literature. However, institutionalization as a main stream educational approach has not happened yet.

Sustainability is barely talked about in a traditional engineering curriculum. As decisions made at early stages of a product's life cycle have a profound impact on improving product sustainability, environmentally conscious design practices from the very beginning of a professional career will contribute to sustainability by considering global ecological factors and resources in addition to traditional functional and cost requirements. Since sustainability is becoming a theme of whatever engineers do, it should be included from the very beginning of the engineering curricula. This study focuses on the sustainability features of CAD, their respective design phases and ways to integrate sustainability education into CAD in an existing engineering graphics course.

1.3 Sustainability and CAD

Design for sustainability and the role of CAD is presented in Rama Murthy and Mani[12]. Proper sustainability tools and techniques are required to implement sustainable design. Life Cycle Assessment (LCA) is used to investigate successfully a spectrum of product life and its impact on P3. A review of sustainable product design approach is presented in Chiu and Chu[11]. Integration of CAD and life cycle inventory is one of the approaches. CADinvolves feature-based modeling to represent the final form of the design intent, and it does not support LCA data related to processes, machines, purchasing and suppliers – factors used to estimate the environmental impacts. Features and capability of CAD based sustainability modules are presented in Morbidoni *et al.* [13]; they evaluate and compare CAD-based SLCA solutions and complete LCA software tools, with a focus on the mechanical product design SolidWorks Sustainability (by Dassault Systems) and GaBi (by PE International) have been considered as references for the comparison.

Two of the leading CAD software companies have introduced sustainability capability in their software by linking with LCA software. SolidWorks Corporation has released SolidWorks Sustainability in 2010, which allows users to perform LCA studies directly on their CAD models[14]. Similarly, AutoDesk's Inventor added sustainable features in collaboration with Sustainable Minds LLC that can perform an LCA on Bills of Materials: a Case Study in Ontario 4 CAD software[15].

The new sustainability module in SolidWorks provides designers with access to environmental databases early in the design process so the designer, in selecting the materials, manufacturing processes and logistics, can make an informed decision considering the environmental impacts and sustainability. This tool not only covers specific design criteria but also allows a wide range of product features[16]. In particular, during the design process a designer is able to run a Life Cycle Assessment (LCA) of the products directly within the SolidWorks Window. LCA determines the consumption of energy and materials and the emissions to air, water, and land occurring throughout the entire life of the products[17]. To integrate this new feature of the SolidWorks software into an existing course is a challenge, but there is an urgent need to fulfill the future needs of the engineering profession.

2. Motivation and Scope of the Work: Engineering Design, Creativity and Sustainability

Engineering graphics design is one of the main languages of the engineering profession and engineering students can do meaningful design projects in the first year[18]. The engineering graphics course plays a large role in developing visualization, creativity and personal imagination. As the first step in engineering education as well as an entry point to a professional engineering career, the engineering graphics class is an appropriate venue to introduce sustainability concepts. The engineering graphics curriculum has continuously developed, incorporating newer technologies and methods and evolving from a 2D drafting to a modern 3D solid model design representation[19]. Sustainability is the next evolution.

Creativity and innovation are becoming more critical in the current high-tech society than at any time in the past. Creativity in engineering is needed to meet functional requirements and to improve quality. Now a third dimension in creativity is essential to meet environmental or sustainable requirements. The object or product designed must not just meet the customers' expectations of specific functional requirements; it must also meet environmental expectations and must not hurt nor pose any hazard to the environment. A broader understanding of sustainability is essential to be a truly creative designer.

The engineering graphics course also supports ABET student outcome criteria including that students should have an understanding of sustainability (criteria c, h, j); be capable of finding a solution (i.e. design a system) (criteria c) by meeting the desired needs of sustainability (criteria h); and be skilled and equipped with tools and software to be able to understand the impact of the solution in the environment (j)[20].

2.1 Existing Content of Engineering Graphics:

The objectives of the engineering graphics course at our university are to familiarize students with technical drawing, and to provide them with some computer aided design skills using AutoCAD and SolidWorks. Concepts of engineering drawing are covered in conjunction with 2D in AutoCAD and 3D in SolidWorks. Existing features of SolidWorks including Modeling, Multiple views, Assembly, Section view, eDrawing, motion study animation, etc. are used for visualization. eDrawing facilitates file transfer and project management. Motion study enables students to simulate a basic motion of a part or assembly. Video recording capability provides flexibility for efficient file transfer. Material selection for a designed part and Creating a Bills of Materials (BOM) are also included. Although students don't have extensive knowledge about the options available in CAD modules, the course provides an exposure to commonly available engineering materials and manufacturing processes. Later in the curriculum students will build on the concepts after receiving relevant knowledge in the higher level courses. Similarly with sustainability, in the engineering graphics course, students learn the options available in the sustainability module and will perform the sustainability study under the direction of the instructor; once they have learned about materials and manufacturing processes in higher level classes they will be able to evaluate the sustainability impact on their own.

