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Enduring Design: Developing Connections Between Art and Engineering

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Abstract

This paper describes the assessed outcomes of a course entitled, "Enduring Design: The Art of Engineering," which was created specifically for the purpose of enabling students to explore the interconnected worlds of art and engineering. With a directed emphasis on identifying the forms that capture the eye and the imagination, students investigated the visual and functional elements that contribute to successful and enduring designs.

Engineering students are a target audience for two reasons. First, engineering students rarely attain a full benefit from their liberal education courses. Second, evidence indicates a strong link between the level of productivity of innovative scientists and their participation in and understanding of the arts. Engineering students tend to place a higher time priority on classes they view as favoring the acquisition of highly marketable skills over educationally enriching experiences. Because of this perspective, engineering students sometimes need encouragement to help them see how their lives and their careers may be positively impacted by their general studies.

Throughout the course, students were encouraged to examine art through the lens of engineering achievement and engineering through the lens of artistic merit. The course aimed to challenge students to see new opportunities that arise from the effective combination of form and function in existing objects and in original designs. The course assessment focused most strongly on the following outcomes: First, that students have the ability to recognize the meanings and uses of form, and second, that students have the ability to use form to create new opportunities for function. Measures to explore the success of meeting these outcomes were obtained by a statistical comparison of student papers prepared at the beginning and end of the course. In these assignments, students suggested possible improvements for one of a given set of objects. The papers submitted were grouped by "initial" or "final" papers and analyzed for content. The analysis focused on the percentage of each paper that students spent on their improvement ideas, as well as the number and type of different ideas presented. In initial papers, the students overwhelmingly focused on functional improvements on given objects. In contrast, student writing in later papers indicated an overall increase in student ability to create ideas and an improved ability to see value creation as a more varied proposition that includes both the form and function of an object. This analysis is also supported by student comments from the final course evaluations wherein a number of students affirmed the course objectives. While the data set is relatively small, the trends are positive and suggest potential for future study.

Introduction

This paper describes the development of a course entitled, "Enduring Design: The Art of Engineering," which has been created specifically for the purpose of enabling students to explore the interconnected worlds of art and engineering. Often considered diametrically opposed, with "art" emphasizing aesthetic form, and "engineering" advocating practical function, the two fields share a historically attested connection. Technological expertise and output can be considered the ultimate goal of a STEM education, yet the meaning of the term, "technology" is rarely considered. "Technology" has its etymological roots in the classical Greek word *techne* (*τέχνη*). In its original usage, *techne* was used to describe general expertise in craft or art. More specifically, *techne* implies a combination of knowing and doing within a certain context. Consequently, *techne* could be used to describe artistic and engineering production that satisfies formal and functional needs. *Techne* underscores the intimate relationship between art and engineering when practiced by a master hand.

The concept of *techne* emphasizes the importance of integrating a liberal education with a technical education. Unfortunately, engineering students frequently schedule their liberal arts courses as a matter of convenience rather than as a matter of intent. This observation is supported by Lichtenstein, et. al., [1] who conclude that engineering majors show the least benefit from their general education as compared to all other majors. These authors suggest that the reason for this lack of benefit is based on time management. Engineering students tend to place a higher time priority on classes they view as favoring the acquisition of highly marketable skills over educationally enriching experiences. Because of this perspective, engineering students sometimes need encouragement to help them see how their lives and their careers may be positively impacted by their general studies.

A history of the efforts to build and develop courses that connect engineering to the liberal arts reinforces the idea that such connections are not developed simply by placing engineering students in liberal arts courses. Accordingly, a variety of approaches have been tried to build such interconnected courses. These approaches typically fall into one of two categories: engineering courses with added liberal arts components, or multidisciplinary courses where students from specific majors populate the course.

