Advances in Engineering Education

SUMMER 2013

Embedding Context in Teaching Engineering Design

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ABSTRACT

Understanding the global, societal, environmental and economic (GSEE) context of a product, process or system is critical to an engineer's ability to design and innovate. The already packed curricula in engineering programs provide few occasions to offer meaningful experiences to address this issue, and most departments delegate this requirement to an early cornerstone or later capstone design experience as a result, making these courses an ineffective "catch all". To address this challenge, we utilize the paradigm of *product archaeology*, to understand the decisions that led to a product's development. Product archaeology is defined as the process of reconstructing the lifecycle of a product – the customer requirements, design specifications, and manufacturing processes used to create it. By considering products, processes and systems as designed artifacts with a history rooted in their development, we embed GSEE context as a central component in developing design solutions. In the current work, students focus primarily on the useful life of products and their design solutions, rather than on product end-of-life issues. Specifically, in our work we have implemented several approaches to integrate contextual thinking related to GSEE dimensions into a senior level engineering design course. Following Kolb's model of experiential learning and an instructional framework adapted for product archaeology (inclusive of evaluate-explain – prepare - excavate activities) we have restructured the course to embed specific and targeted reflection, dissection, and analysis activities so that student teams effectively address the GSEE factors in their design solutions. This paper provides the theoretical framework of our instructional approach, describes the specific didactic activities we implemented, and summarizes results from our qualitative analysis. Overall, our results suggest that the use of product dissection

and GSEE activities is an effective way to equip students with new tools to understand contextual, technical, and functional properties of their design projects.

Key Words: Product architecture, design, global and societal

INTRODUCTION

Embedding global, societal, environmental, and economic aspects (GSEE) into engineering design instruction is a significant challenge to many engineering departments. We address this issue by extending the concept of *product archaeology*, through embedding questions about GSEE aspects into students' regular class deliverables, such as product design specifications, detailed design reports, final reports and others. Product archaeology is defined as the process of reconstructing the lifecycle of a product, including the customer requirements, design specifications, and manufacturing processes used to produce it.

The concept of product archaeology was first introduced by Ulrich and Pearson [1] as a way to measure the design attributes that drive cost through analysis of the physical products themselves. Our view not only considers the manufacturing cost of a product (i.e., economic issues), but also the global and societal context that influenced its development. It also provides a framework for studying the environmental impact of a product by considering, for example, the energy and material usage throughout the life cycle of the product. When implemented in an engineering classroom, product archaeology 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 led to its development.

Similar to archeologists out in the field, digging in the dirt, hoping to uncover artifacts that help them understand the life and times of the previous inhabitants, product archaeology asks students to dig out information related to GSEE aspects through product dissection (virtual and physical), user testing, interviews and observation, textbooks, newspaper and journal articles, and others. Students are asked to not only reconstruct life and culture of the past ages, but embed their project into current global, societal, environmental and economic developments.

We apply the four stages of an archaeological dig [2]: (1) preparation, (2) excavation, (3) evaluation, and (4) explanation to Kolb's four-stage process of learning, involving concrete experience, reflective observation, abstract conceptualization, and active experimentation [3] (see Fig. 1). Therefore, creating meaningful experiences for teaching students to develop an understanding of the global, societal, environmental and economic contexts related to the design of any product, system or process [4–7].

Archaeological Model	Kolb's 4-Stage Learning Model
1. *Preparation* • Survey the site • Gather tools, etc. • Historical research	1. *Reflective Observation* • Conduct product research • Plan dissection process • Investigate product lifecycle
2. *Excavation* • Dig and extract • Collect specimens	2. *Concrete Experience* • Dissect the product • Reverse engineering
3. *Evaluation* • Identify available technology • Carbon dating/chronology • Analyze found artifacts, food, tools, art, etc.	3. *Active Experimentation* • Ask "what if" type questions • Benchmark other products • Conduct product and material experiments
4. *Explanation* • Draw conclusions based on gathered evidence	4. *Abstract Conceptualization* • Draw conclusions based on gathered evidence

Figure 1. Mapping between archaeological exploration phases and Kolb's model.

RELATED LITERATURE

Although many researchers and practitioners have contributed to the area through the development of class content, workshops, curricula, programs, and assessment tools in the last 15 years [8–21], it is still challenging to find effective methods to integrate global, societal, environmental and economic aspects into the engineering curriculum. We provide a quick snapshot of recent implementations in Table 1. Specifically, four problems stand out: (a) the faculty's expertise in addressing GSEE aspects, (b) adding new courses or course content into already tight engineering curricula, (c) adapting design projects to include GSEE aspects, and (d) resistance from faculty adopting GSEE instruction [11,22].

