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USING PRODUCT ARCHAEOLOGY TO INTEGRATE GLOBAL, ECONOMIC, ENVIRONMENTAL, AND SOCIETAL FACTORS IN INTRODUCTORY DESIGN EDUCATION

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ABSTRACT

Design education has traditionally been incorporated into the engineering curriculum in the junior or senior year through upper level mechanical design courses and capstone design projects. However, there is a general trend in engineering education to incorporate design activities at the freshman and sophomore level. The design aspects of these courses provide a unique opportunity to integrate global, economic, environmental, and societal factors with traditional design considerations. Incorporating these early in an engineering curriculum supports a broad engineering education in accordance with ABET required Outcome h. In this paper we introduce global, economic, environmental, and societal factors into a sophomore level engineering design course using strategies adapted from a Product Archaeology paradigm. Specifically, functional modeling is synthesized with a product dissection platform to create a foundation to demonstrate the broader impacts of engineering design decisions. The effectiveness of using Product Archaeology-based educational strategies to facilitate the learning objectives of Outcome h is evaluated using student surveys taken over a two year period.

1 INTRODUCTION

Many engineering departments find it challenging to meet the requirements of ABET Outcome h. To fulfill Outcome h ABET requires an engineering program to provide "…*the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,*" [1]. Providing engineering students with useful and engaging educational experiences targeting the global, economic, environmental, and societal impacts of engineering solutions is a difficult task that entire teams of faculty are working to address. Possible course approaches include early cornerstone design courses aimed at engaging students in their freshmen and sophomore years, or later synthesis level design courses targeted at the junior or senior years.

Another common response to provide a more global, socially sensitive context is to engage students in study abroad experiences. While the number of study abroad students has historically been increasing, current economic conditions have impacted the ability of students and universities to fund such experiences. The challenge is therefore obvious – providing opportunities for students to experience global, social, economic and environmental issues in engineering, with no funds to support the actual overseas travel. Addressing this challenge in the classroom has the additional advantage of engaging all engineering students, rather than only those who elect to engage in study abroad activities.

In this paper we address this challenge in an innovative way using *product archaeology* (PA) as the core curriculum paradigm. PA involves the process of reconstructing the lifecycle of a product – the customer requirements, design specifications, and manufacturing processes used to produce it – to understand the decisions that led to its development. By considering products as designed artifacts with a history rooted in their development, we synthesize concepts from archaeology with advances in cyber-enhanced product dissection [2]. This synthesis enables us to implement new educational innovations that integrate global, economic, environmental, and societal concerns into engineering design-related courses using PA.

The imagery typically associated with archaeology is of archaeologists in the field, digging in the dirt hoping to uncover artifacts that help them understand the life and times of the locations previous inhabitants. The responsibility of an archaeologist is "…*to reconstruct life and culture of past ages through the study of objects created by humans, known as artifacts,*" [3]. Although archaeologists use a variety of tools and methods in their work, their approach to a new site can be generalized into four phases: (1) preparation, (2) excavation, (3) evaluation, and (4) explanation [4].

A typical activity for an archaeologist to prepare a site might be to take aerial photographs to assess the layout of the site, and research the history of the inhabitants. The excavation phase is associated with the common imagery for archaeology and archaeologists may indeed spend time digging and exploring the site. During this exploration an archaeologist looks for artifacts, tools, clothes, art, and other relevant evidence of its previous inhabitants. Based on the nature of the site and the artifacts uncovered, the evaluation phase can include methods for chronological analysis (e.g., carbon dating), or analyzing the social, environmental, and technological aspects of the site and its inhabitants. Based on the evidence that is obtained, archaeologists conclude the study by developing suitable theories to explain what transpired at the site drawing from a wide range of theories (e.g., migration, diffusion) and explanations [4].

If we consider consumer products as the artifacts under investigation, then we can create many useful pedagogical analogies with archaeology for engineering. We begin by defining product archaeology as the process of reconstructing the lifecycle of a product – *the customer requirements, design specifications, and manufacturing processes used to produce it – to understand the decisions that led to its development*. The concept of product archaeology is not new; it was first introduced by Ulrich and Pearson [5] as a way to measure the design attributes that drive cost through analysis of the physical products themselves.

Our understanding of archaeology in the context of the design of complex engineered products and systems is much broader. The PA paradigm provides an opportunity to study not only the development and manufacturing cost (i.e., economic issues) of a product, but also the global and societal context that influenced its development. It also provides a context for studying the environmental impact of a product by considering the product's energy and material usage throughout its life cycle. When implemented in an engineering classroom, PA allows students to place themselves in the minds of designers during the time a specific product was developed to try to re-create the global and local conditions that motivated the decision making process driving its development.