Examples of engineering-based courses that introduce liberal arts ideas within the course can be found in references [2-7]. Wikoff et. al[2] describe a third year manufacturing course where students use an artistic depiction of manufacturing (such as a painting of a group of laborers from the early 1900s) as the starting point for a term paper. The same reference also describes a first year humanities course where students are surveyed on whether their technical ability aids them in their appreciation of art and if exposure to art changes their view of technology. Genereux[3] outlines a Web Design course where artistic concepts are introduced and the works of master painters are studied to aid students in their design tasks. Burkett and Snead[4] describe a freshman engineering course where students construct lamps from retired musical instruments. Kelt[5] presents a history of science and technology course designed specifically for engineering majors. Similarly, Andrews et al[6] discuss a philosophy course designed to address the question of "how shall I think and act and to what ends strive" as a professional engineer. Shakerin[7] presents a resource describing how water fountains blend art and engineering that can be included in engineering courses but is not a complete course in itself. While the efforts mentioned in the above references show an interest in connecting approaches, they fall short of truly integrating the disparate fields.

Multidisciplinary courses with controlled enrollments have also been used to integrate engineering with other disciplines[8-10]. Hertzberg, et. al.[8] describe a course that contains a mix of engineering and fine arts students. Similarly, Sochacka, et. al.[9] detail a course that combines students from the disciplines of Civil and Environmental Engineering, Art Education, and

Landscape Architecture. Finally, Marshall[10] discusses a course that integrates students from Engineering, Architecture, and Urban Planning. These and similar courses certainly emphasize diversity of student population, but the students involved often contribute in their area of expertise. Whether this leads to a meaningful integration of disciplines depends on the leaders and participants of the courses.

In contrast to the courses described above, the intent of the course described in this paper is to develop a liberal arts course that appeals to engineering students without necessarily being restricted to any specific enrollment ratios. Engineers are a target audience for two reasons. First, as previously noted, is that these students do not typically attain a full benefit from their liberal education courses. Second, evidence indicates a strong link between the level of productivity of innovative scientists and their participation in and understanding of the arts[11-14]. Although engineering students are a target audience for the course, no major specific restrictions are placed on enrollment. The fact that the course is taught at a technical school results in an enrollment of STEM majors. Because the course does not require the enrollment of students in specific fields, the connections developed in the course could serve equally well to draw liberal arts majors to appreciate STEM topics as it does to draw STEM students to better appreciate the liberal arts, though that dual premise is not investigated in this current paper.

The following sections describe the course and its measurable outcomes. The specific course objectives are presented first, followed by an overview of the course content and structure. The course outcomes are analyzed and some future possibilities for the course are discussed.

Course Description

Enduring Design: The Art of Engineering was developed and taught by Andrew Findley (Art History and Archaeology) and John Mirth (Mechanical Engineering) over the 2014/2015 academic year at Rose-Hulman Institute of Technology. No prerequisites, prior experience, academic major, or class standing limited the composition of the student participants. Consequently, a wide range of STEM disciplines were represented in the course enrollment.

The course was designed as an exploration of the relationship between art and engineering. With a directed emphasis on identifying the forms that capture the eye and the imagination, students investigated the visual and functional elements that contribute to successful and enduring designs. Throughout the course, students were encouraged to examine art through the lens of engineering achievement and engineering through the lens of artistic merit. The course aimed to challenge students to see new opportunities that arise from the effective combination of form and function in existing objects and in original designs.

No single major or field of study was emphasized or represented. To account for the diversity of course participants, the course developers set out with the following universal objectives and outcomes:

<u>Objectives</u>

1. To identify, understand, and appreciate the natural and historical integration of art and engineering.

2. To explore the innovative potential that results from the merger of art and engineering.
3. To identify, understand, and appreciate the enduring quality of objects that are derived from combinations of form and function.
4. To observe successful design through the entire experience one has with an object.
5. To explore the ways by which form impacts the implementation of function, especially in the initial development of an object, and in terms of creative problem solving.

