121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #8971

Assessment of Product Archaeology as a Framework for Contextualizing Engineering Design

Dr. Kemper Lewis, University at Buffalo, SUNY

Kemper Lewis is a Professor of Mechanical and Aerospace Engineering at the University at Buffalo - SUNY. He is the project PI for the collaborative NSF TUES grant, "Assessment of Product Archaeology as a Framework for Contextualizing Engineering Design". The project is a collaborative effort between the University at Buffalo - SUNY, Arizona State University, Penn State University, Northwestern University, Bucknell University, and Virginia Tech.

Dr. Deborah A. Moore-Russo, University at Buffalo, SUNY

Deborah Moore-Russo is an associate professor in the Department of Learning and Instruction in the Graduate School of Education at the University at Buffalo. Her primary research interests include spatial literacy and the use of digital technologies and physical manipulatives in engineering, science, and mathematics education.

Dr. Ann F. McKenna, Arizona State University, Polytechnic campus

Ann F. McKenna is Professor and Chair of the Department of Engineering & Computing Systems in the College of Technology and Innovation at Arizona State University (ASU). Prior to joining ASU she served as a program director at the National Science Foundation in the Division of Undergraduate Education, and was on the faculty in the Department of Mechanical Engineering and Segal Design Institute at Northwestern University. Dr. McKenna received her B.S. and M.S. degrees in Mechanical Engineering from Drexel University and Ph.D. from the University of California at Berkeley. Dr. McKenna is also currently serving as a Senior Associate Editor for the Journal of Engineering Education

Phillip M Cormier, SUNY - University at Buffalo
Dr. Amy M. Johnson, Arizona State University

Amy Johnson received her PhD in experimental psychology (cognitive track) in 2011 from the University of Memphis. She is currently a post-doctoral research associate at the College of Technology and Innovation at Arizona State University.

Dr. Adam R Carberry, Arizona State University

Adam R. Carberry, Ph.D., is an Assistant Professor at Arizona State University in the Fulton Schools of Engineering. He earned a B.S. in Materials Science Engineering from Alfred University, and received his M.S. and Ph.D., both from Tufts University, in Chemistry and Engineering Education respectively. Dr. Carberry was previously an employee of the Tufts' Center for Engineering Education & Outreach and manager of the Student Teacher Outreach Mentorship Program (STOMP).

Prof. Wei Chen, Northwestern University
Prof. David W. Gatchell PhD, Northwestern University

David Gatchell, PhD, is director of the manufacturing and design engineering (MaDE) program at Northwestern University. He is also a clinical associate professor in Northwestern's Segal Design Institute, biomedical engineering department and mechanical engineering department.

Prof. Timothy W. Simpson, Pennsylvania State University, University Park

Dr. Simpson is currently a Professor of Mechanical and Industrial Engineering at Penn State with affiliations in Engineering Design and the College of Information Sciences & Technology. He received his Ph.D. and M.S. degrees in Mechanical Engineering from Georgia Tech in 1998 and 1995, and his B.S. in

Mechanical Engineering from Cornell University in 1994. His research interests include product family and product platform design, product dissection, multidisciplinary design optimization (MDO), and additive manufacturing, and he has published over 250 peer-reviewed papers to date. He teaches courses on Product Family Design, Concurrent Engineering, Mechanical Systems Design, and Product Dissection, and he serves as the Director of the Product Realization Minor in the College of Engineering. He is a recipient of the ASEE Fred Merryfield Design Award and a NSF Career Award. He has received several awards for outstanding research and teaching at Penn State, including the 2007 Penn State University President's Award for Excellence in Academic Integration. He is a Fellow in ASME and an Associate Fellow in AIAA. He currently serves on the ASME Design Education Division Executive Committee and is former Chair of both the ASME Design Automation Executive Committee and the AIAA MDO Technical Committee. He is also a Department Editor for IIE Transactions: Design & Manufacturing and serves on the editorial boards for Research in Engineering Design, Journal of Engineering Design, and Engineering Optimization.

Dr. Conrad Tucker, Pennsylvania State University, University Park
Dr. Gul E. Okudan Kremer, Pennsylvania State University, University Park
Dr. Sarah E Zappe, Pennsylvania State University, University Park

Dr. Sarah Zappe is Research Associate and Director of Assessment and Instructional Support in the Leonhard Center for the Enhancement of Engineering Education at Penn State. She holds a doctoral degree in educational psychology emphasizing applied measurement and testing. In her position, Sarah is responsible for developing instructional support programs for faculty, providing evaluation support for educational proposals and projects, and working with faculty to publish educational research. Her research interests primarily involve creativity, innovation, and entrepreneurship education.