Before studying how global, economic, environmental and societal factors can be integrated into introductory engineering courses using the PA paradigm we first define these terms Section 3. We also provide motivating examples for their exploration and discuss how a PA paradigm emphasizing these factors can be integrated into a sophomore level engineering design course. The details of this implementation are discussed in Section 4. Finally, we examine the effectiveness of our approach using a set of student surveys in Section 5. First, however, we refine the PA paradigm and map PA activities to student level using a framework for product dissection in the following section.

2 BACKGROUND

There is a natural analogy between PA and product dissection activities. We use this analogy to create an educational framework for PA that relates PA activities based on the level of the students involved in the activity. An overview of this framework is shown in Figure 1.

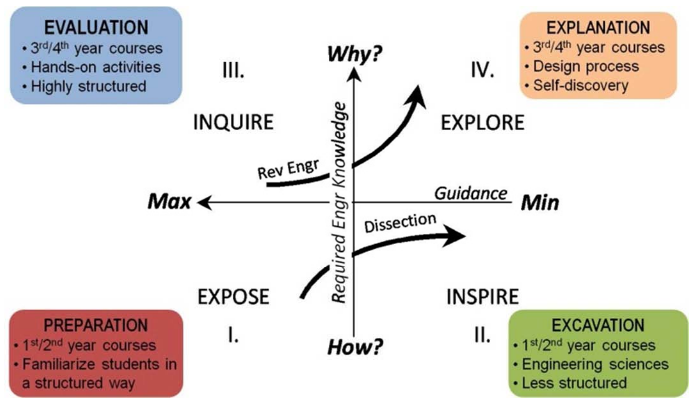

Figure 1: Product Archaeology Framework

The framework utilizes two axes to indicate: (1) the amount of guidance provided by the instructor through either oral or written instructions, and (2) the students' required engineering knowledge, ranging from students being able to answer *how questions* (e.g., how does the device work?) to *why questions* (e.g., why did designers choose this material?) that can be answered through product archaeology activities. The Expose-Inspire-Inquire-Explore quadrant lexicon is based upon the original product dissection-based framework presented in [6]. The level and type of activity for each quadrant are described as follows:

I. ***Expose*** – Best suited for 1st and 2nd year courses to familiarize students with products and artifacts in a structured way, to teach students engineering vocabulary and terminology, and to overcome any anxiety with engineering; must be highly structured to ensure proper progress through the activities.

II. ***Inspire*** – Useful in 1st and 2nd year courses to introduce design, graphics, or reinforce fundamentals from engineering courses such as statics and mechanics of materials; usually less structured to promote self-discovery.

III. ***Inquire*** – Primarily used in 3rd and 4th year courses to provide hands-on activities to reinforce engineering principles and theory; usually highly structured to ensure that the material is covered properly.

IV. ***Explore*** – Appropriate for 3rd and 4th year design courses to support idea generation, redesign, and benchmarking; application of 'core' engineering knowledge; or an integral part of a design process; usually requires the least amount of supervision – intended to foster self-discovery.

These phases are mapped to the four phases of PA as a way to embody tangible strategies for providing opportunities for students to get exposed, get inspired, inquire, and explore.

This framework has been integrated with the Kolb model of experiential learning to guide future pedagogical developments based on more advanced product archaeology exercises. Kolb argues that learning is a four-stage process involving the four learning modes of concrete experience, reflective observation, abstract conceptualization, and active experimentation [7]. It is proposed in [8] that that Kolb's four stages of learning can be mapped to the four phases of archaeological exploration as shown in Figure 2.

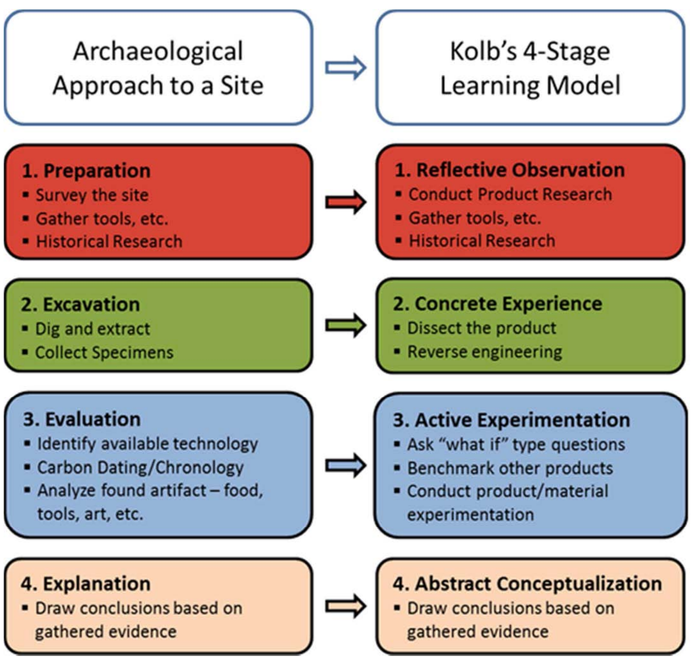

Figure 2: Mapping Archaeological Exploration to Kolb's Model

Specifically, during the *preparation* phase students reflect on what they know about the factors that impact the design of particular products and postulate responses to several questions relating to economic, societal, etc. aspects of the designs. The *excavation* activities serve as concrete experiences where students can physically dissect products and perform appropriate research to develop well-reasoned answers to specific design-related questions. The *evaluation* and *explanation* phases provide opportunities for students to actively experiment and abstract meaning from both their research and concrete dissection experiences, reflecting on their work in the context of how global, economic, environmental and societal factors influence design decisions.