Outcomes

1. Students have the ability to recognize the meanings and uses of form.
2. Students have the ability to use form to create new opportunities for function.
3. Students have the ability to "begin with form" when creating a design. (i.e. design the function around the form, which does not mean that this is how things are always done, but students should show the capability to do this and think like this).
4. Students have the ability to identify and evaluate the elements of form that capture the eye and the imagination.

Course Format and Topics

The course participants met for one hour per day, four days per week over a ten week period. During scheduled meeting periods, the course instructor led the course participants in hybrid lecture/discussion devoted to specific topics of engineering and art. Each week featured a set of varied subjects touching on an aspect or field of professional engineering and explored through examples of fine and functional art. By examining thematically linked examples, the clear relationship between art and engineering was exposed. Two such examples are described below to provide the reader with a better feel for the weekly course format.

The fourth week of the course was devoted to "The Art of Kinetics". This week began with a comparison of the well-respected engineer Leonardo Da Vinci, who was trained as an artist, and the popular artist Alexander Calder, who was trained as an engineer. Other meetings during that week featured discussions about the historically-attested functional and symbolic properties of windmills, as well as the aesthetics of speed and performance in the automobile industry.

The ninth week of the course examined aspects of industrialization and project management, with the continuing dual perspective of the artist and engineer. Course participants were first introduced to the processes and principles of mass and lean production. As the week progressed, the class considered a variety of topics, including 3rd century BC Greek innovations in the mass production of decorative mold-made ceramic bowls and the ways in which the massive projects of artists Jean-Claude and Christo can be viewed as examples of corporate management and the management of populations.

The other weeks of the course were built along similar lines, with each week exploring an engineering theme through the study of art.

Course Assignments

During the course, the students were tasked with a variety of assignments, including group projects and weekly response papers. The most significant portion of their grade, however, was the completion of four short (700 words maximum) writing assignments/projects that focused on one part of the common subject – the relationship between form and function in human-made material objects. The ultimate goal was to inspire the students to think about the relationship between art and engineering and consider ways in which the two may work in harmony through material products. These four short assignments were as follows:

1. *Individual Assignment #1* - Choose one of the following typical objects - a stapler, a hammer, a pen, a key, or a mug. In 700 words or less discuss how your object could be improved, including illustrations or models as appropriate.
2. *Individual Assignment #2* - Choose a publicly visible object on campus that has a useful and necessary function, but which attractive design appears to not have been a concern in the engineering process. In 700 words or less discuss how your object could be improved, including illustrations or models as appropriate.
3. *Individual Assignment #3* - Choose a publicly visible object on campus that has an attractive form or design but not an obvious function. How may the function be something other than what you see as an engineer? In 700 words or less discuss how your object could be improved in terms of its function, including illustrations and models as appropriate.
4. *Individual Assignment #4* - Choose one of the following typical objects - a stapler, a hammer, a pen, a key, or a mug. In 700 words or less discuss how your object could be improved, including illustrations or models as appropriate. Please note, this is the same as Assignment #1. Look back at your submission for that assignment. Knowing what you now know, consider how you can approach the problem differently. Has your improvement emphasis changed?

These four assignments were designed to guide and track the ability of course participants to consider how function and aesthetic form can contribute to the improvement of an engineered object.

Course Enrollment

The course was taught in two sections with a total enrollment of 39 students. Table 1 shows the breakdown of enrollment by both majors and year in school. Because Rose-Hulman is a technical school, all of the enrolled students are STEM majors.

Table 1: Course Enrollment by Major and Year in School

Major (Engineering)	**Bio**	**Chemical**	**Civil**	**Electrical**	**Mechanical**	**Software**	**Physics**
# enrolled	5	3	5	3	16	5	2
Year in School	**Year 1**	**Year 2**	**Year 3**	**Year 4**			
# enrolled	7	9	9	14			

Analyzing the Outcomes

The course assessment provided here focuses most strongly on the first two of the course outcomes. These, as noted above, are:

1. Students have the ability to recognize the meanings and uses of form.
2. Students have the ability to use form to create new opportunities for function.