For example, Neeley's implementation strategy at the University of Virginia included a three-course sequence consisting of interdisciplinary faculty and student teams, a set of industry sponsors (e.g. Lockheed Martin), as well as University of Virginia's Teaching Resource Center [11]. In their study they concluded that students had some difficulty balancing the GSEE and technical aspects of their projects, but appreciated the discussions surrounding the organizational and cultural topics of the class. In addition, instructors diagnosed that projects have to be better customized in order to provide students with an effective and realistic design experience [11].

Similarly, our collaborators from the University at Buffalo –SUNY, embedded their GSEE-integrated design activities in a sophomore-level design class with an annual enrollment of approximately 150 students [6]. The course deliverables are centered on the professional and ethical practice of a mechanical engineer, as well as a semester-long product dissection project. To provide students with examples and learning content, the instructors held a series of lectures covering the motivations and definition of GSEE-integrated design integrating GSEE aspects as well as energy usage, material waste, byproducts, facility geography and human labor. Student achievement was assessed through a survey composed of 132 questions in 23 topic areas (see Table 1). The results indicate that questions concerning ethical issues in engineering practice, professional skills, written and oral communication skills, leadership skills, GSEE considerations, and defining a design problem showed significant increases in students' ratings compared to other engineering courses provided by the department [6].

In another study, researchers focused on sustainability contexts, and assessed student responses using Bloom's taxonomy [23]. Their instructional model is based on a six-course, three-year design curriculum focusing on sustainable design [22]. They concluded that students required more instruction in systems theory as well as exposure to more realistic sustainability case studies (see Table 1). Our curricular implementation continues the emphasis on sustainability, but expands beyond the use of case studies, providing students with an opportunity to practice their knowledge and work with real clients on engineering design projects.

Study	Course level	Instructional and Assessment Tools
Neeley et. al (2004)	Sophomore/junior-level design students & Engineering faculty	Case studies Integration of GSEE dimensions into course exams, projects, and lectures Student and faculty surveys
Pappas and Pierrakos (2010 & 2011)	Junior and sophomore design students	Sustainability Case Studies Bloom's Taxonomy
Lewis et al. (2011)	Sophomore-level design students	Case studies Integration of GSEE dimensions into course exams, projects, and lectures Surveys (forced-choice questions)
McKenna, Neumeyer, and Chen (2011)	Senior-level design students	Contextual analysis and reflection surveys Integration of GSEE dimensions into course exams, projects, and lectures

Table 1. Sample of GSEE-related design implementations.

To address some of the shortcomings of current literature in curriculum design, we triangulate different types of student assignment class deliverables to provide a more holistic perspective on including GSEE aspects into engineering design instruction.

Our approach to develop archaeological exercises embeds 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, social, environmental, and economic (GSEE) influences. Moreover, the specific research questions we ask are the following:

1. How do student teams integrate GSEE aspects into their design decisions?
2. Can we observe differences in the content and level of detail in any of the GSEE assignments?
3. Do design project characteristics (e.g. client, topic, goals) influence the teams' responses in the GSEE categories?

The outcome of our research study yielded new ideas to provide effective learning experiences for engineering design students, as well as insights for translating the results into other areas of engineering instruction. We propose that adapting the product archaeology model will allow students to consider GSEE aspects more adequately.

COURSE OVERVIEW

ME398 – Engineering Design is a senior capstone design course offered to mechanical engineering students. The course provides an experience in the creative aspects of design from project definition to ideation to functional prototypes. Industry sponsored projects are completed by student teams, each with 3-4 members. Throughout the 10-week period, students have the opportunity to experience the entire process of design, including understanding user needs and defining product specifications (weeks 1-2), developing creative design ideas (weeks 3-5), engineering analysis and detailed design (weeks 6-8), and building physical prototypes to demonstrate design feasibility (weeks 9-10). Class deliverables are shown in Table 2.

