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An Exploration of the Effectiveness of Product Archeology in an Undergraduate Engineering Curriculum: What can a Five-Hour Curriculum Do?

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ABSTRACT

In this paper, we present our efforts in embedding product archeology inspired curricula into two engineering courses along with assessment results. The assessment focuses on the effectiveness of the embedded curricula in enhancing students' understanding on the global, societal, environmental, and economic (GSEE) implications of engineering design. The results show the significant positive impact of the curricula as perceived by students in comparison to other engineering courses, and thus, is another testament to the fact that carefully crafted curricula can have substantial impact.

Key Words: Product archeology, embedded curriculum, engineering design

INTRODUCTION

Many scholars have written about the rigidity of engineering curriculum being an inhibiting factor to introduce new content or topics. Odds are especially against topics that are considered to be "soft", i.e., not directly meant to increase the analytical capability of engineering students. Given this setting, it is critical that we find pedagogies that are effective and efficient in particular for non-analytic, yet important and practical topics that foster professional development. In this paper, we present a study of the effectiveness of product archeology as pedagogy to introduce and enhance student awareness of global, societal, economic and environmental (GSEE) issues in an undergraduate engineering curriculum.

Product archeology is a new pedagogical paradigm that embeds context into product dissection activities. Product dissection has been very successful when used in engineering courses to help anchor the knowledge and practice of engineering in students' minds; however, most product dissection activities tend to stress form, function, and fabrication, missing opportunities to explore the broader impacts of engineering design decisions. Contextualization brought through product archeology affords opportunities to seamlessly blend the GSEE concepts to student learning in an active, explorative manner.

In order to understand the effectiveness of this new pedagogical paradigm, we embedded it in two different courses at Penn State (EDSGN 100 and IE 466) and collected data pertaining to student perceptions using an established survey instrument. One of the courses, Introduction to Engineering Design (EDSGN 100), is a required first year course, while the other, Concurrent Engineering (IE 466), is a senior level technical elective. In this paper, we present an overview of our implementations in these courses along with assessment results. Before proceeding with the overview, we first review the relevant literature.

BACKGROUND

Contemporary issues induced by globalization, economic turmoil, environmental resource limitations are impacting the way we live in all corners of the world, and hence, more than ever before, engineers are required to have a much broader perspective of their profession. The Accreditation Board for Engineering and Technology (ABET) has tried to address this in the "a-k outcomes" that are now part of EC 2000 (ABET, 1999). However, as departments undergo their second wave of accreditation reviews under the new criteria, many are still struggling to satisfy Outcome h, namely, "The broad education necessary to understand the impact of engineering solutions in global, economic, environmental, and societal context." For instance, at Trinity College, a first-year design course is used to assess every ABET outcome except Outcomes h and i (Ahlgren, 2001). At Purdue, involvement in extracurricular activities were used to assess each of the ABET outcomes; however, the authors of the study were not able to make any conclusions for Outcomes h, noting the need for "further analysis" of this outcome (Dalrymple and Evangelou, 2006). Briedis (2002) noted that the assessment of Outcome h was "less straightforward" than the other professional outcomes, and a new course had to be developed to address this outcome directly. This strategy was used instead of the alternative of using the humanities and social science general education courses to assess Outcome h. Unfortunately, most departments neither have the flexibility nor the room to develop a new course specifically to address any single ABET outcome, much less Outcome h. As a result, most departments relegate this requirement to their senior capstone design experience along with many other outcomes (Biney, 2007), and the end result mostly is an ineffective "catch all" course with limited exposure to these increasingly important topics – too little, too late.

In an effort to respond to Outcome h in a more effective way, we have proposed the use of a new "product archeology" paradigm, which prompts students to peel the layers of complexity in an engineered solution (product, process, or system), and "dig" the surrounding information and artifact layers to understand the historical and contemporary GSEE implications (Simpson et al., 2011). If we consider consumer products as the artifacts under investigation, this "digging" will entail 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. Indeed, "archaeologists try to reconstruct life and culture of past ages through the study of objects created by humans, known as artifacts" (McMillon, 1991). While archaeologists use a variety of tools and methods in their work, their approach to a new site can be generalized into four phases (Renfrew and Bhan, 2004): (1) preparation, (2) excavation, (3) evaluation, and (4) explanation. These phases constitute a useful framework with which we can engage the student beyond the product itself, with a deeper look into the context and complexities.

Figure 1 shows how we use Kolb's (1984) model of experiential learning to anchor our framework in formal learning theory. Specifically, we have mapped Kolb's four stages of (1) concrete experience, (2) reflective observation, (3) abstract conceptualization, and (4) active experimentation to the corresponding four phases of archaeological exploration. As shown in the figure, students are asked to reflect on what they know about the factors that impact the design of particular products and

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

Figure 1. Mapping between archaeological exploration phases and Kolb's model (adopted from Lewis et al. 2011).

postulate responses to several questions relating to economic, societal, etc. aspects of the designs in the *preparation* phase. 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 and understand their work in the context of how GSEE factors influence design decisions.

The concept of product archaeology is not new; it was first introduced by Ulrich and Pearson (1998) as a way to measure the design attributes that drive cost through analysis of the physical products themselves. Analysis of the physical products is mostly done as product dissection activities within the engineering curriculum and has been in place for two decades. Many forms of such activities that are in use today have their roots in Professor Sherri Sheppard's Mechanical Dissection course at Stanford (Sheppard, 1992a and 1992b). Numerous engineering courses (e.g., Beaudoin and Ollis, 1995; Lamancusa et al., 1996; Carlson et al., 1997; Sakamoto et al., 1999; Marchese et al., 2003; and Ogot et al., 2008) have drawn upon the materials and activities developed for her course. These initial developments were in response to a general agreement by U.S. industry, engineering societies, and the federal government that there had been a decline in the quality of undergraduate engineering education over the previous two decades (Fincher, 1986; Nicolai, 1995). As a result, there was a push towards providing both intellectual and physical activities (such as dissection) to anchor the knowledge and practice of engineering in the minds of students (Lamancusa et al., 1996; Brereton, 1998). Product dissection has since become a popular pedagogy for engaging engineering students given its "hands-on" nature. Product dissection introduces students to functional products and processes, and providing such experiences early in the students' academic careers increases motivation and retention (Carlson et al., 1997). Product dissection can also be used to increase awareness of the design process (Otto and Wood, 2001), and such "learning by doing" activities encourage the development of curiosity, proficiency, and manual dexterity—three desirable traits of an engineer (Beaudoin and Ollis, 1995).