Measures to explore the success of meeting these outcomes were obtained by two methods. The first method is a statistical comparison of student papers prepared at the beginning and end of the course (Assignments 1 and 4). The second method is a subjective examination of student comments from final course evaluations. The following subsections examine the results in more detail.

Form vs. Function: Analyzing the Results

Prior to the course, the course developers hypothesized that, when faced with a challenge to improve a given object, students enrolled in technical disciplines would tend to focus on improving the function, rather than the form, of the object. As articulated by the above outcomes, an overarching goal of the course was for students to develop a more balanced view of how both form and function can be used to add value to objects.

The measure of the above outcomes was obtained through the comparison of student responses to the first and last Individual Assignments described above. In these assignments, students suggested possible improvements for one of a given set of objects. The papers submitted were grouped by “initial” or “final” papers and analyzed for content. The analysis focused on the percentage of each paper that students spent on their improvement ideas, as well as the number and type of different ideas presented. The ideas were broken into three categories:

1. Ideas that focused on improving the functionality of the product.
2. Ideas that focused on improving the aesthetic or ergonomic form of the product.
3. Ideas that integrated improvements of both form and function so the improvements were not clearly separable into either “form” or “function” categories.

Submitted papers were analyzed by counting the number of words in each paper that fell into each of the above categories, as well as by counting the number of unique ideas in each paper that fell into the above categories. The breakdown of these results is presented below.

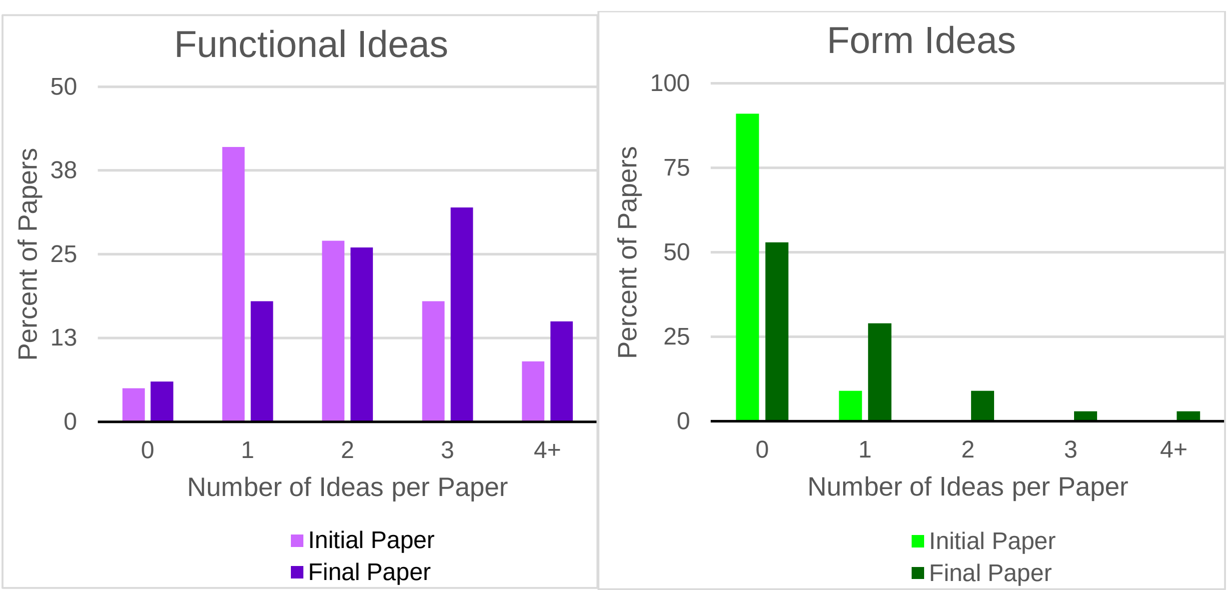
One of the basic course objectives was to improve the ability of students to see the potential for defining and creating added value in an existing object. The hypothesis was that engineering students would focus strongly on function when thinking about added value. As such, the first measure taken from the submitted assignment was to examine if this hypothesis was indeed true, and the extent to which the students might change their perception of added value by the end of the course.