2.2 Scope of the Work and Objectives

Based on the literature and the imperatives that are identified, the goal of this research study is to develop a conceptual framework to teach sustainability concepts to the first year engineering students in a level appropriate way. The framework should accomplish the following student outcomes:

1. Students are exposed to sustainability concepts
2. Students realize that sustainability does matter
3. Students learn that engineering decisions have an impact on the environment
4. Students make progress on the learning outcomes established by ABET about sustainability

In this inquiry SolidWorks Sustainability will be used due to its strong integration of LCA and CAD software (i.e. the LCA software runs directly within the CAD software). The fundamental concepts behind the module and its scope as well as limitations will also be discussed.

3. Solid Works Sustainability Module:

SolidWorks added a feature for pre-production modeling of environmental impacts in the product development process[16]. The sustainability module in SolidWorks provides an option to select materials and perform a comparative environmental impact analysis of the materials. In addition, the sustainability tool produces a meticulous report that explains the product's environmental impacts under different scenarios. The data used in SolidWorks Sustainability is based on PE International's database and its GaBi software. The database is meant to provide an estimate, and the module is good for tracking relative changes in the environmental impacts from one version of a design to the next as a primitive reference.

The sustainability module is easily accessed and is offered free with the SolidWorks academic license. SolidWorks SustainabilityXpress is included in 2010 and later versions and is available to download from their website. SolidWorks SustainabilityXpress is the first version with LCA of parts and material selection, environmental impact dashboard, sustainability report generation, etc. The later full version, SolidWorks Sustainability, adds LCA of assemblies and configurations, expanded reporting capabilities, user inputs for energy consumption and transportation methods, and support for the new assembly visualization functionality[14] . The full version of SolidWorks Sustainability needs a separate license purchase. For classroom instruction, network licensing is available and the program is offered in various languages.

3.1 Input Parameters:

The following options are available for environmental analysis of the design:

1. Material selection
2. Manufacturing process selection
3. Manufacturing location selection
4. Use location selection.

The database maintains a wide range of engineering materials: steel, aluminum, plastic, rubber, etc., allowing the designer to identify low-impact materials quickly in order to lead to a sustainable design. In traditional design, decisions of material selection rely on strength requirements and cost criteria. Environmental factors are considered only later. Now, the impact of material on the environment can be calculated up front in the design process leading to a higher possibility of informed decision about the material selection.

A list of manufacturing processes from traditional milling to much sophisticated processes are available for selection. Due to the increase in energy prices, the cost of transportation of the products must be considered and SolidWorks allows selecting the location of manufacturing and the location of use, encompassing the supply chain and logistics of the product movement.

3.2 Sustainability Report:

In the sustainability report, the contribution of each activity into the environmental degradation is presented in pie and bar charts, showing trends as well as specifics on the environmental impact measured. The report is in the same units selected in the SolidWorks part file. The sustainability module allows setting a baseline and performing a comparative study. The create/update report command button creates a report and the send report feature allows sharing the report via email. The core of the sustainability knowledge is supplied at the end of each sustainability report as a glossary note, which is summarized next in this paper.

3.3 Impact Categories and Matrices

SolidWorks developed indices of impact on key environmental factors. A designer can use the indices to determine trade-offs between the factors. The main environmental factors are natural resource depletion and impacts on air, water, earth, and climate, as measured by the following key indicators.

- Energy demand
- Air acidification
- Eutrophication of water
- Carbon footprint.

Higher energy consumption, especially energy generated from fossil fuel will increase the environmental hazard in addition to increasing the cost. Energy consumption is expressed in MJ. Carbon dioxide (CO_2) and other gases resulting from burning fossil fuel accumulate in the atmosphere which in turn increases the earth's average temperature. The carbon footprint is used as a proxy for Global Warming Potential (GWP). Global warming is responsible for climate change, loss of glaciers, extinction of species and others. The carbon footprint is expressed in kilograms of CO_2.

Air acidification is caused by sulfur dioxide (SO_2), nitrous oxide (NO_X) and other acidic emissions to air that result in acid rain. Higher concentration of acid makes land and water toxic for plant and aquatic life. An acidic environment slowly dissolves manmade building materials (concrete). This indicator is measured in the units of kilograms of sulfur dioxide equivalent (kg SO_2).