With the product archeology paradigm we intended to not only have our students experience the benefits of product dissection but also have them become keenly aware of the GSEE implications. Thus, our view is much broader in the sense that product archaeology provides an opportunity to study not only the 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, for example, the energy and material usage throughout the life cycle of the product (i.e., from cradle to cradle (McDonough and Braungart, 2002)). When implemented in an engineering classroom, product archaeology can allow students to visualize themselves as the designers and, in the time frame during which a specific product is developed, to try to re-create the global and local conditions that led to its development. We have created two types of exercises wherein students "dig" to uncover not only the manufacturing (i.e., economic) issues of a product, but also the global and societal context that influenced its development as well as the environmental impact of the product during its life cycle. As introduced in (Simpson et al., 2011), a competitive "dig" pits teams of students against each other in a time-based competition to unearth the GSEE impact of a product while a collaborative "dig" allows students to work together to dig more deeply into these issues. A collaborative "dig" that is used in a first-year and a senior-level course is discussed next.

PRODUCT ARCHAEOLOGY CURRICULUM

Based on the previous discussion, we have prepared and implemented mini-curricula on product archeology in two different courses (EDSGN 100 and IE 466). We introduce these courses next along with specific implementation details for this study.

"Dig" in EDSGN 100:

Introduction to Engineering Design (EDSGN 100) is a required first-year engineering course for all engineering majors. In 2004, the course had major a revision to include product dissection and redesign activities as the first project, to be followed by an industry-sponsored second project. For the first project, coffee-makers and electric toothbrushes are dissected, focusing on which energy analysis and product teardown are done in a structured fashion. Based on these activities, and accompanying course lectures on engineering design process, students are then asked to redesign the dissected product.

Given the potential we have articulated in Section 2, we have introduced a product archeology curriculum as part of the design project one in Fall 2010. This new curriculum introduced the concept of product archeology in addition to product dissection. We share the following definition with our students during class implementations.

> *We define 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. Product archaeology provides an opportunity to study not only the manufacturing (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, for example, the energy and material usage throughout the life cycle of the product (i.e., from cradle to grave). Through product archaeology, students try to place themselves in the minds of designers and in the time frame during which a specific product is developed to try to re-create the global and local conditions that led to its development.

Given this definition, and the context of the project one, we asked students to redesign the dissected coffee-maker for a contemporary Japanese household. As part of the "dig", students were asked to consider the following:

1. *Global:* Are coffee-makers common kitchen staples in Japan? If not, what is the equivalent drink to coffee in Japan? How do the kitchens change in size across the countries, and why?
2. *Societal:* What impact has coffee had on Japanese society? Examine the trends of coffee drinkers in Japan over the past decade and compare them to the trends over the same time period in the U.S. How do cultural and societal differences in these two countries drive the design of the coffee maker?
3. *Economic:* How much does a cup of coffee cost? Make sure to factor in the cost of electricity, water, filters, and coffee grounds as well as the cost of the coffee maker itself. How much a Japanese household might invest in a coffee-maker? What are the added features or functionalities in coffee-makers? How do these impact the cost of designs?
4. *Environmental:* What is the environmental impact of your coffee maker? Again, how much water, electricity, coffee, and filter material are you using to make each cup of coffee? What impact does that have on the environment (e.g., container, sleeve, milk/cream, sugar)? Is it more (or less) than making coffee daily at home? What about the coffee maker itself: can any of it be recycled, reused, or remanufactured after it has served its useful life?

The total duration of project one is six weeks, during which two class sessions (~ 3.5 hours) are devoted to product dissection activities. One additional class session was used to introduce the product archeology concept (~1.75 hours), but the overall project duration remained unchanged. Students reported on the product dissection, archeology, and redesign activities at the end of the project duration.

"Dig" in IE 466:

We implemented a collaborative "dig" during both Fall 2010 and Fall 2011 in IE 466. This "dig" was part of a senior technical elective on concurrent engineering for students predominantly in industrial engineering and mechanical engineering. The course is also one of the three required courses for the Product Realization Minor and is intended as a follow-on to the sophomore-level product dissection course (within the mechanical engineering curriculum); however, the product dissection course is not a pre-requisite for this course. The instructions for the dig provided direction to students in terms of assessing the global, societal, economic, and environmental impact that we wanted them to explore in the products they have analyzed.

As part of the course, teams of 3–4 students each were dissecting and analyzing a specific coffee-maker while also applying tools discussed in the course (i.e., House of Quality, Failure Mode Effects Analysis, and Design for Manufacturing and Assembly). To complement these regular course activities, a collaborative "dig" was introduced to explore specific aspects of the global, societal, economic, and environmental impact of their coffee-maker. Specifically, the "dig" assignment required each team to assess their coffee maker from the following perspectives:

1. *Global:* Where does coffee come from? Investigate the global supply chain for coffee, tracing the origin of coffee from where it is grown (you can pick one of the many countries that supply coffee) to where you purchase coffee for use in your coffee maker. Also, what can you discern about the origin of the coffee maker itself? Where was it made? Were all of the parts fabricated in the same place?
2. *Societal:* What impact has coffee had on our society? Examine the trends of coffee drinkers in the U.S. over the past decade and compare them to the trends over the same time period in one other country of your choosing. How do cultural and societal differences in these two countries drive the design of the coffee maker? Consider things like frequency of use, location of use, strength of coffee, amount of coffee, etc.
3. *Economic:* How much does a cup of coffee cost? Perform an economic analysis on your coffee maker. Make sure to factor in the cost of electricity, water, filters, and coffee grounds as well as the cost of the coffee maker itself, amortized over its expected life. Are there any other costs associated with making a cup of coffee at home? How does this compare to buying a cup of coffee at Dunkin Donuts or Starbucks?
4. *Environmental:* What is the environmental impact of your coffee maker? Again, how much water, electricity, coffee, and filter material are you using to make each cup of coffee? How does this compare to buying a cup of coffee each day at Dunkin Donuts or Starbucks? What impact does that have on the environment (e.g., container, sleeve, milk/cream, sugar)? Is it more (or less) than making coffee daily at home? What about the coffee maker itself: can any of it be recycled, reused, or remanufactured after it has served its useful life? Is there a market for refurbished coffee makers? Why or why not?