The graphs in Fig. 1 show the number of ideas generated by students on both the initial and final course assignments. Figure 1(a) documents the number of ideas related to function.

Approximately 95% of the students developed one or more ideas to improve the function of one of the designated products. This number was constant across the initial and final assignments, with many students generating multiple ideas to improve the function of the object. In contrast, only 10% of the students presented a form-based improvement in the initial paper and no student presented more than one form-based improvement. By the end of the course, however, these numbers showed improvement with approximately 50% of the students suggesting form-based improvements and several students having multiple ideas to improve the form of the product.

Figure 1 also shows two interesting results that suggest a need for further investigation. The first is the fact that 50% of the students did not develop any form-based improvements at the end of the course. While the course did improve the ability of a number of students to see form as a value-added proposition, a number of other students still did not display the ability to consider improvements in form as part of product development. The second result is the increase in the number of ideas related to function. In the initial paper, students tended to present one or two ideas to improve the function of the product. The final paper shows more students presenting multiple ideas. While the data set is not large enough to draw any definite conclusions, the data suggest a possible improvement in overall student creativity during the course.

Figure 2 shows the average number of ideas generated per paper and provides an alternative analysis of the same data presented in Fig. 1. Figure 2 clearly shows an overall increase in the number of ideas generated by the students. As previously noted, the increase in ideas related to form was expected, while the increase in ideas related to function was not part of the original hypothesis. Figure 2 also includes a third category – ideas that are an inseparable combination of form and function. This third category also shows a slight increase from the initial to final paper.



(a) Ideas related to function (b) Ideas related to form

Figure 1: A comparison of the number of ideas generated on initial and final papers.

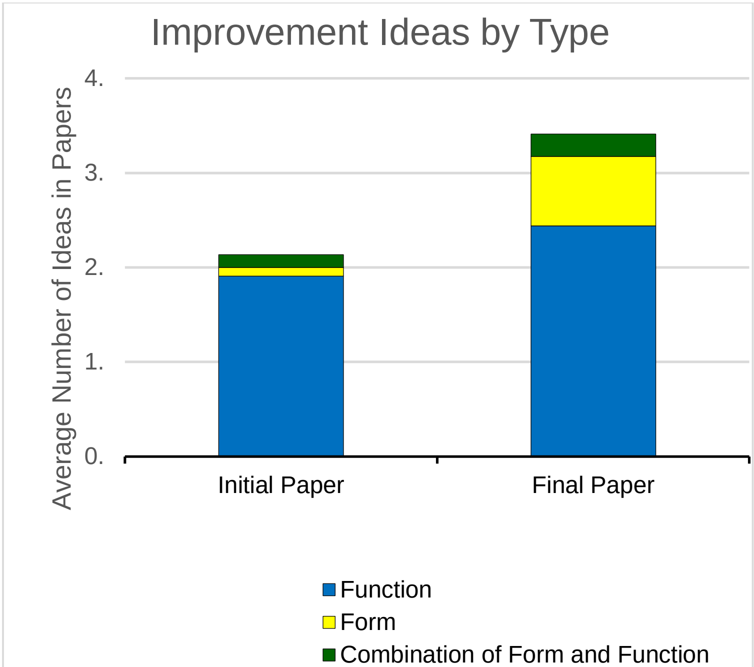


Figure 2: Average number of ideas generated per paper

The overall increase in ideas related to both form and function suggests that students are demonstrating improvements in idea generation as a result of the art-engineering connections presented in the course. While the data set is relatively small, the trends are positive and suggest potential for future study.