Water eutrophication is a process of over abundance of nutrients added to a water ecosystem, which is caused by nitrogen (N) and phosphorus (PO_4) from waste water and agricultural fertilizers. With higher nitrogen, plants like algae bloom and deplete the oxygen level in water killing other plants and animals by depriving them of oxygen. Water eutrophication is measured in kilograms of phosphate equivalent (kg PO_4)

3.4 Impact Assessment Procedure

As listed above, materials, manufacturing, transportation, use and disposition are the main constituents categorized by SolidWorks for environmental impact assessment. The materials category includes activities from ore extraction, enriching and ingot formation. The manufacturing process encompasses activities in shape, size and feature modifications after receiving the ingots. Transportation considers all the movement of the parts from manufacturing to use and disposal. The longer the distance between the manufacturer, suppler and customer, the higher will be the impact of transportation not only in the environment but also in cost and delivery time. SolidWorks Sustainability accounts for both the distance and mode of transportation used to deliver the product throughout its supply chain: air, truck, rail, and ship. In addition to distance and type of transportation, consideration of the quality of the fuel used makes this model detail oriented. The fuel that is used during transportation differs with fuel source and refining technology, and has different acidification potential from the exhaust emission[16].

In comparing different environmental impacts to each other that reflects a comparable scale of effects SolidWorks Sustainability has formulated a sequential computation plan. As a first step, the software gathers specific environmental impacts of each component of the life cycle inventory. The second step is generation of impact indicators derived from the life cycle impact results that facilitates direct comparison of the impact of competing design options. This enables the user to compare completely different materials, for example, plastic and wood. These two steps are mandatory in order to conduct an impact assessment according to the ISO 14044 standard[21]. Two subsequent steps are optional: normalization and weighting. Normalization is useful for scaling the data by a reference factor and helps to isolate the influence of a substance in a given context. Weighting on the other hand facilitates summing all indicators together with different weights to establish a single grade that might be used to create a ranking of the impacts. However, weighting is more a subjective procedure and might differ from company to company[16].

4. Case study: Cup Holder

4.1 Geometric Modeling and Sustainability

Basic part modeling is performed to create a cup holder in SolidWorks involving sketch, extrude, shell and extrude cut features. The part model with drawing and dimension is presented in Figure 1.

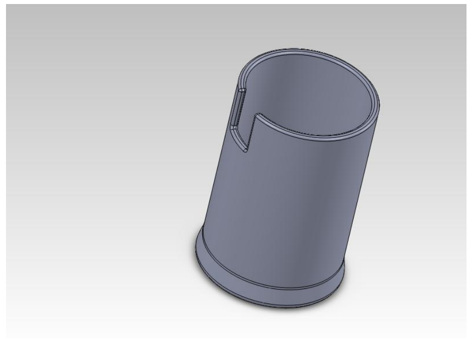

Figure 1. Solid Model of Cup Holder

Using the sustainability module, materials, manufacturing process and its location as well as use region were selected. On clicking the create report button, a Word document is generated automatically with the details shown in Figure 2.