Students used online resources to investigate many of these questions and gather relevant data for the analysis. Teams also relied on their peers in the class to gain initial insight into the global and societal aspects of coffee makers and coffee drinking—roughly 10% of the students in the course were international. Team reports were prepared in Microsoft Word and submitted to the instructor for grading, and presentations were developed in Microsoft PowerPoint so that results could be shared with classmates. As an in-class activity, introduction of the product archeology concept took about 75 minutes to discuss, and 75 minutes to present by students. Students had nearly five weeks to complete the assignment, i.e., from the time it was introduced to the time their report was due. Across Fall 2010 and Fall 2011, there was no substantial difference in the way this curriculum was introduced, and the same instructor taught the course.

EFFECTIVENESS ASSESSMENT METHODOLOGY

In order to understand the effectiveness of this pedagogical paradigm as we have embedded them in two different courses (EDSGN 100 and IE 466) as described in Section 3, we collected data pertaining to student perceptions. Because the faculty members who introduced product archeology in class also contributed to its development, we opted to collect data using a survey (E2020 survey) developed for more comprehensive purposes in order to eliminate potential bias (E2020 survey, http://www.ed.psu.edu/ educ/e2020/surveys-1). As summarized in Table 1, the survey asks students to evaluate the emphasis and impact that all their engineering courses have had on ethical issues, life-long learning, beliefs/values, cultural diversity, creativity, workforce trends, emerging technologies, practical use of theories, professional skills, communication skills, leadership skills, working in teams, project management, cultural context of engineering solutions, the impact of non-engineering fields, systems thinking, the application of knowledge from other fields to solve engineering problems, defining a design problem, and generating solutions to an engineering problem. The E2020 survey was tailored to evaluate the emphasis and impact of the product archaeology curriculum on the same set of issues. Specific questions included, for example, "Overall, how much have all the courses you've taken in your engineering program collectively emphasized each of the following Topics in Engineering (Professional Skills, Problem Solving Skills)." Note that scales 10 and 13, 11 and 14, and 12 and 15 are designed to be evaluated in pairs. The first in each pair (i.e., 10, 11, 12) asks about the relevant items as they relate to students' all engineering courses, while the latter highlights a specific course. This paired system of scales provides a mechanism to evaluate a course's impact on selected issues in comparison to all others'.

For EDGSN 100 students, the survey was administered during Fall 2010 semester; for IE 466 students the same data collection was done in Fall 2010 and then in Fall 2011 in order to collect sufficient data for statistical analysis. The initial data analysis for the IE 466 implementation was reported earlier (Simpson et al., 2011); however, since number of participants who volunteered to partake in the study was only 18, we have repeated the data collection during Fall 2011.

#	Scale
Scale 1	Applying Math and Science
Scale 2	Defining Problems and Generating Design Solutions
Scale 3	Managing a Design Project
Scale 4	Engineering Context
Scale 5	Teamwork
Scale 6	Communication
Scale 7	Leadership
Scale 8	Interdisciplinary Knowledge and Skills
Scale 9	Recognizing Perspectives
Scale 10	The Emphasis of all Taken Courses in Engineering on Some Topics in Engineering
Scale 11	The Emphasis of all Taken Courses in Engineering on Professional Skills
Scale 12	The Emphasis of all Taken Courses in Engineering on Problem Solving Skills
Scale 13	The Emphasis of EDSGN 100 (IE 466) on Some Topics in Engineering
Scale 14	The Emphasis of EDSGN 100 (IE 466) on Professional Skills
Scale 15	The Emphasis of EDSGN 100 (IE 466) on Problem Solving Skills

Table 1. E2020 survey scales selected for the assessment

In addition to the selected survey questions from the E2020 survey, one open-ended question was added to ask students which course activities they thought improved their awareness of GSEE issues. The idea behind inclusion of this question was an affirmation of the source of the impact; in other words, have the students perceived the embedded archeology curriculum as the main source to increase their awareness on GSEE concepts?

The data collection and subsequent analysis served to answer two questions. First, in comparison to product dissection activities, how did performance of the product archeology curriculum compare in gains of learning in GSEE issues as perceived by students? This question was investigated as part of the data collection at the first year course (EDSGN 100). Second, in comparison to other engineering courses' impact, how did a specific course compare in enhancing gains as perceived by students? This question was answered using the statistical analysis of the paired scales as noted above.

RESULTS

Validity of our scales has been already checked in preliminary work (as part of NSF project #0550608 activities); however, in order to account for potential population differences we repeated it for our specific project. Reliability can be estimated by four methods: (1) the re-test method, (2) the alternative-form method, (3) the split-halves method, and (4) the internal consistency method. The internal consistency method is the most suitable method for estimating reliability in our case as this method does not require splitting or repeating of items. Cronbach's alpha is the most popular reliability estimate (Carmines and Zeller, 1979). Cronbach alpha scores for our scales were found to be at acceptable levels, with 12 out of 15 scores greater than 0.8 (see Table 3, second column).

Data Analysis for EDSGN 100

Because EDSGN 100 is the first engineering course for most of our students, we did not expect to see identifiable differences across the scale pairs. Accordingly, we opted to compare student perceptions against EDSGN 100 course sections where only product dissection was implemented (Sections A and B), where dissection and global design were implemented (Section C) and where product archeology was embedded in addition to product dissection (Section D). Because the incoming quality of students could be salient in the first year, we analyzed the potential differences across course sections.

Data in Table 2 presents the Scale 1 results across gender and class standing level. As can be seen in the table, a total of 92 students participated in the EDSGN 100 focused data collection. General Linear Modeling (GLM) and Bonferroni multiple comparisons were used to understand the significance level of differences across sections due to curricular differences. GLM is used to test statistical significance of differences. The normality and the existence of equal variances should be tested in order to apply the GLM. Normality assumption can be verified by looking at the data histogram and normal probability plot. For all scales, normality and variance equivalence are tested although we only show detailed results for Scale 1 in the Appendix A. Figure A-1a and A-1b (in the Appendix A) show the histogram and the normal probability plots for Scale 1. The histogram shows that the data is skewed to the left, and the normal probability plot shows some deviation from normality; accordingly, a data transformation is done, and normality is rechecked. By applying the Johnson transformation, Scale 1 can be transformed to a normally distributed variable. Figure A-2 shows the Johnson transformation completed in Minitab. Figure A-3a and A-3b show the histogram and the normal probability plots, respectively, for Scale 1 after the transformation. In order to check the assumption of equal error variance, Levene's test has been implemented.

Based on these affirmations (normality and equal variances), GLM is implemented to analyze the significance of gender, section (intervention; product dissection only or product archeology), year (class standing), and their interactions having the scales as the performance measures. Table 3 presents these data, where only two scales had statistical significant differences across sections, Scale 1 (Applying math and science) and Scale 13 (The Emphasis of EDSGN 100 on Some Topics in Engineering).