Further validation and understanding of the course outcomes can be obtained from some additional perspectives of the data obtained, as shown in Figs. 3 and 4. Figure 3 shows the average percentage of the content in each student paper that was associated with improvements in form and function. The data in Fig. 3 show that students invested an average of 30-35% of their written effort (by word count) focusing on improvements in function. This was consistent between the initial and final papers. Furthermore, the data in Fig. 3 reveal a significant increase in the space dedicated to improvements in form. With few people providing form-related improvements in the initial paper, less than 1% of total initial paper content discussed form. In contrast, approximately 7% of the final paper content, on average, focused on improvements in form. Similar to the number of ideas presented in Figs. 1 and 2, the increase in attention to form shown in Fig. 3 provides encouragement that students were making appropriate progress in redefining the ways in which value is added to an object.

Figure 4 provides some interesting insights into student development as they contemplated product improvements. Figure 4 shows the average number of words used to present each idea. The premise of Fig. 4 is that the more words required to describe an idea, the more complex (higher-level) the idea being presented. Most significant in Fig. 4 is a notable increase in the average number of words used to present ideas related to improvements in form. Students were not only developing more form related ideas by the end of the term, they were also investing more into each form-based idea.

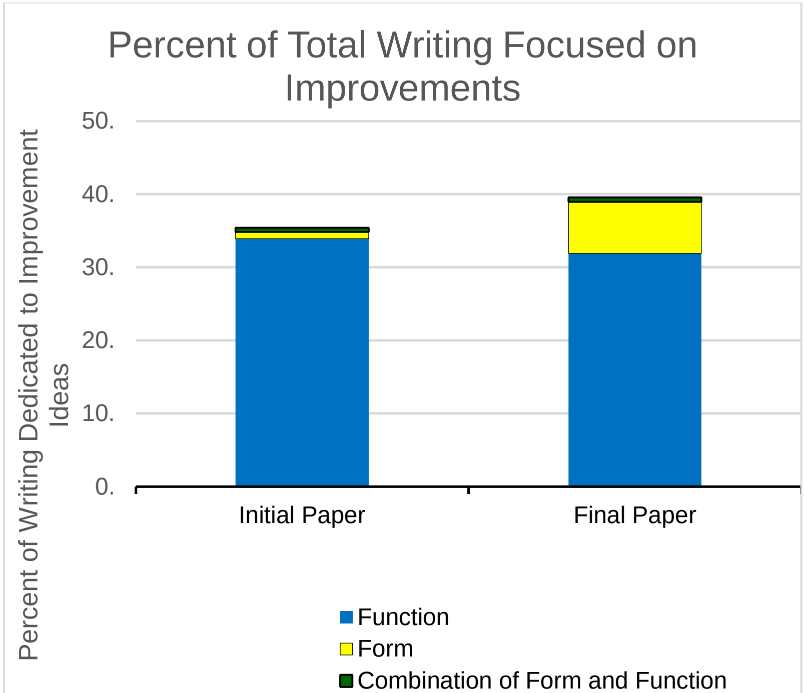


Fig. 3: Percent of Total Writing Focused on Product Improvements

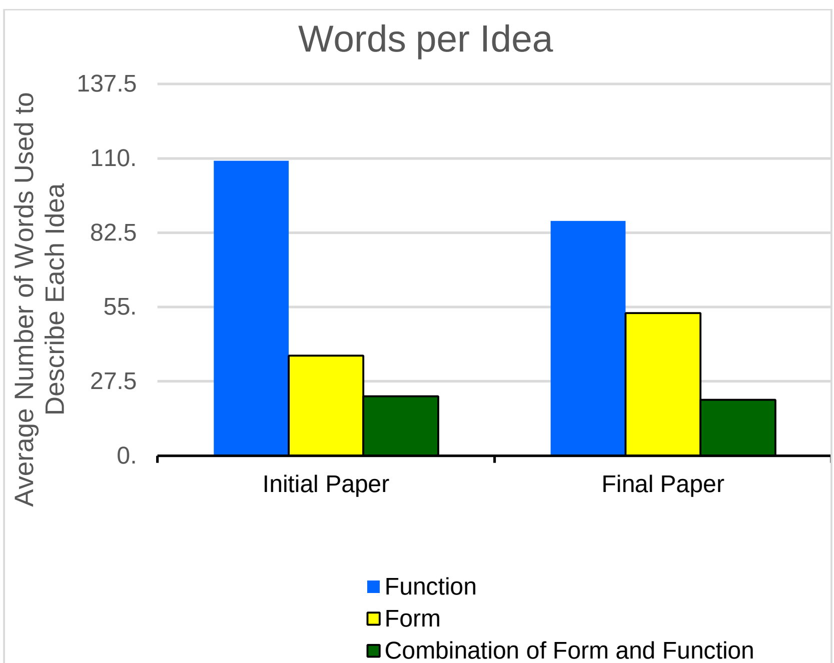


Figure 4: Average Number of Words used to Describe Each Product Improvement Idea.

Figure 4 also shows some evidence for the satisfaction of the course goal of developing students with a more balanced appreciation of the roles of form and function in engineered products. In the initial paper, students spent three times the space describing a given idea related to improving function compared to a given improvement in form. This gap narrowed to less than a 2:1 ratio in the final paper.