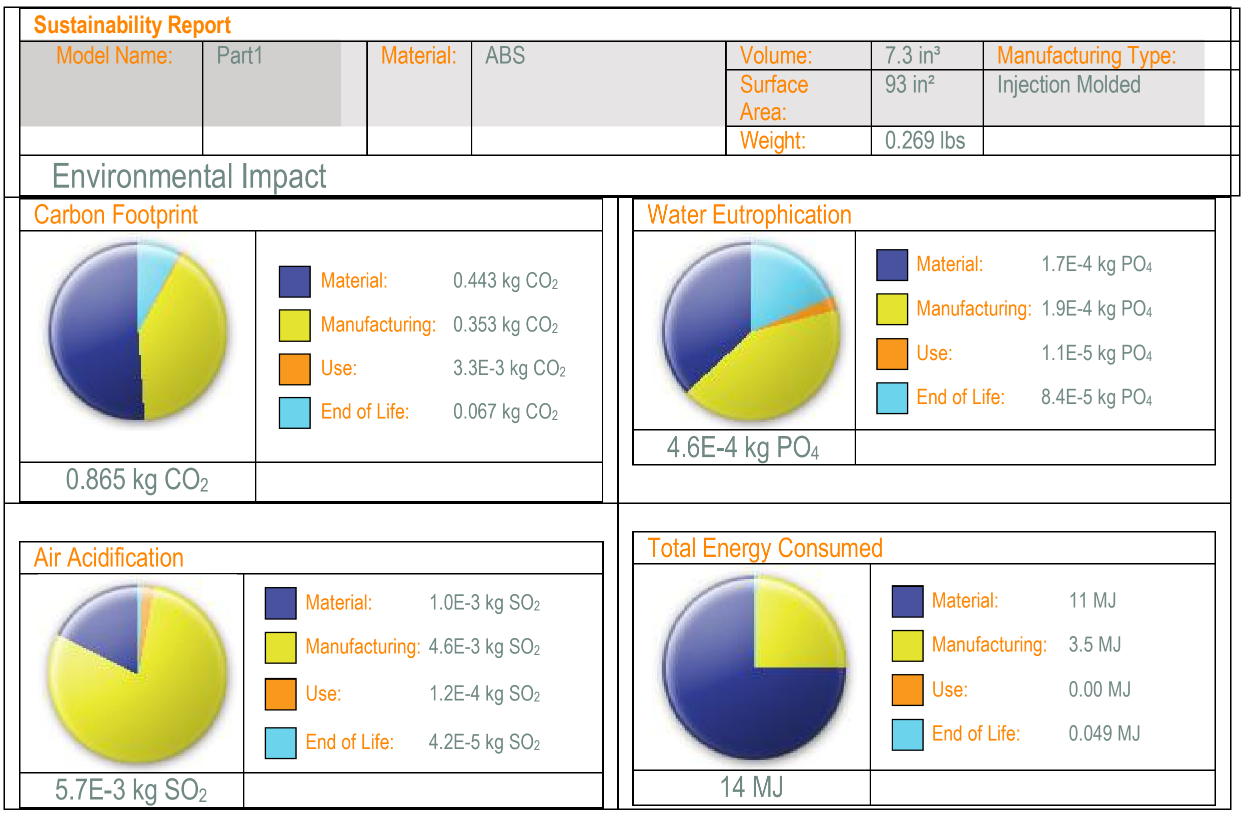

Figure 2. A Typical Sustainability Report with Environmental Impact

As shown in Figure 2, the sustainability report consists of part name, material and its physical information on the top. Pie charts of different environmental matrices are presented under the Environmental Impact heading. Each Environmental Impact indicator consists of the impact caused by material, manufacturing, use, and end of life. Respective units of the matrices are included in the report. At the bottom of each chart, the total amounts of individual impacts are presented. The report is self explanatory with summaries and necessary details.

Next, a comparative study was performed for different options. The set baseline option was used to set a reference, which allowed setting an option as a standard. A sustainability report with environmental impact comparison is presented in Figure 3.