It is important to embed explicit opportunities for students to reflect on their experiences and, based on these reflections, abstract ideas about how components function and why they are made based on global, economic, environmental, and societal influences. In this way, our pedagogy and assessment mechanisms provide a holistic learning experience with equal emphasis on the four learning modes in Kolb's model.

In the remainder of this paper we discuss an application of this model in a sophomore level introduction to mechanical engineering course. The core of this course is a semester long reverse engineering project in which students are engaged in activities described by Kolb's four stage model. In the following section we discuss global, economic, environmental and societal factors in engineering design as they relate to engineering decision making and map the activities of the reverse engineering project to Kolb's model.

3 IMPLEMENTATION

Although there has been significant work to integrate global, economic, environmental, and societal factors, called the four factors, into the engineering curriculum, these terms have a different meaning for different people. In this section we discuss our definitions for the four factors to provide context for their integration into a sophomore level introduction to mechanical engineering course in Section 3.1. In Section 3.2 we discuss the structure of the course and examine the integration of the four factors using PA as the driving paradigm.

3.1 The Four Factors

As part of ABET's criterion 5 for engineering programs, engineering design is defined as *"…the process of devising a system, component or process to meet desired needs,"* [1]. How engineered products and systems are deployed is dependent on the environment into which they must operate. Traditionally this has meant that requirements and design constraints were dictated by the physical environment. However, the diversity of the environments in which products and systems are expected to operate is increasing and influences that extend beyond the physical environment are becoming more important.

For engineers to be successful in the future they must understand these influences, which we present in four broad groups that consider the global, economic, environmental and societal influences on design. In each of the following subsections we define these terms and provide an example of how they can influence the design of engineered products and systems.

3.1.1 Global Factors

We define global factors to be *influences that result from cultural and geographic features specific to a region or originating from the interaction of two or more culturally/geographically distinct regions.* Global factors examine the cultural impact of a product that must be taken into consideration in the design process and the geographic features that influence the design of products and systems. An example of a global factor that relates to design is illustrated in Figure 3.

Figure 3: Global Factor in Design

In Figure 3, two wedding dresses are shown, one on the left in an Eastern style while the one on the right is in a Western style. Traditionally in the West white represents purity, peace and good. In the East, however, white is a symbol for mourning and is worn at funerals. Red, on the other hand, is symbolic of good luck and success [9].

Culturally, color choices can have a significant impact on how a product is perceived and interpreted in that culture. To guide students towards identifying potential global considerations associated with engineered products and systems we provided them with the following prompt questions:

What is the purpose of the product, how does it work, what are the intended global market segments, and how are cultural needs addressed with the product?

How do people with different cultures and demographics use the product and what are the functions that the product fulfills?

How does the company address global market needs in the design of their current line of products?

How can the company address these issues better in their future global product lines?

Student responses to these questions are discussed in the Section 4 where we provide qualitative feedback on their responses. In the next subsection we discuss the economic factors that influence engineering design.

3.1.2 Economic Factors

We define economic factors to be *influences that result from the economic conditions at the time of a product's development and its past, present, projected sales and support life cycle.* Economic factors consider the costs associated with a product across its entire lifecycle. An example of an economic factor that influences an engineering decision is illustrated in Figure 4.

In Figure 4 two sets of wires are shown. The one on the left is traditional copper wire while the one on the right is aluminum wire. Aluminum wire has been used in the United States for electrical transmission applications since the early 1900's. During the 1960's the price of copper increased significantly and aluminum was presented as an alternative conductor for use in homes. Since then it has been attributed to a number of house fires and its use, although not prohibited, largely fell out of practice by the mid 1970's [10].

Figure 4: Economic Factor in Design

The true cost of the switch to aluminum wires is both a function of the reduction in price for the wires, the cost of the fires associated with the installation, and the cost to retrofit homes with copper wire for safety. In this case only a portion of these costs are carried by the home builder, which means there are externalities associated with the decision to use aluminum wires. To guide students in examining economic factors that influence design decisions we provided them with the following prompt questions:

What were the economic conditions at the time this product was designed and manufactured and how are economic issues reflected in the product's design?

What tools are required, how many steps are needed and how easy is it to dissect the product?

What are the competing products, and how are these economic issues reflected in the design of the product?