Section	Gender	Year	Mean	Std. Deviation	N
A	Males	Freshman	2.982	1.0807	14
		Total	2.982	1.0807	14
	Females	Freshman	2.929	.7734	7
		Total	2.929	.7734	7
	Total	Freshman	2.964	.9692	21
		Total	**2.964**	.9692	21
B	Males	Freshman	2.804	.9208	14
		Sophomore	2.417	.7217	3
		Junior	3.500	.7071	2
		Total	2.816	.8813	19
	Females	Freshman	3.292	.7144	6
		Total	3.292	.7144	6
	Total	Freshman	2.950	.8758	20
		Sophomore	2.417	.7217	3
		Junior	3.500	.7071	2
		Total	**2.930**	.8555	25
C	Males	Freshman	3.346	.8135	13
		Sophomore	3.750	.4330	3
		Total	3.422	.7622	16
	Females	Freshman	3.250	.	1
		Total	3.250	.	1
	Total	Freshman	3.339	.7821	14
		Sophomore	3.750	.4330	3
		Total	**3.412**	.7392	17
D	Males	Freshman	3.650	.6559	20
		Sophomore	3.333	.8036	3
		Total	3.609	.6650	23
	Females	Freshman	3.600	.7202	5
		Sophomore	4.500	.	1
		Total	3.750	.7416	6
	Total	Freshman	3.640	.6538	25
		Sophomore	3.625	.8780	4
		Total	**3.638**	.6701	29
Total	Males	Freshman	3.238	.9076	61
		Sophomore	3.167	.8292	9
		Junior	3.500	.7071	2
		Total	3.236	.8850	72
	Females	Freshman	3.237	.7287	19
		Sophomore	4.500	.	1
		Total	3.300	.7635	20
	Total	Freshman	3.237	.8641	80
		Sophomore	3.300	.8882	10
		Junior	3.500	.7071	2
		Total	3.250	.8565	92

Table 2. Descriptive statistics for scale 1: applying math and science.

#	Cronbach's Alpha	Gender	Section	Year	Gender*Section	Gender*Year	Section*Year
Scale 1	0.840	.324	**.036**	.432	.761	.177	.520
Scale 2	0.911	.471	.072	.225	.222	.208	.680
Scale 3	0.832	.496	.749	.164	.295	.414	.776
Scale 4	0.883	.807	.297	.315	.306	.982	.876
Scale 5	0.915	.139	.728	.699	.505	.299	.829
Scale 6	0.854	.565	.974	.358	.257	.711	.925
Scale 7	0.432	.309	.885	.799	.473	.739	.883
Scale 8	0.797	.686	.465	.542	.737	.712	.438
Scale 9	0.636	.326	.132	.805	.463	.733	.789
Scale 10	0.859	.595	.075	.747	.329	.893	.558
Scale 11	0.820	.733	.484	.833	.494	.914	.536
Scale 12	0.822	.651	.174	.424	.216	1.000	.773
Scale 13	0.879	.096	**.028**	.141	.524	.621	.278
Scale 14	0.877	.775	.966	.130	.103	.389	.153
Scale 15	0.842	.540	.542	.335	.512	.662	.467

Table 3. Cronbach's alpha and p-values

The relevant items of the scales with significant differences are discussed next. For Scale 1, Section D was significantly different than Sections A and B (seen in Appendix A, Table 10); for Scale 13, Section C was significantly better than the others (A, B, and D).

Scale 1. Applying math & science:

1.1. Math to engineering problems
1.2. The physical sciences to engineering problems
1.3. Computer tools and applications to engineering problems
1.4. Life sciences to engineering problems

Scale 13. How much did EDSGN100 alone emphasize each of the following topics in engineering:

13.1 Ethical issues in engineering practice
13.2 The importance of life-long learning
13.3 Examining my beliefs and values and how they affect my ethical decisions
13.4 The value of gender, racial/ethnic, or cultural diversity in engineering
13.5 Creativity and innovation

13.6 Current workforce and economic trends

13.7 Emerging engineering technologies

13.8 How theories are used in engineering practice

With relevance to Question 1 (In comparison to product dissection activities, how did performance of the product archeology curriculum compare in gains of learning in GSEE issues?), a deeper look at Scale 15 was required. Although as an overall scale, the course sections were not significantly different for this scale, Item 1 directly related to GSEE issues (see below), we compared performance just for that. However, the comparison of Item15.1 revealed no significant results; in other words, Sections A, B, C, and D performed equivalently.

Scale 15. How much did EDSGN100 alone emphasize each of the following problem solving skills:

15.1 Understanding how an engineering solution can be shaped by environmental, cultural, economic considerations.

Despite the seemingly equivalent performance across section, we also reviewed the responses to the open-ended questions: *Please indicate EDSGN 100 class activities with which you were engaged in/thought of the following: a) How global context influences design, b) How economic context influences design, c) How environmental context influences design, and d) How societal context influences design.*

Open-ended responses were coded by a senior doctoral student who was given the course syllabi of all course sections. This student reviewed all entries and matched the wording from the relevant syllabus to ensure that responses coming from the same section's students pointed to course items consistently. For example, design project 2 also meant the industry-sponsored project, but this was impossible to discern without the course syllabi. This graduate student did not know what intervention was implemented in which section; at the same time, when statistical analysis and coding results were discussed, project investigators did not know which section was which as they were reported as Sections A-D. After the analyses were completed only they were able to match the interventions to the statistical results. The responses to these open-ended questions are provided in Table 4. The entries in the table not only reflect the course features cited for their impact on enhancing GSEE awareness, but also a percentage as calculated by the cumulative number of responses divided by the number of students in the course section. Note that an observation of more than 100% is possible as students were not limited to indicate only one course feature. The percentage was preferred in place of counts as the class sizes were different.