EXPERIMENTAL DESIGN AND PROCEDURE

We collected data in two classes of ME398 (winter 2010 and 2011), totaling 40 responses. However, this paper is focusing on winter 2011 data only, totaling 17 students divided into five teams. For background, examples of the industry-sponsored projects that were completed by students

Deliverable	Description	Due
Product Design Specification	Students were asked to include design specifications such as performance, size, ergonomics and **GSEE aspects (only WQ11)**	Week 3
Conceptual Design Presentation	Students presented their conceptual designs including **GSEE aspects (only WQ11)**	Week 5
Product archaeology postulation report	Students before dissecting their excavation object. Additionally, they have to include any **GSEE aspects (only WQ10)** of their excavation object	Week 5
Product archaeology dissection lab report	Students write up their insights of the physical dissection including functional diagrams of all components **and GSEE aspects (only WQ10)** of their excavation object.	Week 6
Midterm Exam	Students answer technical as well as **GSEE-related questions (only WQ 11)** about engineering design	Week 6
Detailed Design Report	Students compile a document that includes drawings, calculations and other components of engineering analysis. In addition, students were asked to include GSEE aspects in their report **(only WQ11)**	Week 8
Final Presentation	Students present their final designs that include GSEE aspects	Week 11
Final Report	Students compile a final document that includes their design process, calculations, drawings and **GSEE aspects (only WQ11)** of their prototype.	Week 11

Table 2. Overview and descrption of class deliverables.

in our study for winter 2011 are: 1) Finger Positioning Device for Hand Surgery, (FP), 2) Adjustable Pressure Fluid Removal Device (APF), 3) Self Balancing Slicer Head (SBSH), 4) Surgical Step (SSt), and 5) Prosthetic Vacuum Pump (PVP).

Dissection Lab and Postulation

In both iterations of the course we included excavation/dissection and GSEE exercises. The excavation/dissection phase in both iterations consisted of a product archaeology postulation and a product archaeology dissection lab exercise. The postulation exercise was completed in week 3 and aimed to familiarize students with a systematic way of analyzing the functional, as well as the GSEE aspects of their design projects before physically dissecting the excavation object. The product dissection lab was completed at the beginning of week 4 during the conceptual design phase.

In conjunction with both the postulation and the dissection exercises, students responded to questions ranging from identifying the function, material, and manufacturing method of each part to assessing the global, societal, environmental, and economic impact of their excavation object (see Table 9 & 10 in APPENDIX A).


a. Prosthetic Vacuum Pump (PVP)


b. Adjustable Pressure Fluid Removal Device (APF)

Figure 2. Sample product-archaeology excavation objects.

In order to accommodate the range of projects in the class we offered students several options for the excavation phase of the product-dissection lab exercise such as considering (a) an existing competitor product, (b) a previous or current version of their project's product, (c) an add-on to their designed product that would be mounted/installed, or (d) a different product that serves a similar function. Figure 2 shows examples of two "excavation" objects during the lab exercise.

To assess the effectiveness of the product archaeology exercises, students were given a survey one week after the lab activities and at the end of the course to collect their perceptions of how the excavation activities contributed to their understanding of both GSEE topics as well as engineering design topics. The survey used a five-point Likert scale ranging from 1 – strongly disagree to 5 – strongly agree and included items to separate global, societal, environmental, and economic aspects of product design (see Table 3).

Based on the results of the winter 2010 implementation, we found that the dissection activities did not have a strong impact on students' self-report understanding of GSEE issues [24,25]. This was not too surprising since the dissection activity itself focused more of the functional aspect of the product rather than the GSEE-related features. In this way the instructional activities were effective in emphasizing important engineering design issues, but less so on GSEE issues.

Therefore, in winter 2011 we modified our instructional plan to include not only the excavation/dissection activity, but also have students address GSEE factors in repeated activities throughout their design project (see Table 4).

Item No.	Engineering	GSEE
1	Determine the types and numbers of components and subsystems required to design	Describe how global context influences design
2	Consider relevant design criteria	Describe how economic context influences design
3	Relate customers needs to components and their associated functionality	Describe how environmental context influences design
4	Generate design alternatives	Describe how societal context influences design
5	Effectively evaluate alternatives	Build confidence in analyzing the impact of global, economic, environmental, and societal considerations on design

Table 3. Engineering and GSEE items of student survey.

Contextual Analysis

Although, the term "contextual" has been used in many different areas, we use it as an umbrella term for developing engineering design solutions in a global, economic, environmental, and societal context. We implemented two sets of contextual analyses. The first one was disseminated in the second week of class, asking students to identify key questions to consider for each of the GSEE dimensions of their design projects and report on the sources that could help answer those questions. The main purpose was to get students acquainted with the idea of including GSEE factors in their design solutions, but also help them identify future sources of reference. The second one was integrated into the midterm exam (see **Midterm Exam**).