Dr. Steven B. Shooter, Bucknell University

Steve Shooter is a professor of Mechanical Engineering at Bucknell University.

Prof. Charles Kim, Bucknell University

Charles Kim is an associate professor of mechanical engineering at Bucknell University. He received Ph.D. and M.S.E. degrees from the University of Michigan and B.S. from Caltech. Prof. Kim teaches courses in design and innovation and is currently director of the Innovation, Design, Entrepreneurship, Applications, and Systems program at Bucknell.

Dr. Christopher B. Williams, Virginia Tech
Dr. Lisa D. McNair, Virginia Tech

Lisa D. McNair is an Associate Professor of Engineering Education at Virginia Tech, where she also serves as Assistant Department Head of Graduate Programs and co-Director of the VT Engineering Communication Center (VTECC). She received her PhD in Linguistics from the University of Chicago and a B.A. in English from the University of Georgia. Her research interests include interdisciplinary collaboration, design education, communication studies, identity theory and reflective practice. Projects supported by the National Science Foundation include interdisciplinary pedagogy for pervasive computing design; writing across the curriculum in Statics courses; as well as a CAREER award to explore the use of e-portfolios to promote professional identity and reflective practice. Her teaching emphasizes the roles of engineers as communicators and educators, the foundations and evolution of the engineering education discipline, assessment methods, and evaluating communication in engineering.

Dr. Marie C Paretti, Virginia Tech

Marie C. Paretti is an Associate Professor of Engineering Education at Virginia Tech, where she co-directs the Virginia Tech Engineering Communications Center (VTECC). Her research focuses on communication in engineering design, interdisciplinary communication and collaboration, design education, and gender in engineering. She was awarded a CAREER grant from the National Science Foundation to study expert teaching in capstone design courses, and is co-PI on numerous NSF grants exploring communication, design, and identity in engineering. Drawing on theories of situated learning and identity development, her work includes studies on the teaching and learning of communication, effective teaching practices in design education, the effects of differing design pedagogies on retention and motivation, the dynamics of cross-disciplinary collaboration in both academic and industry design environments, and gender and identity in engineering.

Prof. Joe Tranquillo, Bucknell University

Joe Tranquillo teaches at Bucknell University, offering courses in signals and systems, neural and cardiac electrophysiology, instrumentation and medical device design. He has published widely on electrical dynamics in the heart and brain, biomedical computing, engineering design and engineering education.

Assessment of Product Archaeology as a Framework for Contextualizing Engineering Design

Abstract

Product archaeology refers to the process of reconstructing the lifecycle of a product to understand the decisions that led to its development and has been used as an educational framework for promoting students' consideration of the broader impacts of engineering on people, economics, and the environment. As a result, product archaeology offers students an opportunity to reconstruct and understand the customer requirements, design specifications, and manufacturing processes that led to the development and production of a product. This paper describes: 1) the identification and development of assessment tools for evaluating the impact of product archaeology, 2) the implementation of the product archaeology framework during two recent academic year semesters in undergraduate engineering courses at all levels across six universities, and 3) assessment results with evidence of the effectiveness of the product archaeology framework. This project uses existing survey instruments, including the Engineer of 2020 survey and the engineering design self-efficacy instrument to assess positive student attitudes and perceptions about engineering. Our assessment plan also uses two newly-developed design scenarios. These scenarios require students to respond to open-ended descriptions of real-world engineering problems to assess students' ability to extend and refine knowledge of broader contexts. Emerging pre-test/post-test comparison data reveal that the product archaeology activities lead to more positive student ratings of both their own knowledge of broader contexts and their self-efficacy regarding engineering design. Analysis of the design scenarios (used to assess students' ability to apply contextual knowledge to engineering design situations) includes results from the Spring and Fall 2013 semesters.

1. The Challenge of Contextualizing Engineering Education

Engineers face tremendous challenges that include globalization of technical labor, economic turmoil, environmental resource limitations, and the increasingly blurred lines between the social and technical aspects of design. Developing innovative strategies to teach effectively the skills necessary to succeed in the changing global marketplace is not only a national need, but one of international significance. For instance, the UK is stressing engineering education to develop solutions to the "local, social, economic, political, cultural, and environmental context"[1], and China is training engineers to "adapt to changing economic conditions" and "create and explore the new global society"[2].