Given current and projected economic conditions, what can engineers at the company do to enhance the economic impact of the product on the company?

Student responses to these questions are discussed in Section 4. Since economic decisions often involve externalities, student responses also tended to address the environmental factors associated with engineering design. In the following subsection we discuss these environmental factors.

3.1.3 Environmental Factors

We define environmental factors to be *influences that result from the product's environmental impact during development, manufacturing, sales, operation and disposal.*

Environmental factors are often closely linked to global, economic and societal factors in engineering decision making. This is because their impact on an organization is often felt indirectly through fines or changing public opinion. An example of an environmental impact on product design is shown in Figure 5.

Figure 5: Environmental Factor in Design

In Figure 5 one of the new Sun Chips bag is shown. In the past, bags of this type have been made of a polymer resin which does not break down easily in the natural environment. For Sun Chips, Frito Lay introduced a new bag in April 2009 that breaks down in 14 weeks in a hot, active compost heap [11]. Unfortunately, complaints about the noise the bag makes led to its pullback in the United States. However, the marketing of Sun Chips as an environmentally conscientious product demonstrates the potential for environmental considerations to play a major role in engineering decisions. A set of prompt questions were developed and used to guide students in exploring environmental factors in engineering.

What are the planned environmental impacts of this product and what are the environmental factors engineers had to consider in the design of the product?

What material type and manufacturing process was used for each major component or group of components?

What are the actual environmental impacts of this product and what are the environmental factors engineers have to consider in the design of the product?

How can the company reduce the cradle to grave environmental impact in future products and product lines?

Responses to these questions are discussed in Section 4 as part of our qualitative assessment of the students. Many students noted in their response, however, that environmental factors were closely linked to global and societal factors. We define societal factors in the following subsection.

3.1.4 Societal Factors

We define environmental factors to be *influences that result from considering the impact like safety, ergonomics and lifestyle on the people and society within which a product is being used*. Societal factors are often closely associated with cultural considerations where culture summarizes the set of beliefs and traditions associated with a people, societal impacts examine their behavior and actions. Changes to lifestyle are possible within the same set of cultural values and norms. An example of a societal factor that demonstrates this is illustrated with the BlackBerry shown in Figure 6.

Figure 6: Social Factor in Design

The first BlackBerry was released by Research in Motion in 1999 [12]. The BlackBerry made it possible for individuals to access the internet and e-mail from most locations with cellular phone reception and significantly increased employee availability. The lifestyle impact of the BlackBerry and other smartphones has been significant they are now an integral part of people's daily lives [13]. To guide students in identifying the societal factors influencing product decisions a set of prompt questions have been developed.

What is the planned impact of the product on the culture and lifestyles of the customer base?

What is the primary function of each major component or group of components? Note how its structural form helps fulfill its function.

What is the actual impact of the product on the culture and lifestyles of the customer base?

How can the company address social use issues such as safety, ergonomics, product use experiences, and lifestyle impact better in future products?

Student responses to these questions are discussed in Section 4. Before examining these results, however, we describe how the definitions presented for the four factors are integrated into an introductory engineering course. This integration uses a PA paradigm and cyber-enhanced dissection as described in the following section.

3.2 MAE 277 Course Description

MAE 277 is a sophomore level course with an annual enrollment of approximately 150 students, for mechanical engineering students at the University at Buffalo-SUNY. The purpose of this course is to introduce the basic tenets of professional and ethical practice as a mechanical engineer while emphasizing the role of engineers in making system level decisions; this is grounded by introducing the concept of engineering design and the design process. It is through the lens of engineering design that students are introduced to basic estimation, modeling, and analysis techniques. These concepts are reinforced through in-class exercises, homework assignments, and a semester long product dissection project.

The course project requires that students work in groups of four to six members to dissect and analyze the design of a product. These products range from consumer electronics to automobile engines. The project follows a gated process which is aligned with Kolb's four-stage learning model. This relationship along with the corresponding PA phase for each gate is shown in Table 1. In the next section, the implementation of the four factors is described.

Table 1: Project Gate Alignment to Kolb's Stages

Kolb's 4-Stage Learning Model	Project Gates
Reflective Observation - Conduct Product Research - Gather Tools, etc. - Research	**Gate 1: Preparation and Initial Assessment** Students research the background of their product and perform an initial assessment of how the product works and what tools will be needed for the dissection.
Concrete Experience - Dissect the product - Reverse engineering	**Gate 2: Product Dissection** Students dissect their product to collect detailed information on utilized components, component connectivity, and product assembly.
Active Experimentation - Ask "what if" questions - Benchmark other products - Conduct product/material experimentation	**Gate 3: Product Analysis** Students perform a detailed analysis of components analyzing material choice, shape, etc. in relation to product functionality and performance.
Abstract Conceptualization - Draw conclusions based on gathered evidence	**Gate 4: Product Explanation** Students synthesize detailed information to draw higher level design decision conclusions.