Midterm Exam

The midterm exam consisted of eight questions focusing on product and customer development, concept generation, contextual analysis, and product dissection totaling 75 points. For the contextual analysis students were asked to list at least two aspects for each GSEE category and describe how these aspects could influence product design decisions when redesigning a coffee maker (see Table 4). The contextual analysis accounted for about 13% of the total points in the midterm and students spend about an average of 15-20 min on the assignment.

Product Design Specification

The Product Design Specification (PDS) was mainly used to test students' understanding of the clients' expectations and the overall framework of their design project. The instructor introduced the concept of a Product Design Specification in class, asking students to compile a list of requirements related to product performance, materials, ergonomics, specifications and standards, *GSEE dimensions* and other relevant design criteria. They were also asked to include information on project

Class Deliverable	WQ10	WQ11
Product Design Specification	N/A	• Include GSEE items into PDS
Contextual Analysis	N/A	• Identify the key questions to consider for each of the global, societal, environmental, and economic impact categories. • Report on the resources (e.g. websites, books, etc.) that could help to answer these questions.
Product Archaeology Dissection Postulation	SEE APPENDIX A	N/A
Product Archaeology Dissection Lab	SEE APPENDIX A	N/A
Conceptual Design Presentation	N/A	• Integrate insights from PDS and contextual analysis into their design decision-making
Midterm Exam & Survey	N/A	• Provide a list of GSEE aspects to consider when designing a coffee-maker. • List at least two aspects for each GSEE • Describe how these aspects could influence product design decisions.
Detailed Design Report	N/A	• Include contextual analysis to support design decisions
Final Report & Survey	N/A	• Include selection criteria for all four GSEE dimensions into your overall design-decision matrix • Add rationale, values (as applicable), dimensions (as applicable) and references for each of your GSEE selection criteria.

Table 4. Integration of GSEE aspects in WQ10 and WQ11.

planning using Gantt charts and the assigning of team roles. The PDS was assigned in week 2 and revised by faculty and teaching assistants by the end of week 4.

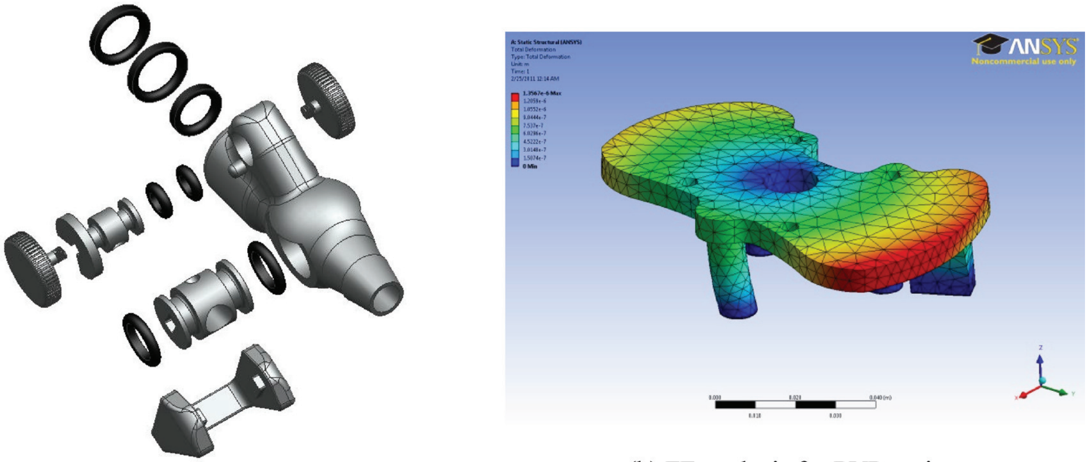
Detailed Design Reports

Students' detailed design reports included a variety of sections such as engineering analysis, problem background, product architecture, functional prototype and other related components. Figure 3 shows some examples of engineering analysis deliverables, such as finite-element analysis (FEA) and computer-aided design (CAD) drawings.

DATA ANALYSIS AND RESULTS

Contextual Analysis

To analyze students' responses we extracted the most commonly cited sources and clustered them into broader categories. Based on Weida et al we established the following three classifications: (a)



(a) CAD model for APF project

(b) FE analysis for PVP project

Figure 3. Sample engineering analysis deliverables.