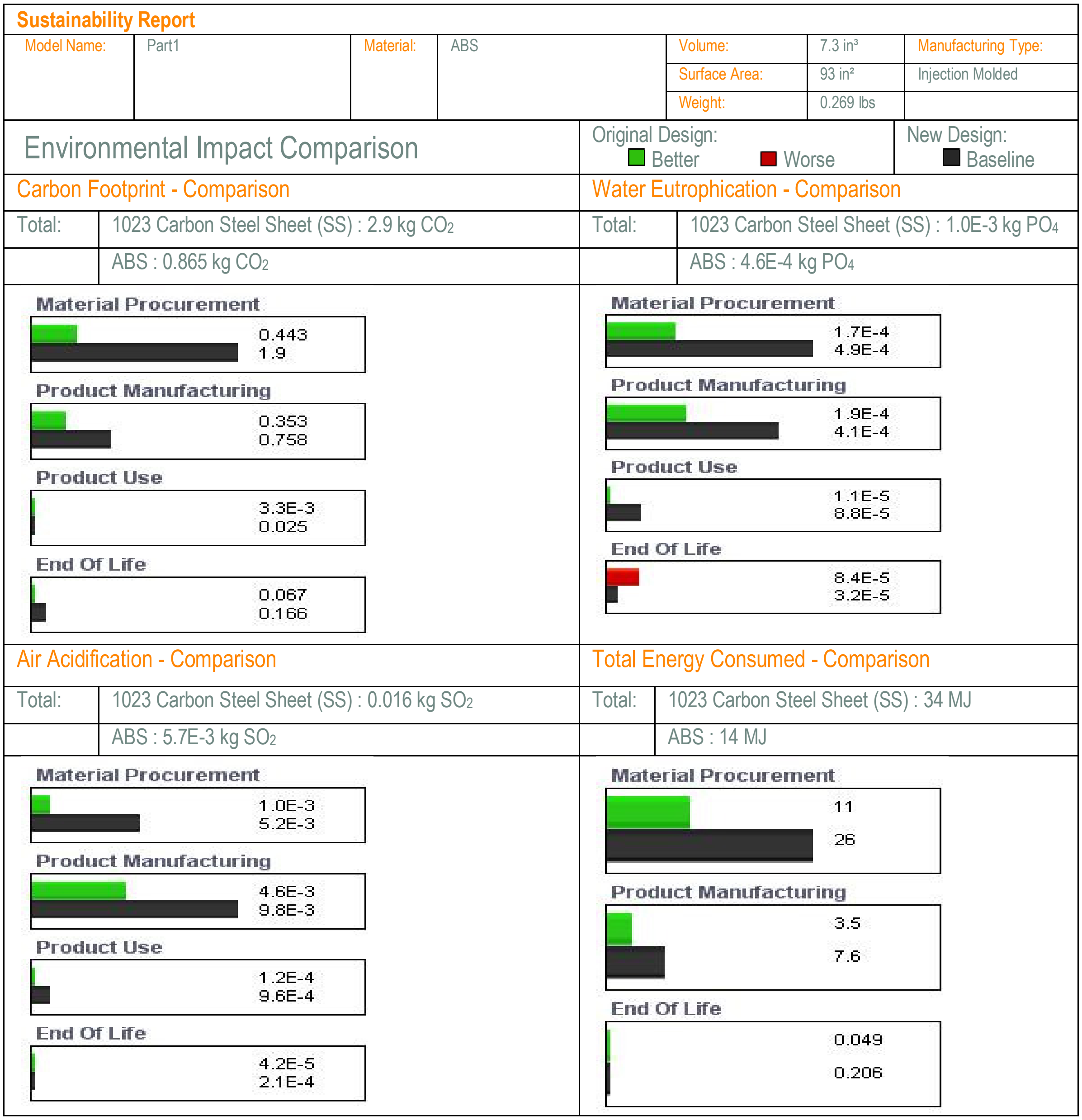

Figure 3. Environmental Impact Comparison of Different Materials

As shown in Figure 3, a comparison between carbon steel and ABS Plastics is displayed with the bar chart. As seen in the graph, comparison of individual impact indicators is presented. Use of different color schemes assists in visualization of the difference. The green color is used in the bar graph if the alternative has improved the environmental impacts, whereas red is used if the alternative posed further degradation into the environment. The comparison will be helpful to investigate the comparative merits of different options and to facilitate the identification of the better one. Only two options can be compared at a time in SolidWorks, which may not be enough in many cases. In that case one needs to manually record the data from multiple reports and compile them to analyze. After performing sustainability evaluation of some typical materials and manufacturing processes the authors have summarized and presented the information in Table 1.

Table 1. Environmental Impact Summary of Different Materials and Manufacturing Processes

Material	Manufacturing		Use region	Weight (lbs)	Carbon Footprint (kg CO_2)	Water Eutrophication (kg PO_4)	Air Acidification (kg SO_2)	Total Energy Consumed (MJ)
	Process	Region						
1023 Carbon Steel	Stamping	China	USA	2.1	2.9	$1*10^{-3}$	0.016	34
Aluminum (1060- Alloy)	Stamping	China	USA	0.713	4.7	$1.2*10^{-3}$	0.031	57
		USA	USA	0.713	4.6	$1*10^{-3}$	0.028	58
Plastics (ABS)	Injection Molding	China	USA	0.269	0.865	$4.6*10^{-4}$	$5.7*10^{-3}$	14

As shown in Table 1, Carbon steel, aluminum alloy and plastics are compared for their environmental impacts. Stamping is selected for metal manufacturing whereas injection molding is selected for plastics. Most of the time the manufacturing region is China or East Asia. The USA is selected as the use region. The weight of the cup holder varies with the material: steel 2.1 lbs, aluminum 0.713 lbs and plastics 0.269 lbs. The carbon footprint, air acidification and energy consumption of aluminum are the highest, suggesting that aluminum is not good for the environment and needs to be avoided whenever possible when selecting a material during a product design.

4.2 Learning Outcome:

Assessment is an important step in learning process to gauge the students' understanding and monitor their improvements. A framework is needed to guide the process of integrating sustainability concepts, including ecological, social and financial factors, into the engineering design processes. The following free response questionnaire was used to assess the outcome of teaching sustainability to engineering students in engineering graphics class. A pre-test and post-test were administered to examine the effectiveness of the module. Students were asked to respond to the following questions:

1. What is sustainability?
2. Does it matter?
3. How can you design for sustainability?
4. How do products make environmental impacts?
5. What are the factors used to measure the environmental impacts?