4 FOUR FACTORS IMPLEMENTATION

This section highlights how the four factors were integrated into the existing structure of the course. This was done through lectures, in-class activities, and the course project. Additionally, the importance of the four factors was reinforced with their inclusion on course exams.

4.1 Four Factors Lectures and In-class Activities

The first lecture introduces the motivation and definitions of the four factors. As a class discussion, products are introduced and the four factors are applied to them. A sample of the products used in this discussion is shown in Figure 7. This lecture comes after engineering design and the design process have been introduced, and before the course moves into engineering models. This timing places the lecture in the middle of the students' first project gate.

The second lecture finalized the unit on manufacturing. Here the relationship between the four factors and the manufacturing of products was examined. The topics covered included energy usage, material waste, byproducts, facility geography, and human labor.

Figure 7: Products to Demonstrate the Four Factors

The third lecture leveraged functional models [14] that were created earlier in the semester by each project group. These functional models were created as part of the engineering models unit. The functional models were annotated as shown in Figure 8 to identify where there may be potential engineering concerns that arise from the four factors. Examples of this include how the product imports and stores energy. This was demonstrated initially with the functional model for a vacuum cleaner, shown in Figure 9 (and reproduced in larger format in the Appendix), and then each project group worked together to identify four factors design considerations for their own products.

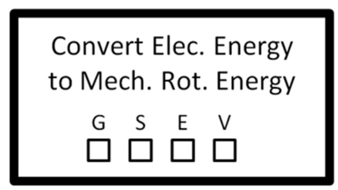

Figure 8: Annotated Function

Towards the end of the semester, three additional lectures included the four factors and how they related to more advanced engineering design concepts. One lecture focused on how the four factors influenced distributed design networks. Another lecture introduced the basic concepts of optimization, discussing the impact of the four factors on the objective function and constraints. The last lecture focused on how product families and reconfigurable systems can be used to address design constraints that arise from the four factors.

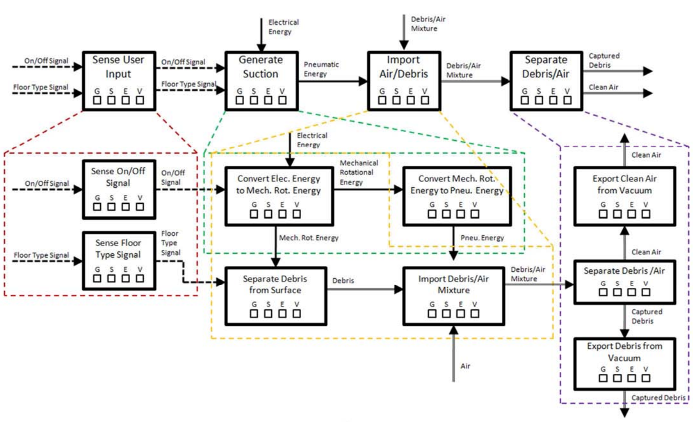

Figure 9: Functional Model for a Vacuum Cleaner

4.2 Four Factors and the Project Dissection Project

The four factors played an integral role in expanding the scope of product analysis. The four factors were used in developing analysis prompt questions, and scoping the design revisions section. The influence of the four factors on each of the project gates is shown in Table 2.

Table 2: Four Factors Influence on the Project Gates

Project Gate	Four Factors Influence
Preparation and Initial Assessment	**Analysis Prompt Questions** What were the key economic and global concerns at the time of development? In what countries or regions is the product intended to be sold? What was the intended impact on the consumer and the society in which it is used?
Product Dissection	**Analysis Prompt Questions** How do global, societal, economic, and environmental concerns influence how subsystem connections are made? Is the product intended to be disassembled? Why or why not?
Product Analysis	**Analysis Prompt Questions** What environment do the components function in? What manufacturing methods were used to make the part? What evidence supports this? Did material choice impact this decision? Did shape impact the method selected? How did global, societal, economic, and environmental factors influence the decision? **Design Revisions** Recommend at least 3 design changes for the product at the ***component or subsystem*** level, including features you would change or eliminate and components you would combine or eliminate. These changes should address one or more of the following: global, societal, economic, or environmental concerns. The changes should improve performance, serviceability, cost, etc. Keep in mind the products target audience and price point when making changes.
Product Explanation	**Analysis Prompt Questions** How was the product originally assembled? **Design Revisions** Recommend at least 3 design changes for the product at the ***system*** level, including features you would change or eliminate. These changes should address one or more of the following: global, societal, economic, or environmental concerns. The changes should improve performance, serviceability, cost, etc. Keep in mind the products target audience and price point when making changes.

In the next section, we present the results of evaluating the impact of these course implementations and compare these results to those from the 2009 offering of the same course.