For over a decade, the National Academy of Engineering (NAE), the National Academy of Science (NAS), the National Science Foundation (NSF), and the Accreditation Board for Engineering and Technology (ABET) have identified engineering education as a principle source for inculcating future engineers with new competencies to thrive in a globalized society. At the same time, they lamented about the "disconnect between the system of engineering education and the practice of engineering" that accelerating global challenges have only exacerbated[3]. Since 1996 the ABET Outcomes Assessment Criteria have offered a set of guidelines to assure that engineers are equipped to succeed and lead in this new world[4]. Among the most vital of these criteria is Outcome h: "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context". Properly understood, Outcome h goes far beyond contextual awareness. It provides the bond between virtually all other ABET outcomes, linking the profession's traditional strengths in scientific knowledge (Outcome a) with design (Outcomes b and c), multidisciplinary teamwork (Outcome d), and knowledge of contemporary issues (Outcome j). Outcome h is doubly important for engineering education because such global, economic, environmental, and societal issues have become critical for preparing, engaging, and retaining the nation's best students[5-6]. Furthermore, educators need tools which can reliably assess students' understanding of the broader contexts of engineering design.

In an effort to address this significant educational gap, we have formalized a novel pedagogical framework called *product archaeology*[7] that transforms product dissection activities by prompting students to consider products as designed artifacts with a history rooted in their development. With an "archaeological mindset," students approach product dissection with the task of evaluating and understanding a product's global, societal, economic and environmental context and impact. These hands-on, inductive learning activities require students to move beyond rote knowledge to hone their engineering judgment, analytical decision-making, and critical thinking. This pedagogical framework thus provides students with formal activities to think more broadly about their professional roles as engineers. Students are instructed to carefully examine man-made products to understand how design decisions are informed by and bring about broader impacts on people, economics, and the environment.

2. From Product Dissection to Product Archaeology

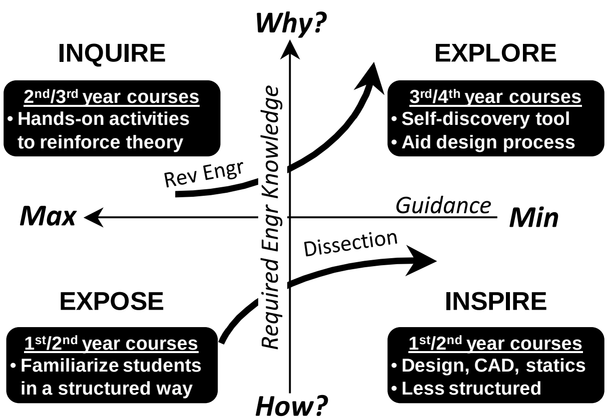
Product archaeology originally emerged from a rich product dissection background. Initial developments in product dissection at Stanford[8-9] were in response to a general agreement by U.S. industry, engineering societies, and government that there had been a decline in the quality of undergraduate engineering education over the previous two decades[10-11]. The result was a strong push towards providing both intellectual and physical activities (such as dissection) to anchor the knowledge and practice of engineering in the minds of students[12-13].

Product dissection was successful in achieving this for several reasons. First, it helps couple engineering principles with significant visual feedback[14] and increase awareness of the design process[15]. Product dissection activities spread around the world as a community emerged around the development and propagation of these activities[12-13,16-22]. These activities have since evolved to all levels of undergraduate education (see Figure 1a) as they migrated from one university to the next. For instance, the power drill dissection activity used at Stanford[9] was adopted at Penn State[13] for sophomores and juniors, migrated to Virginia Tech for freshmen[22], and was adapted at Northwestern for use in a senior design course[23].

Unfortunately, most product dissection activities only emphasize the technical aspects of products (e.g., form, function, fabrication)[24]. While there are exceptions (e.g., dissection of single-use cameras to explore recycling and reuse[13]), most activities miss opportunities to explore the wide range of non-technical issues that can influence product development including global, economic, environmental, and societal factors.

Product archaeology was born to address these shortcomings of product dissection[7]. The term product archaeology was initially coined by Ulrich and Pearson[25] as the process of dissecting and analyzing a physical product to assess the design attributes that drive cost. Shooter and his colleagues advanced the archaeological aspects of dissection by combining excavation (literally "digging in the sand to find parts") with a WebQuest they developed to enhance middle school students' awareness of and competency in engineering[26]. More recently, we formally defined 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*[7].

A recent special issue captured the evolution and impact of product dissection and product archaeology with a series of papers, including a number of studies from participants in the project reported on in this paper[27-34]. There is also a module on product archaeology in a recent engineering textbook as well[35].