In general, the pretest shows that students have struggled to grasp the core concept of sustainability, wondered how they could use it, realized its importance and demonstrated an interest to learn and practice in the future. The post test responses of the students were well developed and informative with examples. They understand how a material impacts the environment, and why one material is better than others. They had a firsthand experience of the significance of manufacturing process and transportation into energy consumption. The summary of the results are presented in Figure 4.

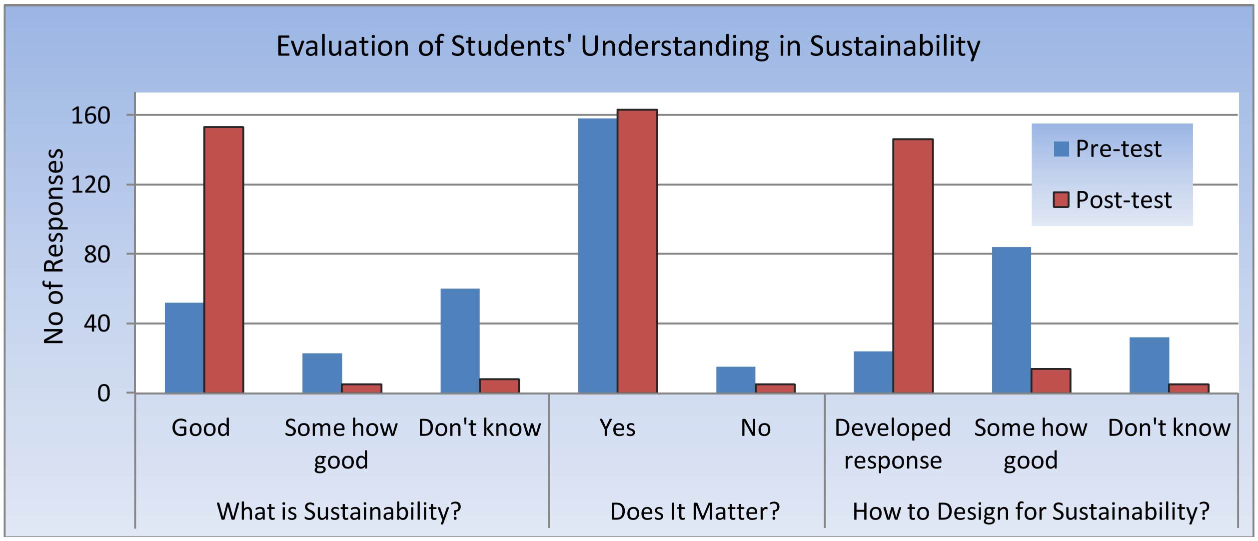

Figure 4 Sustainability Understanding of Students Pre and Post Study

On the pre-test question "What is sustainability," 52 students gave an answer that related to saving the environment, but 60 students said "I don't know." Typical other answers involved specific approaches, such as solar energy or a hybrid car. On the post-test, 138 students gave an answer that related to saving the environment and serving human purposes. Only 8 said "I don't know." On the pre-test, 91% of students already agreed that sustainability matters, but that percent did increase to 97% on the post-test. Student answers on how one can design for sustainability improved greatly. Answers on the pre-test usually involved consumer oriented approaches (car pooling, use of recycled material), and 32 (18%) students said "I don't know. On the post-test, 84% of students gave answers about selecting better materials, better manufacturing processes, and better manufacturing locations; only 5 (3%) said "I don't know."

Two detail oriented follow-up questions were asked and the summary of the responses is presented as a bar chart in Figure 5.