5 RESULTS

In this section we discuss the results of incorporating the four factors into MAE 277, a sophomore level introduction to mechanical engineering course. To assess the implementation of the materials in Section 4, items from the national Prototype to Production (P2P) Engineer of 2020 (E2020) study [13] and additional course-specific items were used to create a survey that was administered at the end of the fall 2009 and 2010 semesters. The fall 2009 students completed the course without directly being introduced to the four factors. The 2009 results were used as a control to compare to the 2010 class who were introduced to the four factors as part of the course curriculum as described in Sections 3 and 4. Some of the course-specific items measured the effectiveness of cyber-enhanced product dissection, the results of which are discussed in [2]. We present the quantitative results of this survey in Section 5.2. Before presenting these results, however, we introduce the survey questions used to assess the students' perception of the four factors.

5.1 Survey Formulation

The full survey was composed of 132 questions, broken into three separate surveys. These surveys were administered over three separate class periods and students were permitted to take them home to complete them. All surveys were conducted anonymously and were collected by an individual not associated with the course.

In the portion of the survey being used to assess the impact of the four factor implementation, the students were asked to evaluate how much two sets of courses had emphasized four groups of learning objectives: 1) Applying Math & Science, 2) Topics in Engineering, 3) Professional Skills, and 4) Problem Solving Skills. The learning objectives for each group are shown in the Appendix.

Two rounds of surveys were used to isolate the impact of MAE277 on these learning objectives. The first set of questions evaluated how much *all other engineering courses besides MAE277* emphasized the objectives; the second set evaluated how much *MAE277 alone* emphasized them. The questions were all multiple choice questions using a Likert scale as illustrated with the sample question in Figure 10. As shown in the Appendix, the sample question shown in Figure 10 was grouped under the general heading "Problem Solving Skills". A scale from -2 to 2 was used to score the survey questions for this assessment.

Problem Solving	Little/no emphasis	Slight	Moderate	Strong	Very strong
Understanding how an engineering solution can be shaped by environmental, cultural, economic, and other considerations	❍	❍	❍	❍	❍

Figure 10: Sample Survey Question

In the surveys there are 4 questions directly related to assessing Outcome h, as they address the students' understanding of global, economic, environmental, and societal issues in engineering practice. These questions are summarized in Table 3 along with two control questions.

Table 3: Four Factors Survey Questions

Question #	Survey Question	Related Factor
7	Examining my beliefs and values and how they affect my ethical decisions.	G
8	The value of gender, racial/ethnic, or cultural diversity in engineering.	G
10	Current workforce and economic trends (globalization, outsourcing, etc.).	G, E
18	Understanding how an engineering solution can be shaped by environmental, cultural, economic, and other considerations	G,E,V,S
20	Systems thinking	Control
23	Generating and evaluating ideas about how to solve an engineering problem	Control

The student questions listed in Table 3 were formulated to examine the factor(s) shown in the right hand column. The abbreviations in this column are: global (G), economic (E), environmental (V) and societal (S). The student responses to these questions are evaluated and discussed in the following section.

5.2 Quantitative Assessment

This section looks at the students' survey responses for the questions related to the four factors. Figure 11 shows the mean response to the questions outlined in Table 3, with one standard deviation shown as an error bar. Questions 7, 8, 10, and 18 which are aligned with the four factors show an increased response rate. This suggests that the introduction of the four factors helped emphasize the multidisciplinary topics. The responses for Questions 20 and 23 are shown to indicate that the emphasis on the four factors did not negatively impact other important areas.

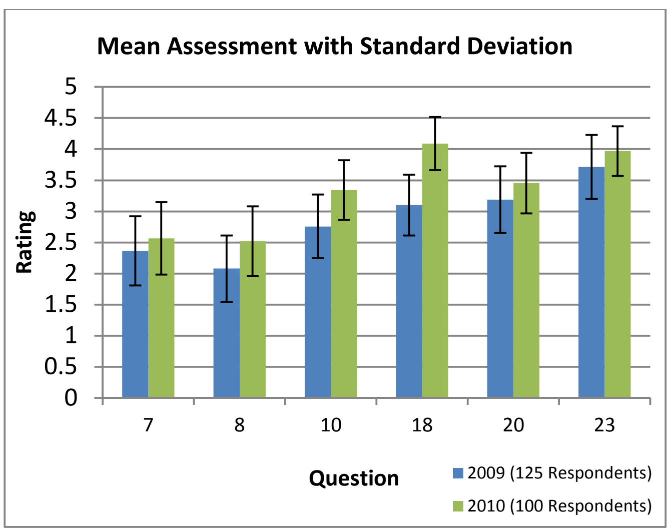

Figure 11: Student Response to Survey Questions (Table 3)

Of the 23 topic areas shown in the Appendix, the 2010 offering of MAE277 had a statistically significant impact (with p-values of less than 0.05) relative to the other engineering courses in 6 of them as shown in Table 4. Paired samples t-tests were used to compare student's responses to items regarding the two sets of courses. To control for multiple comparisons, a post hoc Bonferroni correction was administered. The technical communication differences are likely a result of the semester long project, which includes a presentation to the class. The impact of the four factors is clearly shown in the difference in response to Question 18. To further understand the impact of the four factors, the survey results were compared with the results from the previous year.