A final observation on Fig. 4 pertains to the column representing the ideas that are a combination of form and function. As described in the paper introduction, the classical definition of art (*techne*) produces objects that satisfy both form and function. The highest objective of the presented course is to move students to a point where they consider form and function to be interwoven with one another. Students made some advances in this area, but did not appear to fully achieve this level of integration of ideas in the course. This result should not be a surprise given the results from Fig. 1 where students began the course with almost no ideas for form-related improvements. To move students from this starting point to a final point where form and function are highly integrated is a large step for a single course. Additional work needs to be performed to determine the necessary student experiences to move to this highest level.

The above information focuses on student development in the course as a function of their ability to generate and discuss ideas related to product development. These measures provide some indication that the course enabled students to think more broadly about how value is added to a product. The broad thinking also appears to have helped the students' creativity, as indicated by the increase in the number of ideas generated. Since the data are from a relatively small sample of students, however, attention also needs to be given to other assessment methods. A second method used to gauge the course outcomes was a review of the course evaluations. This is described in the next subsection.

Analysis of Student Comments from Course Evaluations

Standard course evaluations were conducted at the end of the course. These evaluations contain generic questions that are used for every course taught on campus. The questions include invitations to comment on the strengths and weaknesses of a course, as well as the meaningful learning experiences in a course.

Because student comments on course evaluations can be somewhat difficult to quantify, this section presents a broader overview of student comments and their relationship to the central theme of the course outcomes. While the course had four listed outcomes, these might all be lumped together in an overarching outcome: *Students will recognize the importance of form and its role and importance in engineering design.* The four outcomes of the course listed previously provide specific details for this broad outcome. Student comments are more easily evaluated in terms of the broader context.

The course evaluations were open-ended questions that did not specifically ask students to comment on the course objectives or outcomes. Even without prompting, the student comments listed below provide evidence of students realizing the overarching course outcome.