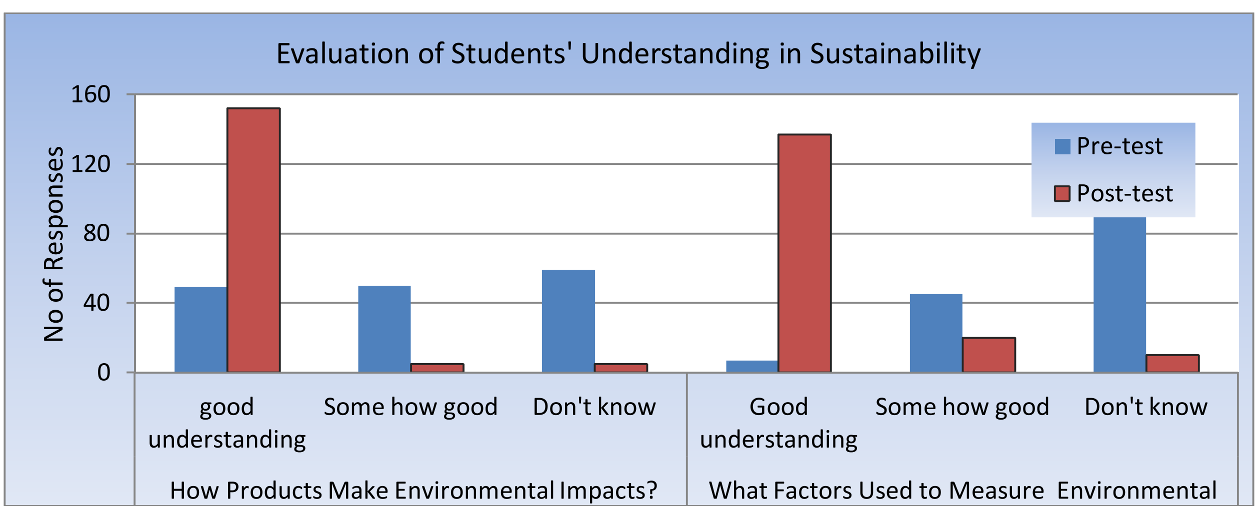

Figure 5 Sustainability Understanding of Students Pre and Post Study (contd.)

As shown in Figure 5, on both the nature of environmental impacts and the factors used to measure environmental impacts, the number of "I don't know" answers decreased, from 34% to 3% on the impacts and from 62% to 6% on the factors. Typical answers on the factors used to measure environmental impacts were more sophisticated and more detailed, including air acidifcation, water eutrophication, and carbon footprint.

This class helped to draw the attention of the students towards sustainability and they were able to have a better perception about sustainability and acquire some ways and means to incorporate sustainability in their design.

From the statistical analysis of the students' responses, it is evident that students' understanding of sustainability has significantly improved on the ABET student outcomes. Students were able to identify a solution (i.e. design a system, criterion c) by meeting the desired needs of sustainability (criterion h). Software, SolidWorks with sustainability, was provided with guided instruction (criterion k) and students were able to understand the impact of the solution to the environment (criterion j).

4.3 Advice to Anyone Adding Sustainability to Engineering Graphic Course

SolidWorks is identified as a design tool that integrates CAD and LCA databases efficiently by extracting and combining geometrical (CAD) data and non-geometrical (LCA or PLM) data.

Although it is claimed that the SolidWorks sustainability package quantitatively assesses the environmental impact of a product throughout its entire lifecycle, from the procurement of the raw materials through the production, distribution, use, disposal, and recycling; the options are not clear for the method of disposal and recycling.

Although it creates an instant and vigorous evaluation of the product by using LCA, the result is just an estimate and lacks reliability. A white paper from SolidWorks states that it should not replace sophisticated LCA software and should be used as an environmental impact dashboard, giving immediate feedback on the impact of design decisions[16].

Toxicity is one of the most dangerous environmental hazards but it is not included in the key indicators' list. The logic behind not including toxicity is that its harmfulness to humans depends upon the level of exposure and time, which is hard to trace in LCA databases. Although this logic is valid to some extent, toxicity cannot be ignored and it should have been incorporated by any means.

The environmental impact comparison capability is limited; only two materials can be compared at a time. The report of the environment impact is presented in SI units only (even for a part modeled with FPS unit). Post processing (formatting) is needed for better presentation of the report. The estimation of material used and manufacturing cycle impact are treated with too little detail. Validation of the proposed approach is lacking, and sensitivity analysis might need to determine the correct order of priorities for the data/parameters.

However, the SolidWorks sustainability module is the only CAD Software that provided an opportunity for engineering students to recognize environmental impacts early in the program and that is relevant to all engineering majors. Use of this module allows a faculty member with limited experience to incorporate sustainability into an engineering graphics class.

5. Conclusion:

In conclusion, relevant software to teach sustainability was identified and used in an engineering graphics class. The sustainability component of SolidWorks was integrated into the existing course. Student learning outcomes were evaluated and a significant improvement in sustainability knowledge was observed. The results also reinforced the ABET learning outcomes related to sustainability.

Teaching two CAD programs in addition to technical drawing concepts might be too much for a two credit hour class, but proper selection of the tools and integration of drawing concepts with CAD served well two interdisciplinary engineering programs: Mechatronics and Industrial Engineering, at our university. Adding sustainability into an already strained course was thought to be a challenge in the beginning, but easy selection options and the automatic sustainability report generation feature in SolidWorks saved both time and complexity, making the course a success.

In summary, integrating sustainability into the engineering graphics course is important to the engineering students because they must understand sustainability and practice it from the beginning and they must be prepared to design sustainable products in future. SolidWorks is a convenient and efficient tool to teach the basics of sustainability design and environmental impact assessment.