(a) Classifying dissection-based activities[36]

Archaeological Approach to a Site	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

(b) Mapping Kolb's Model to Archaeology[7]

Figure 1. Key Components of Our Product Archaeology Framework

To create our product archaeology framework, we mapped Kolb's four-stage learning model[37] to the four phases of archaeology[38]: (1) *Preparation*, (2) *Excavation*, (3) *Evaluation*, and (4) *Explanation*, as shown in Figure 1b. The four keywords from Outcome h, global, societal, economic, environmental (GSEE), are then used as triggers to develop questions pertaining to a specific product, usage, and impact.

During the *preparation* phase, students reflect on what they know about the factors that impact the design of the particular product and postulate responses to questions about its design. The *excavation* activities lead to concrete experiences where students can physically dissect the product and perform appropriate research to develop well-reasoned answers to specific design-related questions. The *evaluation* phase provides opportunities for students to actively experiment and abstract meaning from their research and concrete dissection experiences. Finally, they articulate their findings during the *explanation* phase to describe the global, societal, economic, and environmental impact of the product.

The descriptive nature of our framework provides the flexibility to create hands-on, inductive learning activities for all levels of undergraduate education. We have used our framework to **expose** freshmen in their introductory design courses to these contextual factors[39-40], **inspire** sophomores in their project-based courses and make juniors **inquire** in their engineering electives[40-42], and help seniors **explore** during their capstone projects[43-44]. Product archaeology represents a low cost, natural extension of product dissection and related hands-on activities that many faculty members are already using. Its flexibility lowers barriers to entry as we heard from participants in our product archaeology workshop[45], and they appear to exhibit the same "*stickiness*"[46] that product dissection does. In the next section, we present a number of our implementations across various engineering curricula from our partner institutions.

3. Product Archaeology Implementations

In the most recent multi-university implementation (Spring and Fall 2013 semesters), six universities exercised product archaeology modules and teaching strategies. This section presents a look at each of the courses and accompanying implementations. A table is provided for each implementation presenting the necessary information for each course implementation. Tables 1-11 show how various universities implemented product archaeology across different disciplines, course sizes, course levels, locations of the implementations (in-class, outside class, laboratory setting), types of implementations (individual or group), and length of the implementations (1 class/lab session, 1-2 weeks, 1 month, entire semester/quarter). The tables also illustrate the variety of assessment instruments (design scenarios, pretest/posttest comparisons, student work, other) in the far right column.

3.1 University at Buffalo - SUNY

At the University at Buffalo, two implementations were conducted. In the sophomore level "Introduction to Mechanical Engineering" course (Table 1), the focus was on the *preparation*, *excavation*, and *evaluation* phases of PA. Products were student-selected and included power tools, small appliances, electromechanical toys, and machine equipment. Semester-long archaeology projects were developed in staged gates corresponding to the phases of the archaeological process.

Course Information			Implementation Information			
Discipline	**Course Size**	**Level**	**Location**	**Type**	**Length**	**Assessment Instruments**
☐All Eng Majors ☐Biomedical Eng ☑Mechanical Eng	☐ < 25 ☐ 25-50 ☐ 50-100 ☑ 100-200 ☐ > 200	☐ Fr ☑ So ☐ Ju ☐ Sr	☐ In-class ☑ Outside class ☑ Lab setting	☐ Individual ☑ Group	☐ 1 class/lab session ☐ 1-2 weeks ☐ ~1 month ☑ Entire semester/ quarter	☑Design scenarios ☑Pre-test / Post-test ☐Student work ☐Other

Table 1. Sophomore Implementation at the University at Buffalo – SUNY in *Introduction to Mechanical Engineering* (All checked boxes apply)

In the senior level "Design Process and Methods" course (Table 2), the focus was on the *excavation*, *evaluation*, and *explanation* phases of PA. Two different implementations were conducted – one was one month long and the others were on average one week long. The one month long implementation required a student-selected product that was more than a decade old. Examples included a PlayStation, electric scooters, and small appliances. The one-week long implementations were conducted on Facebook, as described in an earlier work[32]. Students competed to guess what product was being revealed as clues were unveiled in an "archaeological dig". Clues included technical, global, economic, social, and environmental aspects of a product.