First-hand research, (b) Second-hand research, and (c) Other. First-hand research included sources such as client-, user- and expert interviews as well as students' intention to conduct user observations, testing and market research (see Table 5).

Second-hand research included sources such as textbooks, industry reports, standards/regulations, journals, and databases. Table 6 shows some sample student responses for each category.

First-Hand Research		Example
Interviews	Client	*"We'll also ask our client, Elliott who is a surgery resident, what he thinks would be most ergonomical for him to hold the device" .(Team Fluid)*
	User	*"We also could talk to Alberto [user] about medicine in other countries because he has worked in the medical field in other countries" .(Team Fluid)*
	Expert	*"Determine level of satisfaction of current products with non-active lifestyle users from other clients (**experts**)" .(Team Prosthetic)*
User	Observations	*"We also plan to **observe** a surgery so that we can see how surgeons currently use suction cannulas, and see what is most comfortable and natural for them to hold." (Team Fluid)*
	Testing	*"**User testing** is necessary to determine comfort." (Team Fluid)*
Market Research		*"Find out how much interest there is in this product by doing market research." (Team Fluid)*

Table 5. Examples of first-hand research categories and responses.

Second-hand research	Examples
Textbooks	*"Use 340-1 book to determine approximate energy consumption of producing our product". (Prosthetic Team)*
Industry reports	*"www.mindbranch.com (surgical devices & Tech industry reports)". (Team Hand)*
Standards/regulations	*"ISO/TR 7250-2: 2010, Basic human body measurements for technological design – part 2: Statistical summaries of body measurements for individual ISO populations". (Team Surgical)*
Journal papers	*"Therapeutic and economic impact of modern amputation program" (Team Prosthetic)*
Databases	*"Material database to see what materials are recyclable". (Team Hand)*

Table 6. Examples of second-hand research categories.

The 17 participants from winter 2011 generated a total of 161 sources of which more than two-thirds fell into the first-hand research category (see Figure 4). In addition, second-hand research mainly consisted of URLs describing a variety of sources on the web, such as product information, regulatory agencies, not-for-profit organizations, or design guidelines.

Some students described how, "*[they] can also use a medical device website . . . to look up the prices of current suction cannulas*" estimating "*[the] reasonable added cost*" (Team Fluid). However, the majority of responses (~73%) only included the actual web address without a more detailed description.

Product Design Specification

Student teams generated a total of 129 items for engineering and GSEE categories. Among the most frequently reported categories were performance, ergonomics, user safety as well as specifications and standards. Only performance, ergonomics and user safety were included by all teams (see Table 7). GSEE items were only included by the teams PVP and APF.

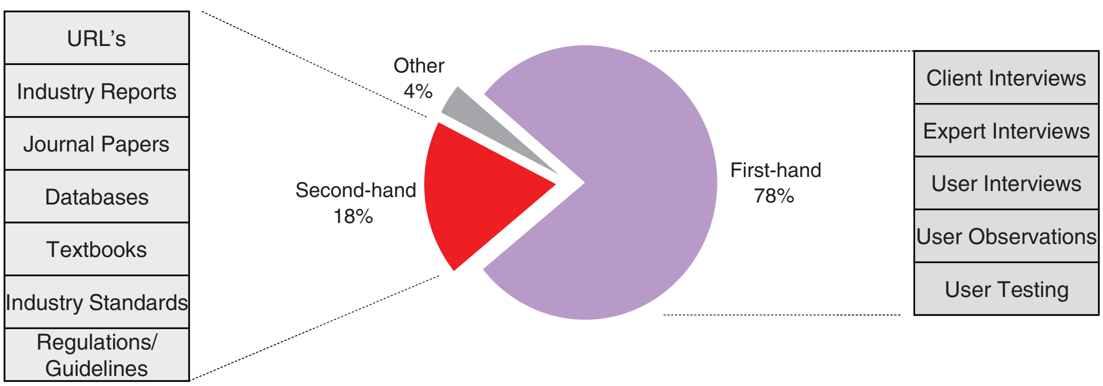


Figure 4. Distribution of first- and second-hand research categories.