Upon review of Table 4, it is clearly seen that Section D, in which product archeology curriculum is embedded, has resulted in a higher percentage of students in identifying course features with

	Class Activity	# of Res.	Class Activity	# of Res.	Class Activity	# of Res.	Class Activity	# of Res.
Global Context	Fire Extinguisher Redesign Mini Project	4	Fire Extinguisher Redesign Mini Project	3	In Class Discussion	1	Product Archeology	20
	Product Design Challenges	2	Product Design Challenges	2	Power Point Presentations	1	Industry Sponsored Design Project	13
	Practice Problem of Water Resource	4	Practice Problem of Water Resource	2	Team Work	1	Customer Needs Assessment	1
	Readings	1	Dissection Project	2	Global Design Project	5	Green Design	3
	Geographic Region of the Product	2	EMS Modeling	2	Projects	2		
	Marketing	1	Marketing	2			CAD	1
%	SECTION A: 67%		SECTION B: 52%		SECTION C: 59%		SECTION D: 128%	
Economic Context	Dissection Project	11	Dissection Project	8	Dissection Project	5	Product Archeology	17
							Industry Sponsored Design Project	16
	Fire Extinguisher Redesign Mini Project	2	Industry Sponsored Design Project	1			Customer Needs Assessment	1
	Problem Solving	1	Fire Extinguisher Redesign Mini Project	1			Camera Dissection	1
	EMS Modeling	1	EMS Modeling	1				
	Practice Problem of Water Resource	1	Product Dissection	1	Global Design Project	2	CAD	1
	Cost Calculations	1	Cost Calculations	3				
	Market Competition	1	Marketing	1	In Class Discussion	1	Budget	1
%	SECTION A: 86%		SECTION B: 64%		SECTION C: 47%		SECTION D: 128%	
Environmental Context	Dissection Project	7	Dissection Project	4			Product Archeology	12
							Industry Sponsored Design Project	21
	Fire Extinguisher Redesign Mini Project	5	Industry Sponsored Design Project	1	Dissection Project		Geographic Locations	1
	EMS Modeling	1	EMS Modeling	1		3	CAD	1
	Practice Problem of Water Resource	1	Practice Problem of Water Resource	3			Camera Dissection	1
	Green Design	1	Product Dissection	1	Global Design Project			
	Energy Saving	1	Fire Extinguisher Redesign Mini Project	1				
	Product Design Challenges	2	Design Problems	1		1	Green Design	
	Readings	1	Lab2-Noise and Battery Life Measurement	3	In Class Discussion	2		7

Table 4 Open-ended question summary

(Continued)

	Class Activity	# of Res.	Class Activity	# of Res.	Class Activity	# of Res.	Class Activity	# of Res.
%	SECTION A: 90%		SECTION B: 64%		SECTION C: 35%		SECTION D: 148%	
Social Context	Dissection Project	9	Dissection Project	9			Product Archeology	15
							Industry Sponsored Design Project	14
	Fire Extinguisher Redesign Mini Project	3	Industry Sponsored Design Project	1	Dissection Project	4	Japanese Culture	1
	Customer Needs	1	EMS Modeling	1			Customer Needs Assessment	1
	Team Work	1	Practice Problem of Water Resource	1	Global Design Project	2		
	Product Design Challenges	4	Design Problems	2			CAD	2
			Women in Engineering	1				
	Readings	1			In Class Presentation	1		
			Customer Needs Analysis	2			Green Design	2
%	SECTION A: 90%		SECTION B: 68%		SECTION C: 41%		SECTION D: 121%	

Table 4 Open-ended question summary

relevance to GSEE activities. Given that, by and large, all these 92 students have similar qualities as identified by the mostly equivalent scale values, it is very encouraging to see that product archeology curriculum was able to garner much higher awareness of GSEE issues.

Data Analysis for IE 466

Across the two data collection years a total of 57 valid observations were achieved. Using these data, this part of the analysis concentrated on Question 2: “In comparison to other engineering courses’ impact how did IE 466 compare in enhancing GSEE gains as perceived by students?” This question was answered using the statistical analysis of the paired scales as noted in Section 4. Descriptive statistics and significance test tables are provided in Tables 5 and 6 for Scales 10 and 13, and in Tables 7 and 8 for Scales 12 and 15.

A review of Table 5 shows that on all scale items students rated their experience in IE 466 to be better in comparison to all other engineering courses. The differences are also evaluated as shown in Table 6. It is seen that Items 5-8 revealed significant differences. Item 6 focuses on “current workforce and economic trends” and, thus, is related to GSEE issues.

		Mean	N	Std. Deviation	Std. Error Mean
Ethical issues in engineering practice.	Scale10.1	3.39	57	1.114	.148
	Scale13.1	**3.51**	57	.889	.118
The importance of life-long learning.	Scale10.2	3.67	57	1.006	.133
	Scale13.2	**3.68**	57	.929	.123
Examining my beliefs and values and how they affect my ethical decisions.	Scale10.3	3.04	57	1.133	.150
	Scale13.3	**3.32**	57	1.072	.142
The value of gender, racial/ethnic, or cultural diversity in engineering.	Scale10.4	2.95	57	1.260	.167
	Scale13.4	**3.11**	57	1.030	.136
Creativity and innovation.	Scale10.5	4.14	57	.915	.121
	Scale13.5	**4.67**	57	.607	.080
Current workforce and economic trends (globalization, outsourcing, etc.).	Scale10.6	3.82	57	.928	.123
	Scale13.6	**4.21**	57	.881	.117
Emerging engineering technologies.	Scale10.7	3.70	57	.981	.130
	Scale13.7	**4.05**	57	.833	.110
How theories are used in engineering practice.	Scale10.8	3.74	57	.917	.121
	Scale13.8	**4.09**	57	.912	.121

Table 5. Paired scales statistics, scales 10 & 13.

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Scale10.1 - Scale13.1	–.123	1.415	.187	–.498	.253	–.655	56	.515
Pair 2	Scale10.2 - Scale13.2	–.018	.896	.119	–.255	.220	–.148	56	.883
Pair 3	Scale10.3 - Scale13.3	–.281	1.221	.162	–.605	.043	–1.735	56	.088
Pair 4	Scale10.4 - Scale13.4	–.158	1.222	.162	–.482	.166	–.976	56	.333
Pair 5	Scale10.5 - Scale13.5	–.526	.947	.125	–.778	–.275	–4.196	56	**.000**
Pair 6	Scale10.6 - Scale13.6	–.386	1.098	.145	–.677	–.095	–2.654	56	**.010**
Pair 7	Scale10.7 - Scale13.7	–.351	1.077	.143	–.637	–.065	–2.459	56	**.017**
Pair 8	Scale10.8 - Scale13.8	–.351	1.246	.165	–.682	–.020	–2.126	56	**.038**

Table 6. Significant differences (scale 10–scale 13).