Course Information			Implementation Information			
Discipline	**Course Size**	**Level**	**Location**	**Type**	**Length**	**Assessment Instruments**
☐All Eng Majors ☐Biomedical Eng ☑Mechanical Eng	☐ < 25 ☐ 25-50 ☐ 50-100 ☐ 100-200 ☑ > 200	☐ Fr ☐ So ☐ Ju ☑ Sr	☐ In-class ☑ Outside class ☐ Lab setting	☐ Individual ☑ Group	☐ 1 class/lab session ☑ 1-2 weeks ☑ ~1 month ☐ Entire semester/ quarter	☑Design scenarios ☑Pre-test / Post-test ☑Student work ☐Other

Table 2. Senior Implementation at the University at Buffalo – SUNY in *Design Process and Methods* (All checked boxes apply)

3.2 Northwestern University

At Northwestern University, the implementation focused on the senior "Capstone Design" course in mechanical engineering, as shown in Table 3. Lectures were delivered on contextual analysis, functional decomposition, and product dissection, complemented by hands-on product dissection activities. Student deliverables included a contextual analysis assignment in which students list global, societal, economic, and environmental issues relevant to their projects, a product archaeology pre-lab in which students speculate as to how an analogous competitive product works and how it compares to the concept they are designing, and a product archaeology report which summarizes the teams' experiences in dissecting the competitive product including insights of how GSEE issues informed the design.

Their design challenges included designing a medical step for an operating room, an at-home plastic bottle grinder, and the improvement of a surgeon's headlamp. Students in true archaeological form turned to the past where they found solutions in the dissection of a pneumatic office chair (for the medical step), a paper shredder (for the bottle grinder), and a spelunking headlamp (for the surgeon's headlamp).

Course Information			***Implementation Information***			
Discipline	**Course Size**	**Level**	**Location**	**Type**	**Length**	**Assessment Instruments**
☐All Eng Majors ☐Biomedical Eng ☑Mechanical Eng	☑ < 25 ☐ 25-50 ☐ 50-100 ☐ 100-200 ☐ > 200	☐ Fr ☐ So ☐ Ju ☑ Sr	☐ In-class ☑ Outside class ☑ Lab setting	☐ Individual ☑ Group	☐ 1 class/lab session ☑ 1-2 weeks ☐ ~1 month ☐ Entire semester/ quarter	☑Design scenarios ☑Pre-test / Post-test ☑Student work ☐Other

Table 3. Senior Implementation at Northwestern in *Capstone Design* (All checked boxes apply)

3.3 Bucknell University

At Bucknell University, three implementations were used including the junior "Mechanical Design" course (Table 4) that focused on the design of rice cookers. Students read and discussed literature that discussed the cultural implications of rice cookers, dissected various kinds of rice cookers, and delivered presentations on the global, societal, economic, or environmental aspects of the cookers.

Course Information			***Implementation Information***			
Discipline	**Course Size**	**Level**	**Location**	**Type**	**Length**	**Assessment Instruments**
☐All Eng Majors ☐Biomedical Eng ☑Mechanical Eng	☐ < 25 ☑ 25-50 ☐ 50-100 ☐ 100-200 ☐ > 200	☐ Fr ☐ So ☑ Ju ☐ Sr	☑ In-class ☐ Outside class ☑ Lab setting	☐ Individual ☑ Group	☐ 1 class/lab session ☑ 1-2 weeks ☐ ~1 month ☐ Entire semester/ quarter	☐Design scenarios ☑Pre-test / Post-test ☐Student work ☐Other

Table 4. Junior Implementation at Bucknell University in *Mechanical Design* (All checked boxes apply)

Secondly, the "Senior Design – 2" capstone course (Table 5) focused on the design of coffee makers. Students heard from entrepreneurs in the coffee roasting business, along with engineers who were bringing clean water resources to a coffee-growing village in Nicaragua. Students completed reports detailing their dissection and a discussion of the production and consumption of coffee from GSEE perspectives.

Course Information			***Implementation Information***			
Discipline	**Course Size**	**Level**	**Location**	**Type**	**Length**	**Assessment Instruments**
☐All Eng Majors ☐Biomedical Eng ☑Mechanical Eng	☐ < 25 ☑ 25-50 ☐ 50-100 ☐ 100-200 ☐ > 200	☐ Fr ☐ So ☐ Ju ☑ Sr	☑ In-class ☐ Outside class ☑ Lab setting	☐ Individual ☑ Group	☐ 1 class/lab session ☐ 1-2 weeks ☑ ~1 month ☐ Entire semester/ quarter	☐Design scenarios ☑Pre-test / Post-test ☐Student work ☐Other

Table 5. Senior Implementation at Bucknell University in *Senior Design – 2* (All checked boxes apply)

Lastly, the junior "Biomedical Signals and Systems" course (Table 6) focused on the design of interactive clothing. Students searched for examples where fashion and technology intersected, addressed technical, global, societal, economic, and environmental issues in their uncovered product, and developed and built their own interactive fashion.