Categories	Examples	# Teams that included category in PDS	Total Share
Performance	*"Device will reach desired pressure in less than 50 steps."*	All	17%
Ergonomics	*"Comfortable to hold in the positions used during surgery."*	All	13%
User Safety	*"No sharp protrusions or other damage-inflicting features."*	All	10%
Specifications and Standards	*"The device is in compliance with FDA standards and regulations."*	4/5	16%
Materials	*"Does not corrode or degrade while in contact with bodily fluids."*	4/5	7%
GSEE	*"Raise quality of life for users by allowing them to return to their jobs."*	2/5	8%

Table 7. Overview of PDS categories.

Detailed Design Reports

Although, we asked all five teams to add relevant requirements and adjustments for all four GSEE dimensions in their detailed design report, only teams PVP and APF did. Both teams identified a diverse set of GSEE aspects for their respective projects (see Figure 5).

In the global dimension, team APF recognized that, "*as a device for military users, our design will be used all over the world . . . [and] will need to accommodate varying levels of resources abroad as*

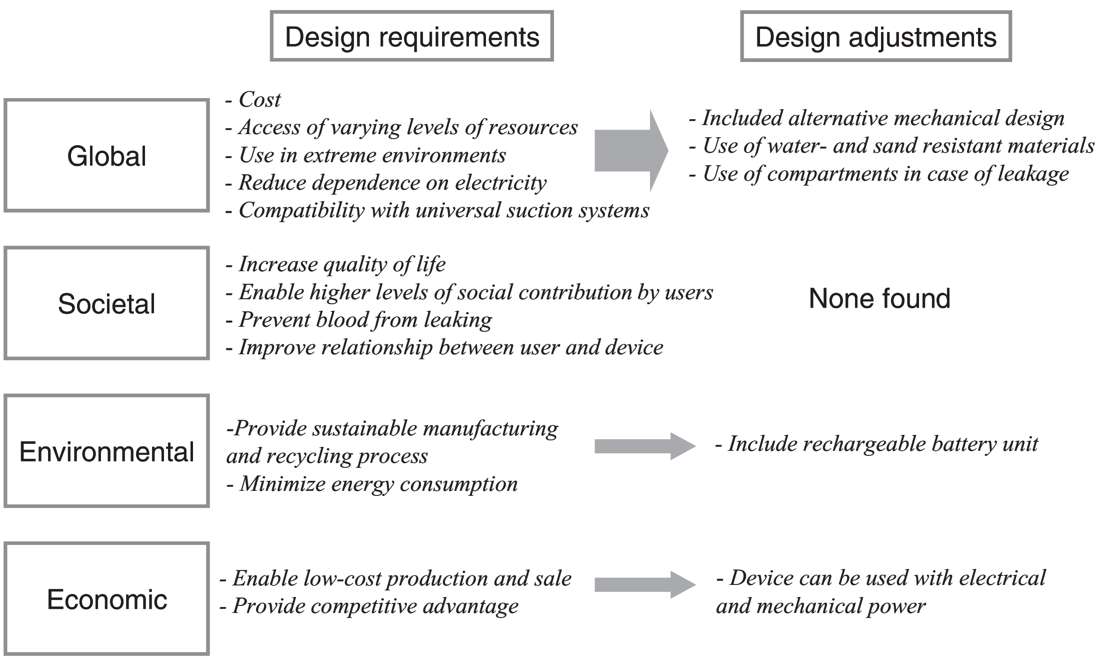


Figure 5. Overview of GSEE design requirements and adjustments for teams PVP and APF.

well as the extreme environments where soldiers may work". Therefore, they decided to *"include a mechanical portion of [their] design to accommodate those places where electricity and wall outlets are few and far between."* Also, they *"designed the electrical component of the device to be water tight and free from sand penetration."*

Team PVP, on the contrary, decided to focus more on "*compatibility with universal suction systems and cost"* in order to *"allow applications in developing countries."*

In summary, only teams APF and PVP included GSEE sections in their detailed design report. Compared to the technical aspects of their projects, however, their contextual analysis lacks specific analytical metrics that could provide a more rigorous framework for their decision-making. For example, team AFP emphasized that they constructed their device *"with an eye to environmental consciousness, including but not limited to a fundamentally sustainable manufacturing process and a detailed recycling process."* Similarly, they required the device to provide *"a better quality of life for amputees . . . [as well as] benefits of higher levels of social contribution by new users.* In both cases, the students missed the chance to provide information such as measurement units, performance metrics or particular design features, to specifically characterize the concepts of **sustainable** manufacturing or a **better** quality of life.