Scale comparison 12 vs. 15 focuses on Problem Solving Skills in general, emphasizing how knowledge from other fields can be used in solving engineering problems. Relevant to our focus and the embedment of the product archeology curriculum into IE 466, the first item intends to compare how the course in comparison to all other engineering courses enhances students' "***Understanding on how an engineering solution can be shaped by environmental, cultural, economic, and other considerations".*** As it can be followed in Tables 7 and 8, on this specific item along with Items 2 and 4, students rated the IE 466 course to have a higher rating in comparison to all other engineering courses they have taken. The significance of these results is also confirmed in Table 8.

Overall, across the scale pairs analyzed, the perceived impact of all other engineering courses students have taken versus the product archeology embedded course (IE 466) alone, the results point to the effectiveness in contributions to one carefully designed course or set of product archaeology activities. Considering that the first item in Scale pair 12 and 15 is "*Understanding how an engineering solution can be shaped by environmental, cultural, economic, and other considerations*", overall it is concluded that the efforts presented are in the right direction.

In an effort to understand how much impact we can expect with the product archeology intervention at different class standing levels (first-year to senior), we have compared the paired-scale differences across courses using t-tests. The results are presented in Table 11 of Appendix B. Other than only few items (i.e., 11-14.1 (professional skills); 11-14.3 (leadership skills); 12-15.1 (systems thinking) and 12-15.5 (defining a design problem)), the positive impact of the product archeology curriculum

		Mean	N	Std. Deviation	Std. Error Mean
Understanding how an engineering solution can be shaped by environmental, cultural, economic, and other considerations	Scale12.1	3.46	57	.983	.130
	Scale15.1	**3.98**	57	.876	.116
Understanding how non-engineering fields can help solve engineering problems	Scale12.2	3.04	57	1.117	.148
	Scale15.2	**3.75**	57	.872	.115
Systems thinking	Scale12.3	3.32	57	1.121	.148
	Scale15.3	3.11	57	1.205	.160
Applying knowledge from other fields to solve an engineering problem	Scale12.4	3.13	56	1.010	.135
	Scale15.4	**3.55**	56	.829	.111
Defining a design problem	Scale12.5	3.98	57	.896	.119
	Scale15.5	4.11	57	.838	.111
Generating and evaluating ideas about how to solve an engineering problem	Scale12.6	4.09	57	.830	.110
	Scale15.6	**4.18**	57	.848	.112

Table 7. Paired scales statistics, scales 12 & 15.

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Scale12.1 - Scale15.1	–.526	.984	.130	–.787	–.265	–4.039	56	.000
Pair 2	Scale12.2 - Scale15.2	–.719	1.013	.134	–.988	–.450	–5.359	56	.000
Pair 3	Scale12.3 - Scale15.3	.211	1.191	.158	–.106	.527	1.334	56	.188
Pair 4	Scale12.4 - Scale15.4	–.429	.931	.124	–.678	–.179	–3.443	55	.001
Pair 5	Scale12.5 - Scale15.5	–.123	1.019	.135	–.393	.148	–.910	56	.367
Pair 6	Scale12.6 - Scale15.6	–.088	1.106	.147	–.381	.206	–.599	56	.552

Table 8. Significant differences (scale 12–scale 15).

in comparison to students' all other engineering courses significantly grew (as per students' perception data). These results also point to the effectiveness of the curriculum.

We note several limitations in our assessment. First of all, our results are mostly based on self-reported student perceptions, and we are not testing content knowledge or learning directly. In addition, we are only testing two courses to embed the product archeology curriculum, and although we have four course sections in which we tested the curriculum at the first-year course (EDSGN 100), for IE 466 multiple sections were not offered. In relation to the latter point, the limitation due to having one section precludes us from being definitive with the conclusions about the GSEE activities, i.e., we cannot definitively say that the GSEE activity is what makes IE 466 different—it could just be the overall topical coverage of IE 466 (beyond the mini curriculum). Since we do not have data for this course prior to introducing the GSEE activity, it is impossible to affirm GSEE activities' sole contribution. Current data collections are underway to eliminate the limitations we are citing here.

DISCUSSION AND CONCLUSIONS

In this paper, using a validated survey we have investigated the effectiveness of the product archeology curriculum in enhancing students' awareness on GSEE issues. Assessment was done in a first-year course as well as in a senior-level technical elective. With the first-year level data collection, we have sought to understand if product archeology curriculum can more effectively introduce the GSEE issues in comparison to frequently used product dissection and redesign projects. Accordingly, four sections of the EDSGN 100 course were included in the study, where two sections

(A and B) included product dissection projects and an industry-sponsored project, one section (C) included a product dissection project and a global design project, and one section (D) included a product archeology project and an industry-sponsored project. The comparisons across sections first ensured that students were overall at similar levels as assessed using the 15 scales. A review of the responses to the open-ended questions revealed that students in the course section, which embedded product archeology curriculum, had a much higher level of identification of course features that impacted their awareness on GSEE issues.

The data collection and subsequent analysis completed for the IE 466 course revealed that across half of the item pairs for Scales 10 and 13 as well as Scales 12 and 15, the product archeology curriculum positively and significantly impacted students' perception of their learning in areas relevant to GSEE issues.

Overall, embedding product archeology is found to be effective in both the first year (as compared to the other sections of the course that did not use the product archeology) as well as the senior year (as compared to all other engineering courses). Given the fact that in both courses, the implementation activities took no more than 5 hours of actual in class time, we assert that product archeology is an effective and efficient way of increasing awareness of GSEE concepts in engineering students based on the assessment results. These results indicate that the "product archeology" can be an effective pedagogy to create the desired effect to address ABET's Outcome h. However, as acknowledged further data collection is necessary in other courses, and we are developing assessment methods to use content knowledge/learning data to draw conclusive evidence.

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APPENDIX A

Statistical procedures followed for each scale across data collection years.