Table 4: Statistical Significance of Four Factors (2010)

#	Question	All other courses (avg)	MAE 277 (avg)	*p*-value
5	Ethical issues in engineering practice	2.57	3.94	< 0.001
13	Professional skills (knowing codes and standards, being on time, meeting deadlines, etc.)	3.16	4.04	< 0.01
14	Written and oral communication skills	3.45	4.35	< 0.001
15	Leadership skills	3.05	4.16	< 0.05
18	Understanding how an engineering solution can be shaped by environmental, cultural, economic, and other considerations	2.72	4.27	< 0.05
22	Defining a design problem	3.22	4.64	< 0.05

Table 5 compares the results from 2010 to 2009, where the *four factors were not implemented*. These results demonstrate that the four factors improved the emphasis of key concepts related to ABET Outcome h, as can be seen in the responses to the Question 18. One additional difference that was not necessarily expected was the difference in response to Question 22, which focuses on defining a design problem. While the course was taught by different instructors, the curriculum did not change significantly enough for this result to be expected. One explanation for this is the discussion of the four factors helped emphasize the multidisciplinary nature of design.

Table 5: Comparison of 2009 and 2010

#	Question	MAE 277 (avg)		*p*-value
5	Ethical issues in engineering practice	2009	2.71	>0.05
		2010	3.94	< 0.001
13	Professional skills (knowing codes and standards, being on time, meeting deadlines, etc.)	2009	3.61	>0.05
		3.16	4.04	< 0.01
14	Written and oral communication skills	2009	3.91	< 0.001
		2010	4.35	< 0.001
15	Leadership skills	2009	3.56	< 0.01
		2010	4.16	< 0.05
18	Understanding how an engineering solution can be shaped by environmental, cultural, economic, and other considerations	2009	3.10	>0.05
		2010	4.27	< 0.05
22	Defining a design problem	2009	3.78	>0.05
		2010	4.64	< 0.05

6 CONCLUSIONS

This paper summarizes an effort to incorporate global, economic, environmental, and societal considerations into a sophomore level engineering course. These four factors were integrated into course lectures and the semester long product archaeology project. The introduction of the four factors served to emphasize the principles associated with ABET Outcome h. Further, it appears that the four factors also improve the students understanding of the multidisciplinary nature of design. Exposure to the four factors early in the curriculum offers the additional advantage of providing context for more specialized courses which will be taken later on.

The four factors were found to integrate easily with the existing curriculum. Additionally, they provide context for a number of traditional introductory engineering topics, including but not limited to analysis, units and dimensions, modeling, and ethics. A key contribution of the four factors is that they effectively highlight the current state of engineering. Engineering is no longer a profession driven solely by technical issues – engineers must now understand the global implications of their decisions on social communities, corporate economics, and the environment. In this work, we are focusing on enriching the limited exposure that students currently get to many of these topics.

Current work includes continued development of instructional material, course plans, and assessment strategies across the entire undergraduate design curriculum and studies aimed at identifying multi-year trends in the results. These materials will be disseminated through continuing workshops for faculty and students as well as through the product archaeology website: www.productarchaeology.org.

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APPENDIX

#	Applying Math & Science	Little/no emphasis	Slight	Moderate	Strong	Very strong
1	Math to engineering problems	❍	❍	❍	❍	❍
2	The physical sciences to engineering problems	❍	❍	❍	❍	❍
3	Computer tools and applications to engineering problems	❍	❍	❍	❍	❍
4	Life sciences to engineering problems	❍	❍	❍	❍	❍
	Topics in Engineering	**Little/no emphasis**	**Slight**	**Moderate**	**Strong**	**Very strong**
5	Ethical issues in engineering practice.	❍	❍	❍	❍	❍
6	The importance of life-long learning.	❍	❍	❍	❍	❍
7	Examining my beliefs and values and how they affect my ethical decisions.	❍	❍	❍	❍	❍
8	The value of gender, racial/ethnic, or cultural diversity in engineering.	❍	❍	❍	❍	❍
9	Creativity and innovation.	❍	❍	❍	❍	❍
10	Current workforce and economic trends (globalization, outsourcing, etc.).	❍	❍	❍	❍	❍
11	Emerging engineering technologies.	❍	❍	❍	❍	❍
12	How theories are used in engineering practice.	❍	❍	❍	❍	❍
	Professional Skills	**Little/no emphasis**	**Slight**	**Moderate**	**Strong**	**Very strong**
13	Professional skills (knowing codes and standards, being on time, meeting deadlines, etc.)	❍	❍	❍	❍	❍
14	Written and oral communication skills	❍	❍	❍	❍	❍
15	Leadership skills	❍	❍	❍	❍	❍
16	Working effectively in teams	❍	❍	❍	❍	❍
17	Project management skills (budgeting, monitoring progress, managing people, etc.)	❍	❍	❍	❍	❍
	Problem Solving	**Little/no emphasis**	**Slight**	**Moderate**	**Strong**	**Very strong**
18	Understanding how an engineering solution can be shaped by environmental, cultural, economic, and other considerations	❍	❍	❍	❍	❍
19	Understanding how non-engineering fields can help solve engineering problems	❍	❍	❍	❍	❍
20	Systems thinking	❍	❍	❍	❍	❍
21	Applying knowledge from other fields to solve an engineering problem	❍	❍	❍	❍	❍
22	Defining a design problem	❍	❍	❍	❍	❍
23	Generating and evaluating ideas about how to solve an engineering problem	❍	❍	❍	❍	❍