Midterm Exam

We collected 108 items in total and items were about equally distributed among the four GSEE categories. Since students' responses included only a couple of sentences, we performed a word frequency analysis through NVivo and used the most frequently cited words to establish general response categories such as manufacturing, materials, cost, compatibility, safety, etc (see Table 8). In addition we used commonly cited terms in engineering design such as customization, product aesthetics, or ergonomics to combine with the response categories established through the word frequency analysis. For example, all items that fit the following definition: *"to make or alter a product to individual or personal specifications"* [26] were coded as **customization**. Customization was further separated into sub-categories such as product aesthetics, ergonomics, product variety (e.g., "latte macchiato" versus "black coffee"), capacity ("one pot" versus "one cup") or lead time ("fast" versus "slow roasting") (see Table 8). A response item was categorized as **product aesthetics** if students' responses used the actual word or it fit the following definition: "visually appealing and appropriate for the customers' sociocultural use environment [27]." Similarly, students' responses were classified as **ergonomics**, if students used the word "ergonomics" or their description fit the following definition: "characteristics of products that impact people's efficiency and comfort of use [28]."

Concerning the distribution of different coding categories outlined in the experimental design section, we could further discern some interesting distinctions between the fours GSEE categories. For example, in the societal impact dimension, students' responses were categorized into: (a) customization (76%),

Global	Societal	Environmental	Economic
Compatibility	*Customization*	*Energy and resource consumption*	*Cost Market*
– Climate	– Product aesthetics	– Recycling	– Growth
– Power	– Ergonomics	– Waste reduction	– Competition
– Language	– Product variety	*Materials*	– Price
– Units of measurement	– Capacity	– Hazardous materials	*Customization*
Customization	– Lead time	*Manufacturing*	– Quality/price ratio
– Customer taste	*Safety*	– Design for manufacturing	– Accessories
– Product variability	– A fail safe device		*Manufacturing Materials*

Table 8. Coding categories of students' midterm responses.

and (b) safety (24%). Safety items included both user- as well as non-user safety. The suggestions ranged from making the *"device safe for younger children who may be in the vicinity"* to the consideration of *". . . settings to control strength/concentration of coffee"* in response to the question, *"How can/does [a coffee maker can] create an addiction?"*

In the global dimension, the largest categories that emerged were: (a) compatibility (58%), (b) customization (23%), and (c) other (19%). Compatibility included such aspects as language-, power-, unit of measurement-, and climate compatibility (see Table 8). To address potential language barriers amongst users of the newly designed coffee maker, one student recommended the *"heavy use of visual icons and text"* so that *"users who speak different languages [could] still be able to operate the device,"* highlighting the importance of universality and cross-cultural accessibility.

Responses in the environmental dimension revolved around the categories of energy and resource consumption (60%), materials (25%), and manufacturing (15%). One student discussing the challenge of the coffee maker's energy and resource consumption suggested to: *"minimize waste produced"* by considering *"reusable filters"* and *"increase the efficiency of the maker"* through the use of *"settings that automatically turn off when not used."*

In the economic dimension, the categories that emerged included: (a) cost (36%), (b) market (19%), (c) manufacturing (19%), (d) customization (14%), (e) materials (7%) and (f) other (5%). Concerning specificity and content, students offered a range of notably different responses. For instance, one respondent suggested that we *"look at the current economy and economic outlook [and] see if the product has a place in the market"*. Others addressed added more design details such as *"timers or automatic traits"* making *"coffee more competitive against the five hours energy shot"* thus broadening the scope of their competitive analysis.

Given the time constraint of the exam, we were surprised to see that students included a variety of aspects and design recommendations for the various GSEE aspects of a coffee maker. However, the majority of the answers lacked specificity to support their arguments. For example, in the environmental dimension many students wanted to "*make the manufacturing processes as sustainable as possible,*" but did not provide any specific numbers or measurement units. Exceptions included the following design recommendation for the globally differing electrical input requirements: *"If we can make coffee maker work with both US 120V/60HZ AC and European 240V/50Hz we will increase our potential customer base."*

SUMMARY AND FUTURE WORK

This paper presents the overall framework for our product archaeology approach and includes specific details for how we structured our instruction and assessment over two course implementations. The in-depth qualitative data provided us with insight into students' conceptual understanding of GSEE dimensions as well as how they applied this knowledge to their design process.