1. Normality test is done.

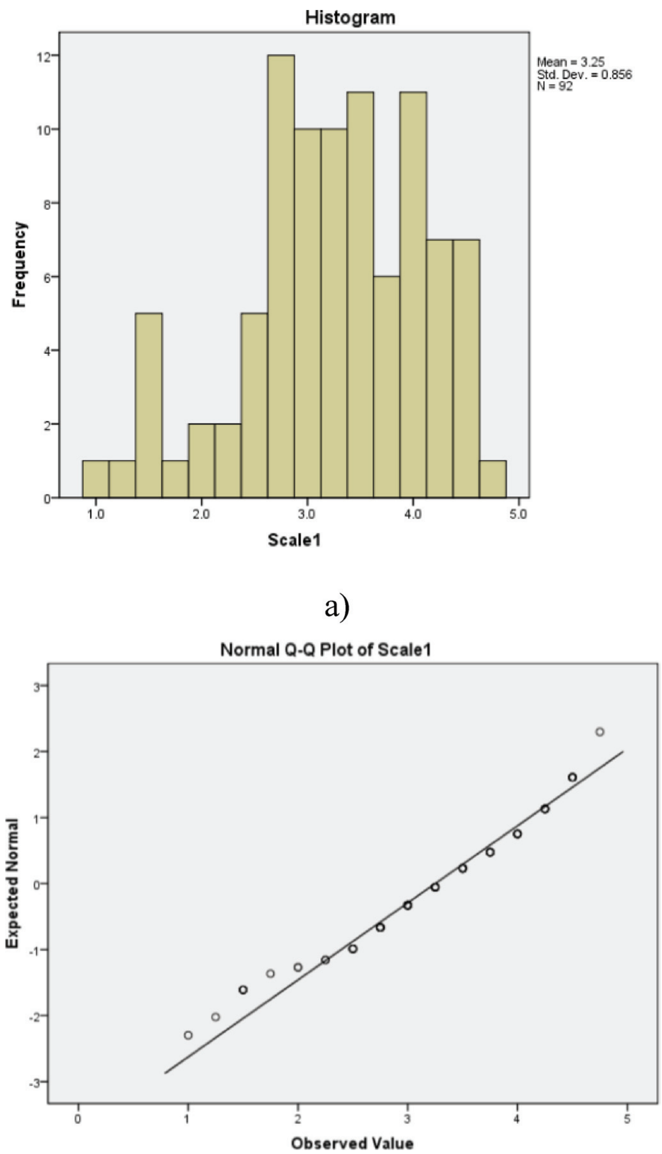

Figure A-1. a) Histogram, b) Normal probability plot of scale 1.

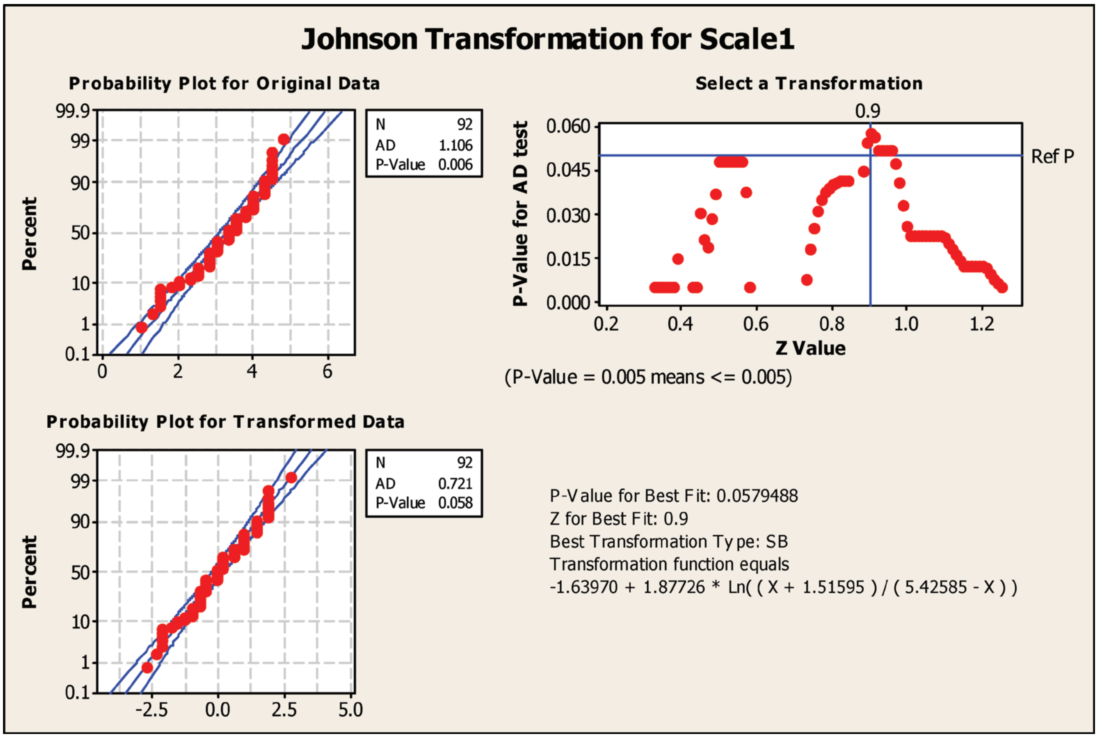

Figure A-2. Johnson transformation for scale 1.

If the data is not distributed normally, data transformation was done. By applying Johnson transformation, scale 1 can be transformed to a normally distributed variable. Figure A-2 shows the Johnson transformation completed in Minitab.

Figure A-3.a and A-3.b show the histogram and the normal probability plots, respectively, for scale 1 after the transformation.

In order to check the assumption of equal error variance, Levene's test has been implemented as shown in Table 8. We fail to reject the null hypothesis (equal error variance) because the p = 0.770 > 0.05.

Dependent Variable:Scale1_T

F	df1	df2	Sig.
.675	12	79	.770

Table 8. Levene's test for scale 1 (Levene's test of equality of error variances)

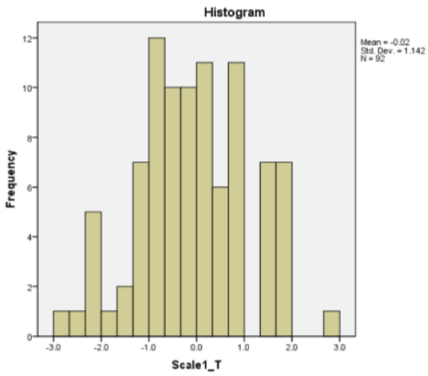

Figure A-3.a Histogram

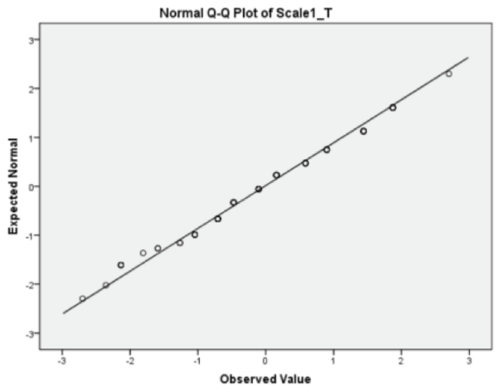

Figure A-3.b Normal Probability Plot of Scale 1

GLM can be implemented after the confirmation of normality and equal variances. Table 9 shows the ANOVA table. ANOVA table shows that there are significant differences across sections (p=0.036 < 0.05). While the other variables and the interactions are not statistically significant (p > 0.05).