Course Information			***Implementation Information***			
Discipline	**Course Size**	**Level**	**Location**	**Type**	**Length**	**Assessment Instruments**
☐All Eng Majors ☑Biomedical Eng ☐Mechanical Eng	☑ < 25 ☐ 25-50 ☐ 50-100 ☐ 100-200 ☐ > 200	☐ Fr ☐ So ☑ Ju ☐ Sr	☑ In-class ☐ Outside class ☐ Lab setting	☑ Individual ☐ Group	☑ 1 class/lab session ☐ 1-2 weeks ☐ ~1 month ☐ Entire semester/ quarter	☐Design scenarios ☑Pre-test / Post-test ☐Student work ☐Other

Table 6. Junior Implementation at Bucknell University in *Biomedical Signals and Systems* (All checked boxes apply)

3.4 Virginia Tech

At Virginia Tech, the implementation focused on the sophomore "Engineering Design and Economics Course" (Table 7) where the products included electric drills, internal combustion engines, humanitarian aid packages, disposable cameras, and 3D printers. The exercise was conducted in an active classroom with dissection guides, floating instructors, and discussion led by faculty from the Science and Technology in Society Department. Control and experimental groups were also used to compare the difference between simple dissection exercises and the full product archaeology experiences.

Course Information			Implementation Information			
Discipline	Course Size	Level	Location	Type	Length	Assessment Instruments
☐All Eng Majors ☐Biomedical Eng ☑Mechanical Eng	☐ < 25 ☐ 25-50 ☐ 50-100 ☐ 100-200 ☑ > 200	☐ Fr ☑ So ☐ Ju ☐ Sr	☑ In-class ☐ Outside class ☑ Lab setting	☐ Individual ☑ Group	☑ 1 class/lab session ☐ 1-2 weeks ☐ ~1 month ☐ Entire semester/ quarter	☑Design scenarios ☑Pre-test / Post-test ☐Student work ☐Other

Table 7. Sophomore Implementation at Virginia Tech in *Engineering Design and Economics* (All checked boxes apply)

3.5 Arizona State University

At Arizona State, two implementations were conducted - one at the freshmen level in the "Foundations of Engineering Design" course (Table 8) and one at the sophomore level in the "Use-Inspired Design Project" course (Table 9). The general product focus for both courses was on dental hygiene products. As part of the archaeological exercises, students interviewed other people regarding their oral hygiene use and experiences, developing a set of needs and requirements. They also dissected a number of current dental hygiene tools developing a set of needs and requirements covering GSEE perspectives. The students then developed rapid innovations to meet these needs and solicited feedback from diverse groups.

Course Information			Implementation Information			
Discipline	Course Size	Level	Location	Type	Length	Assessment Instruments
☑All Eng Majors ☐Biomedical Eng ☐Mechanical Eng	☐ < 25 ☐ 25-50 ☐ 50-100 ☐ 100-200 ☑ > 200	☑ Fr ☐ So ☐ Ju ☐ Sr	☑ In-class ☐ Outside class ☑ Lab setting	☐ Individual ☑ Group	☐ 1 class/lab session ☑ 1-2 weeks ☐ ~1 month ☐ Entire semester/ quarter	☑Design scenarios ☑Pre-test / Post-test ☐Student work ☐Other

Table 8. Freshman Implementation at Arizona State University in *Foundations of Engineering Design* (All checked boxes apply)

Course Information			Implementation Information			
Discipline	Course Size	Level	Location	Type	Length	Assessment Instruments
☑All Eng Majors ☐Biomedical Eng ☐Mechanical Eng	☐ < 25 ☐ 25-50 ☑ 50-100 ☐ 100-200 ☐ > 200	☐ Fr ☑ So ☐ Ju ☐ Sr	☑ In-class ☐ Outside class ☑ Lab setting	☐ Individual ☑ Group	☐ 1 class/lab session ☑ 1-2 weeks ☐ ~1 month ☐ Entire semester/ quarter	☑Design scenarios ☑Pre-test / Post-test ☐Student work ☐Other

Table 9. Sophomore Implementation at Arizona State University in *Use-Inspired Design Project* (All checked boxes apply)

3.6 Penn State University

At Penn State, two implementations were conducted - one at the freshmen level in the "Introduction to Engineering Design" course (Table 10) and one at the sophomore level in the "Product Dissection" course (Table 11). In the freshman course, the focus was on Launchpad toy helicopters and electric toothbrushes where students dissected the products and then were challenged to think about their GSEE implications. For example, for the helicopters, students considered global issues (e.g., the crash in London), the societal need for helicopters (e.g., Lifeflight), the environmental ramifications (e.g., the students toured the Penn State sustainability plant), and the economic impact of the development and use of helicopters. For the electric toothbrushes, health benefits versus environmental implications were contrasted along with cost implications that make product out of reach for some populations.