The analysis of students' individual contextual design assignments shows that early in the course, students extracted a variety of factors related to GSEE aspects from a diverse set of resources such as websites, clients and users. Specifically, students' interactions with users and clients provided them with information (e.g., biographical and career information, medical history, ethnical background, etc.) that is critical to successfully integrate GSEE aspects in product design.

The results from the midterm indicate that students generated a variety of responses ranging from design aspects such as power compatibility to market growth. Specifically, the category **customization** emerged as a common theme among all four GSEE dimensions. One possible explanation could be that these engineering students are exposed to a first-year required human-centered design two course sequence that exposes them to the different aspects of customization.

The data extracted from the product design specifications, detailed design and final reports suggests that some teams included GSEE dimensions into their design decisions, whereas others ignored them entirely. Specifically, human-centered design projects such as the Prosthetic Vacuum Pump (PVP) and the Adjustable Pressure Fluid Removal Device (APF), resulted in students exploring and integrating more GSEE dimensions than typical product-centered design projects, such as the Self-Balancing Slicer Head (SBSH). For example, students working on the PVP project identified design requirements for all four GSEE dimensions and developed adjustments for three of them in their final design. In contrast, students working on the SBSH largely ignored GSEE dimensions and mainly focused on the technical aspects such as materials, mechanical balance and slicing performance. We also observed that students often lacked the appropriate analytical tools to accurately assess GSEE-related aspects and struggled to consider an "extra" set of GSEE criteria in their design process. As one student put it, *"I often times just try to maximize one or two variables (cost, weight, etc.) and very rarely consider things like the global context. Not because I don't want to but because engineering can be difficult enough without extra considerations."*

More importantly, students provided us with a set of interesting suggestions to improve on the integration of GSEE aspects into engineering design instruction, such as *"a class where international design standards [were] the focus"* or the *"use of concrete products that [students] already use [to] analyze their contextual aspects."* Building on some of these suggestions, we will focus future research efforts on addressing students' different cultural and educational backgrounds. We might achieve this through assigning personal essays, short individual contextual design projects, and hosting competitions. For example, we could ask students to describe an object of their daily life (e.g., smartphones, mp3 players, clothing items, etc.) and develop functional and GSEE design criteria for this item.

In summary, there are a variety of approaches to develop specialized course work [6,7,17,22,25] and extend conventional project selection criteria [27,28] to better accommodate the four GSEE dimensions in the existing design education curricula. Instructional and assessment activities should embed explicit opportunities for students to reflect on their experiences and, based on these reflections, abstract ideas about how GSEE-related factors issues may have impacted the design of a product, process or entire system.

ACKNOWLEDGEMENT

This material is partly based upon work supported by the National Science Foundation Grant DUE-0920047. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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APPENDIX A

1. Postulate the major parts in your archaeology product. Postulate the function, material, and manufacturing (production) method for each part. Document your answers in the following table.
2. How do you think your archaeology product works internally (use sketches/functional diagram to help you explain)? Provide as much details as possible regarding how the different components are assembled together.
3. If your group chooses to study product type a, b, or d, please answer the following question. What do you think should be in common between the product you study and the product you design? What should be different?
4. What are the intended global market segments of the product?
5. What do you think were the competing products, and how do you think economic issues are reflected in the design of the product?
6. What do you think were the environmental impacts of this product and what were the environmental factors engineers had to consider in the design of the product?
7. What do you think is the impact of the product on the culture and lifestyles of the customer base?

Table 9. Questions for dissection postulation.

1. Identify the type of product, manufacturer, model #, and major performance specifications
2. Disassemble the product slowly to the lowest level possible so that it can still be reassembled into working order after you are done. Keep track of all of the parts. Describe your disassemble procedure and the difficulties you encounter.
3. After disassembling the product, list major parts, and describe their materials, functions, and production method(s). Document your answers in the following table.
4. Describe how the product works internally (use sketches/functional diagram to help you explain). Provide as much details as possible regarding the interfaces between different parts and how they are assembled together.
5. Provide team's collective opinion related to features of the product using the following list as a starting point. You may revise the list based on your Product Design Specification.
6. Reassemble the product. What features make it easy or hard to assemble? Are there any parts that could be eliminated or combined?
7. After the dissection exercise, how would your answer to Question 3 in "Product Dissection Postulation" be different from your answer before the dissection exercise?
8. Please rate how this dissection exercise may help you in the following aspects related to your design project. Circle the rating that best matches your response

Table 10. Questions for dissection lab exercise.