Table 10 shows the Bonferroni multiple comparisons. Using this method, we can identify which sections have significantly different means. According to Bonferroni multiple comparisons, section A and D, and section B and D are statistically different.

Source	Type IV Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	22.736[a]	12	1.895	1.561	.121
Intercept	.315	1	.315	.260	.612
Section	10.879[b]	3	3.626	2.989	.036
Gender	1.194[b]	1	1.194	.984	.324
Year	2.056[b]	2	1.028	.847	.432
Section * Gender	1.419[b]	3	.473	.390	.761
Section * Year	1.601[b]	2	.800	.660	.520
Gender * Year	2.253[b]	1	2.253	1.857	.177
Section * Gender * Year	.000	0	.	.	.
Error	95.862	79	1.213		
Total	118.629	92			
Corrected Total	118.598	91			

[a]. R Squared = .192 (Adjusted R Squared = .069), [b]. The Type IV testable hypothesis is not unique.

Table 9. ANOVA output (tests of between-subjects effects).

(I) Section	(J) Section	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A	B	.043	.3261	1.000	−.839	.926
	C	−.537	.3594	.837	−1.509	.436
	D	−.908*	.3156	.031	−1.763	−.054
B	A	−.043	.3261	1.000	−.926	.839
	C	−.580	.3463	.589	−1.517	.358
	D	−.951*	.3006	.013	−1.765	−.138
C	A	.537	.3594	.837	−.436	1.509
	B	.580	.3463	.589	−.358	1.517
	D	−.372	.3365	1.000	−1.282	.539
D	A	.908*	.3156	.031	.054	1.763
	B	.951*	.3006	.013	.138	1.765
	C	.372	.3365	1.000	−.539	1.282

Based on observed means. The error term is Mean Square(Error) = 1.213. *. The mean difference is significant at the .05 level.

Table 10. Bonferroni multiple comparisons of scale 1.

APPENDIX B. COMPARISON OF FIRST-YEAR STUDENTS TO SENIOR STUDENTS

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Scale10.1_13.1	Equal variances	2.517	.115	–5.358	134	.000	–.92500	.17263	–1.26644	–.58356
	Unequal variances			–5.514	128.960	.000	–.92500	.16775	–1.25689	–.59311
Scal210.2_13.2	Equal variances	8.002	.005	–1.934	134	.055	–.40357	.20865	–.81624	.00910
	Unequal variances			–2.059	133.995	.041	–.40357	.19604	–.79130	–.01584
Scale10.3_13.3	Equal variances	2.646	.106	–3.377	134	.001	–.69107	.20463	–1.09579	–.28636
	Unequal variances			–3.461	127.684	.001	–.69107	.19968	–1.08617	–.29597
Scale10.4_13.4	Equal variances	7.180	.008	–2.709	134	.008	–.56964	.21031	–.98561	–.15368
	Unequal variances			–2.821	131.890	.006	–.56964	.20192	–.96907	–.17022
Scale10.5_13.5	Equal variances	1.936	.166	–4.295	134	.000	–.58571	.13638	–.85546	–.31597
	Unequal variances			–4.572	133.992	.000	–.58571	.12811	–.83909	–.33233
Scale10.6_13.6	Equal variances	1.629	.204	–5.653	134	.000	–.96429	.17057	–1.30165	–.62692
	Unequal variances			–5.810	128.542	.000	–.96429	.16598	–1.29269	–.63588
Scale10.7_13.7	Equal variances	10.357	.002	–2.813	134	.006	–.49107	.17458	–.83635	–.14579
	Unequal variances			–2.948	132.938	.004	–.49107	.16659	–.82057	–.16157
Scale10.8_13.8	Equal variances	1.641	.202	–3.527	134	.001	–.60893	.17267	–.95043	–.26742
	Unequal variances			–3.611	127.443	.000	–.60893	.16862	–.94258	–.27527
Scale11.1_14.1	Equal variances	1.071	.303	.159	134	**.874**	.02679	.16878	–.30703	.36060
	Unequal variances			.156	112.334	**.876**	.02679	.17120	–.31241	.36598
Scale11.2_14.2	Equal variances	3.010	.085	–3.204	134	.002	–.50714	.15826	–.82015	–.19413
	Unequal variances			–3.317	130.498	.001	–.50714	.15290	–.80963	–.20466
Scale11.3_14.3	Equal variances	.479	.490	–.661	134	**.510**	–.11786	.17821	–.47032	.23460
	Unequal variances			–.675	126.282	**.501**	–.11786	.17464	–.46346	.22775
Scale11.4_14.4	Equal variances	.769	.382	–1.900	134	.060	–.26607	.14007	–.54310	.01096
	Unequal variances			–2.022	133.994	.045	–.26607	.13159	–.52634	–.00580
Scale11.5_14.5	Equal variances	.012	.913	–1.842	134	.068	–.30893	.16774	–.64069	.02284
	Unequal variances			–1.860	122.466	.065	–.30893	.16611	–.63776	.01990
Scale12.1_15.1	Equal variances	4.308	.040	–2.846	134	.005	–.47679	.16755	–.80817	–.14540
	Unequal variances			–2.924	128.518	.004	–.47679	.16305	–.79940	–.15417
Scale12.2_15.2	Equal variances	4.880	.029	–4.855	134	.000	–.89464	.18426	–1.25908	–.53021
	Unequal variances			–5.120	133.646	.000	–.89464	.17474	–1.24026	–.54902
Scale12.3_15.3	Equal variances	.009	.926	.407	134	**.685**	.08571	.21078	–.33116	.50259
	Unequal variances			.407	118.469	**.685**	.08571	.21080	–.33171	.50314
Scale12.4_15.4	Equal variances	1.688	.196	–2.954	134	.004	–.51607	.17470	–.86161	–.17054
	Unequal variances			–3.105	133.347	.002	–.51607	.16618	–.84476	–.18738
Scale12.5_15.5	Equal variances	.235	.629	–1.511	134	**.133**	–.23929	.15840	–.55257	.07400
	Unequal variances			–1.546	127.353	**.124**	–.23929	.15473	–.54546	.06689
Scale12.6_15.6	Equal variances	1.330	.251	–1.767	134	.080	–.27321	.15463	–.57904	.03261
	Unequal variances			–1.791	123.811	.076	–.27321	.15259	–.57523	.02880

Table 11. Independent samples test.