- *"I felt like Art of Engineering truly tied in concepts of art and engineering and their interplay. .. The span and depth of material is both varied and excellent and it truly made me question everything and learn how to think outside of the box… I've never taken a Humanities class as evoking in thought and as poignant as Art of Engineering."*

- *"I was forced to think about engineering and art constantly. I think it would benefit every student to take this course."*
- *"I think about the art of things such as buildings and cars a lot more now."*
- *I wish I had more classes that dealt with creating and theory like this class. It was the perfect hybrid for me. … I would recommend this class to any person interested in engineering it connects so many vital aspects of being a well-rounded engineer.*
- *This class really helped me think about different aspects to engineering and what we are taught in every other class at this school. I learned a lot and am now able to demonstrate the similarities that are found between engineering and art.*
- *"[The course] gave me a perspective on a different way to think. Instead of always thinking like an engineer, it taught me how to think more creatively and think about other functions for objects than just engineering functions."*
- *"[T]he assignments were very comprehensive and allowed us to learn more about our environment and to think just beyond the engineered function of something."*
- *Thinking about how and why objects where made and who they were made for. It had an interesting approach of showing the application of what engineers do and how they go about making products for consumers.*
- *I learned to look at designing something through a different lens, not just making something more efficient but at the same time making it more appealing and beautiful which overall makes a better product.*

The two sections of the course contained a total of 39 students. The fact that 23% of these students volunteered course comments that relate directly to the overarching theme of the course outcomes provides a reasonable level of additional support that the course was indeed helping students make the desired connections between art and engineering.

Summary of Course Assessment
As indicated by the above subsections, the course seems to have successfully met its stated objectives and outcomes. An analysis of student writing indicates an overall increase in student ability to create ideas and an improved ability to see value creation as a more varied proposition that includes both the form and function of an object. Student comments from course evaluations support the numerical results.

The best opportunity for improving the course appears to be in the area of taking students to a higher ability to synthesize ideas that integrate form and function. While the course helped students develop an appreciation of aesthetic appeal of engineered objects, one missing outcome was evidence of the ability to synthesize simultaneous improvements to form and function. Students have gained an understanding that the form and appearance of engineered objects is important, but have not perhaps made a bigger step to understand that art and engineering can integrate seamlessly rather than being separate considerations. The course presented here can perhaps provide a better lead-in to this topic with a slightly stronger emphasis on the "Enduring Design" aspect of the course – making a stronger connection to the idea that objects of enduring design are such because they have succeeded in the integration of form and function.

Overall, the assessment results indicate that the first offering of the course proved to be very successful in providing an appropriate bridge between the topics of Art and Engineering.

Conclusions and Future Development

The "Enduring Design" course has performed well in its first offering. Student response was overwhelmingly positive and encouraging. Continuing refinements for the course include some refinement of topics as well as a stronger emphasis on the integration of art and engineering. The course developers had an overabundance of topics from which to choose for the course, which allows for relatively easy course refinements with the swapping in of topics to replace the one or two topics that were received with less enthusiasm. For course emphasis, students seem to have a need to be pointed more directly to the idea that enduring design is derived from a successful integration of art and engineering rather than from the separate consideration of art and engineering.

The presented course is somewhat unique in that the course was developed as an art course for engineering majors. While the course format proved to be a success, the question arises as to how well the course might transfer to a broader audience. In particular, is this the type of course that ought to be part of the core curriculum at a liberal arts college, or at a comprehensive university? Many aspects of this course suggest a potential for success in such a role. The course presents a variety of topics that attempt to integrate perspectives from multiple disciplines, which is a common charge for many core curricula. An increase in the diversity (by academic discipline) of students enrolled in the course would also likely help to better integrate the course perspectives. As such, the next challenge in course development may be to take the course to a broader audience to see if results similar to those described in this paper can be achieved.

Another possible area of study for the course outcomes is to break the students down by major and by year in school. Right now, these numbers, presented in Table 1, are too small to show any statistical significance. The future accumulation of several years' worth of data will allow for a more refined look at the course outcomes.

"Enduring Design: The Art of Engineering" was created as a means to provide an appropriate context for students in technical disciplines to achieve a better appreciation of the impact and influence of art on the world around them. The course certainly met this modest goal and assessment suggests the potential for refinement and possible expansion to reach a broader audience.

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