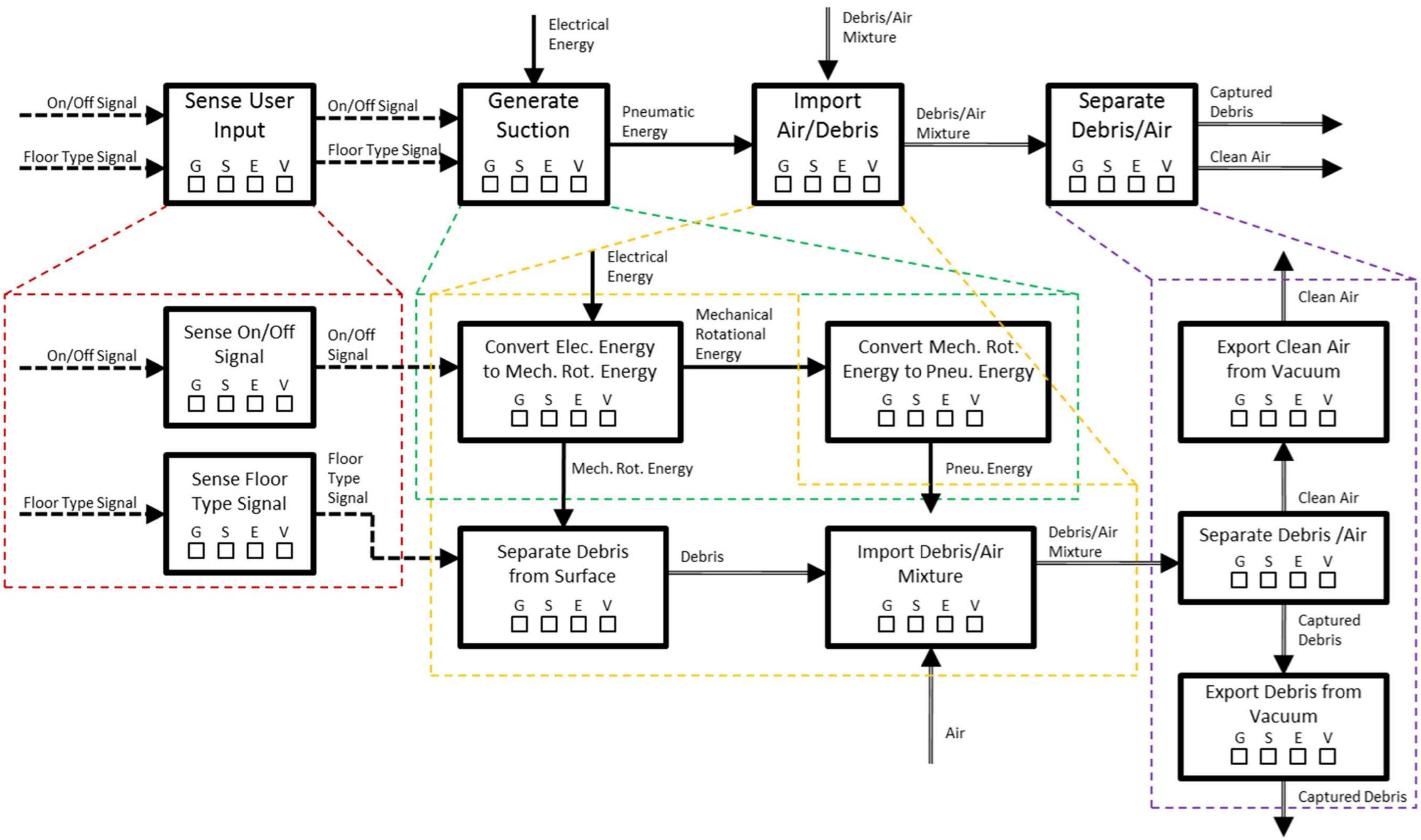

Figure 9 (Reproduced): Functional Model for a Vacuum Cleaner