6. Future study:

This study was performed over a period of two years in a university offering only two interdisciplinary engineering programs. The study could be extended to other universities offering multiple traditional engineering programs. A more comprehensive comparative study of SolidWorks Sustainability with other CAD and LCA software might lead to a better solution.

References

[1] United Nations, "Report of the World Commission on Environment and Development. 42/87 " United Nations, New York, USA1987.

[2] EPA. P3: People, Prosperity and the Planet [Online]. Available: http://www.epa.gov/P3/

[3] A. Mayyas, A. Qattawi, M. Omar, and D. Shan, "Design for sustainability in automotive industry: A comprehensive review," *Renewable and Sustainable Energy Reviews,* vol. 16, pp. 1845-1862, 5// 2012.

[4] S. A. Waage, "Re-considering product design: a practical “road-map” for integration of sustainability issues," *Journal of Cleaner Production,* vol. 15, pp. 638-649, // 2007.

[5] W. H. Vanderburg, "On the measurement and integration of sustainability in engineering education," *Journal of engineering education-Washington-,* vol. 88, pp. 231-236, 1999.

[6] S. J. Grimberg, T. A. Langen, L. D. Compeau, and S. E. Powers, "A theme-based seminar on environmental sustainability improves participant satisfaction in an undergraduate summer research program," *Journal of engineering education-washington-,* vol. 97, p. 95, 2008.

[7] E. Pappas, O. Pierrakos, and R. Nagel, "Using Bloom's Taxonomy to teach sustainability in multiple contexts," *Journal of Cleaner Production*, 2012.

[8] K. Blincoe, A. Fuad-Luke, J. H. Spangenberg, M. Thomson, D. Holmgren, K. Jaschke*, et al.*, "DEEDS: a teaching and learning resource to help mainstream sustainability into everyday design teaching and professional practice," *International Journal of Innovation and Sustainable Development,* vol. 4, pp. 1-23, 2009.

[9] M. R. Othman, L. Hady, J. U. Repke, and G. Wozny, "Introducing sustainability assessment and selection (SAS) into chemical engineering education," *Education for Chemical Engineers,* vol. 7, pp. e118-e124, 8// 2012.

[10] C. Boks and J. C. Diehl, "Integration of sustainability in regular courses: experiences in industrial design engineering," *Journal of Cleaner Production,* vol. 14, pp. 932-939, // 2006.

[11] M.-C. Chiu and C.-H. Chu, "Review of sustainable product design from life cycle perspectives," *International Journal of Precision Engineering and Manufacturing,* vol. 13, pp. 1259-1272, 2012.

[12] S. Rama Murthy and M. Mani, "Design for sustainability: The role of CAD," *Renewable and Sustainable Energy Reviews,* vol. 16, pp. 4247-4256, 8// 2012.

[13] A. Morbidoni, C. Favi, and M. Germani, "CAD-Integrated LCA Tool: Comparison with dedicated LCA Software and Guidelines for the improvement," *Glocalized Solutions for Sustainability in Manufacturing,* pp. 569-574, 2011.

[14] SolidWorks. SolidWorks Sustainability: FAQ [Online]. Available: http://www.solidworks.com/sustainability/products/2795_ENU_HTML.htm

[15] S. Minds. Connecting ecodesign with LCA for a new generation of greener products [Online]. Available: http://www.sustainableminds.com/business-case/ecodesign-and-lca

[16] A. P. Rudy Ruggles, Benjamin Linder. (2012, 09/06/12). *Guide to Sustainable Design Using SolidWorks Sustainability*.

[17] W. Wimmer, R. Zuest, and K.-M. Lee, *Ecodesign Implementation - A Systematic Guidance on Integrating Environmental Considerations into Product Development*. Dordrecht, Netherlands: Springer, 2004.

[18] C. L. Dym, "Learning engineering: Design, languages, and experiences," *Journal of engineering education-washington-,* vol. 88, pp. 145-148, 1999.

[19] R. Barr and D. Juricic, "From drafting to modern design representation: The evolution of engineering design graphics," *Journal of Engineering Education,* vol. 83, pp. 263-270, 1994.

[20] ABET. General Criteria 3. Student Outcomes [Online]. Available: http://abet.org/DisplayTemplates/DocsHandbook.aspx?id=3149

[21] I. O. f. Standardization, "Environmental management - Life cycle assessment - Requirements and guidelines," in *Life cycle impact assessment (LCIA)* vol. ISO 14044, ed. Switzerland: International Organization for Standardization, July, 2006, pp. 16-23.