Course Information			Implementation Information			
Discipline	Course Size	Level	Location	Type	Length	Assessment Instruments
☑All Eng Majors ☐Biomedical Eng ☐Mechanical Eng	☐ < 25 ☐ 25-50 ☐ 50-100 ☐ 100-200 ☑ > 200	☑ Fr ☐ So ☐ Ju ☐ Sr	☑ In-class ☑ Outside class ☑ Lab setting	☐ Individual ☑ Group	☑ 1 class/lab session ☐ 1-2 weeks ☐ ~1 month ☐ Entire semester/ quarter	☑Design scenarios ☑Pre-test / Post-test ☐Student work ☐Other

Table 10. Freshman Implementation at Penn State University in *Introduction to Engineering Design* (All checked boxes apply)

In the sophomore course, products included bicycles, engines, small appliances, disposable cameras and rice cookers. Students went through all four product archaeology phases, including in-class preparatory lectures, and then interactive sessions where the products were *excavated*, *evaluated*, and *explained*.

Course Information			Implementation Information			
Discipline	**Course Size**	**Level**	**Location**	**Type**	**Length**	**Assessment Instruments**
☐All Eng Majors ☐Biomedical Eng ☑Mechanical Eng	☐ < 25 ☑ 25-50 ☐ 50-100 ☐ 100-200 ☐ > 200	☐ Fr ☑ So ☐ Ju ☐ Sr	☑ In-class ☐ Outside class ☑ Lab setting	☐ Individual ☑ Group	☐ 1 class/lab session ☑ 1-2 weeks ☐ ~1 month ☐ Entire semester/ quarter	☑Design scenarios ☑Pre-test / Post-test ☐Student work ☐Other

Table 11. Sophomore Implementation at Penn State University in *Product Dissection* (All checked boxes apply)

In the following section, we present some of the assessment instruments that we have institutionalized across our network of collaborators. In addition, results from the Spring and Fall semesters in 2013 are presented.

4. Product Archaeology Assessment

Product archaeology activities were implemented in the six institutions during the Spring 2013 and Fall 2013 semesters. A total of 209 students participated in Spring 2013 and a total of 220 participated in Fall 2013. In the Spring semester, 82.3% of participants (n = 172) were male; in the fall semester, 84.1% (n = 185) were male. The actual number of students that participated was larger, but a number of the responses were unable to be matched between pre- and post-test results.

The research project was aimed at assessing student attitudes and perceptions about engineering as well as their ability to extend and refine knowledge about broader contexts to novel situations. Attitudes and perceptions about engineering were assessed using pre-test and post-test versions of two self-report surveys: 1) the engineering design self-efficacy instrument[47]; and 2) the Engineer of 2020 survey[48]. The adapted engineering design self-efficacy instrument consists of 15 Likert-type items requiring students to rate self-confidence in the ability to conduct a variety of engineering design tasks, from 0 (low) to 100 (high). The Engineer of 2020 survey asks students to provide self-ratings from 1 (Weak/None) to 5 (Excellent) for the following four items:

1) Knowledge of contexts (social, political, economic, cultural, environmental, ethical, etc.) that might affect the solution to an engineering problem;
2) Knowledge of the connections between technological solutions and their implications for the society or groups they are intended to benefit;
3) Ability to use what you know about different cultures, social values, or political systems in developing engineering solutions; and
4) Ability to recognize how different contexts can change a solution. More details about these two survey instruments can be found in previous work[49].

Students' abilities to extend and refine knowledge about broader contexts were evaluated using design scenarios. Although the results from the design scenarios are beyond the scope of this paper, an explanation of their development and coding procedures, as well as assessment results from their use can be found in previous work[49].

In order to assess the impact of the product archaeology activities on student attitudes and perceptions, we utilized a pretest-posttest comparison design. Pre-test surveys were administered before the students completed product archaeology activities and post-test surveys were administered immediately after they finished the product archaeology elements of their courses.

4.1 Spring 2013 Results

To examine differences between pre-test and post-test surveys on student attitudes and perceptions about engineering, we conducted a series of paired-samples t-tests, using time of survey (pre vs. post) as the within-subjects variable, and student ratings on the survey instruments as the dependent variables. Table 12 displays the descriptive statistics for each of the dependent variables, as well as results of the inferential tests comparing pre-test and post-test survey ratings. The results of the comparisons revealed that students had significantly higher average ratings on the engineering design self-efficacy instrument following the product archaeology activities (i.e., post-test), compared to their ratings before the product archaeology units began (i.e., pre-test). Additionally, post-test ratings were significantly higher compared to pre-test ratings for average student ratings on the Engineer of 2020 survey, as well as on each of the four individual items that comprise the survey.

	Engineering Design Self-Efficacy (Average rating)	**Engineer of 2020 Survey**				
		Question 1	Question 2	Question 3	Question 4	Average rating
	M (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)
Pre-test	72.3 (16.5)	3.11 (0.92)	3.17 (0.89)	3.20 (0.96)	3.51 (0.93)	3.25 (0.77)
Post-test	77.5 (14.7)	3.40 (0.85)	3.52 (0.79)	3.46 (0.90)	3.70 (0.87)	3.52 (0.74)
Inferential Statistics t(df = 208); p	5.98; < .001	4.43; < .001	5.50; < .001	3.94; < .001	2.94; .004	5.52; < .001

Table 12. Descriptive and Inferential Statistics for Spring 2013 Pre-test/Post-test Comparison Data

4.2 Fall 2013 Results

The Fall 2013 data were subjected to a series of paired-samples t-tests analogous to what was used for the Spring data. Table 13 displays the descriptive and inferential statistics for each of the dependent variables. Results revealed significantly higher average post-test ratings, compared to pre-test ratings for the same survey variables as in the Spring semester including the average engineering design self-efficacy ratings, the Engineer of 2020 ratings, and individual ratings for each question on the Engineer of 2020 survey.

	Engineering Design Self-Efficacy (Average rating)	**Engineer of 2020 Survey**				
		Question 1	Question 2	Question 3	Question 4	Average rating
	M (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)
Pre-test	70.8 (15.0)	3.21 (0.92)	3.25 (0.90)	3.12 (0.90)	3.53 (0.91)	3.28 (0.71)
Post-test	79.4 (13.0)	3.68 (0.83)	3.76 (0.84)	3.67 (0.92)	3.95 (0.83)	3.77 (0.71)
Inferential Statistics t(df = 219); p	9.17; < .001	7.25; < .001	7.85; < .001	7.72; < .001	5.97; < .001	9.42; < .001

Table 13. Descriptive and Inferential Statistics for Fall 2013 Pre-test/Post-test Comparison Data

5. Conclusions and Implications

Students today are more aware of the global, social, economic, and environmental problems all over the world than ever before, but they still struggle to find efficient pathways of connecting their skills, passions, and knowledge to help solve these problems in a timely fashion. In this paper, we present an overview of product archaeology implementations across six institutions and portions of the assessment results that have been analyzed thus far.

It is clear that the students' experiences with product archaeology have impacted their self-assessed abilities along a number of engineering design dimensions. The framework also creates a rich archaeological analogy that provides relevant context and authentic experience for the students. Our current work and future plans include the following:

- While not statistically significant, we did note an improvement in the results between the Spring and Fall semesters. While different faculty were often engaged between the semesters, this might reflect collective and shared learning among the involved faculty members, increasing their ease and experience with which to incorporate the developed curricula in various classroom settings. We are interested in studying the level of comfort faculty have with the teaching material and the impact of multiple exposures on students' learning across their curriculum.
- We are processing the results for the design scenario assessments. Since these assessments are more open-ended, they require a rubric to be applied by our assessment team to determine the impact on students' awareness of global, societal, economic, and environmental issues when facing an open-ended design scenario.
- We are curating "proven" product archaeology materials (i.e., activities, rubrics, and assessment) for dissemination through our primary portal, www.productarchaeology.org. By "proven", we mean well-structured product archaeology activities that have been shown to be effective in the classroom, have been successfully used by multiple faculty, and have transferred across universities.

- We have offered a number of half-day workshops to faculty and graduate students interested in developing product archaeology materials for their own courses. These workshops have been offered at the American Society for Engineering Education (ASEE) and American Society for Mechanical Engineers (ASME) conference.
- Our long-term plan includes expanding the deployment to over a dozen institutions with more emerging annually. Some partners will serve as material developers, while others will serve as material adopters.

6. Acknowledgements

This work was funded under a collaborative Phase II grant from the Transforming Undergraduate Education in Science (TUES) program at the National Science Foundation (Grant Nos. DUE-1225925, 1225836, 1225856, 1225578, 1223674, and 1225726). Any opinions, findings, and conclusions or recommendations presented in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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