LEARNING DESIGN FROM ARTIFACTS: SINGLE–USE CAMERAS AS TEACHING TOOLS

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ABSTRACT
Because engineering design is both art and science, teaching students to look at everyday consumer products through "engineer's eyes" can be an effective method of teaching design. Engaging students directly with engineered artifacts affords them the opportunity to see how engineers deal with real constraints, and helps them to develop critical skills for evaluating designs. Here we present our experience using a common consumer item, the single–use camera, to teach several aspects of design. The cameras have been used with students ranging from first–term freshmen to practicing engineers, and have been a useful adjunct to lecture materials in every case.

Keywords: functional decomposition, product design education

1 INTRODUCTION

The educational experience for engineering and design students is greatly enhanced by the use of sophisticated, well–designed products in the classroom. The challenge for educators is to find engineered artifacts that have a good balance of complexity and transparency. Finding the "right" product for any given educational context can be quite challenging, and often inhibits wider use of real objects in design classes.

Ideally, artifacts used in the classroom should be complex enough to hold the students' interest, but at the same time should not be so sophisticated that a great deal of time and effort is expended on understanding the product's function. An ideal artifact for classroom use should challenge students who are at different stages of development, and allow students from various disciplines to take something away from the encounter.

In this paper we present our work at Ohio State University in adapting a familiar consumer product, the single–use camera, to teach design and engineering principles to students at different educational levels. We have used the camera in "Introduction to Engineering" classes for students who are just entering college, in advanced design classes for upper–division engineering students, and in continuing education classes for experienced NASA engineers. We have employed the camera as a tool for teaching product design, basic statistics, system architecture, design for manufacturing and assembly, and manufacturing processes, and in every case it has proven to be an effective addition to lecture material.

2 TEACHING WITH ARTIFACTS

Over the past several years, the trend in US engineering education has been away from an almost exclusive emphasis on engineering analysis and toward a more even balance between engineering science and design. While engineering curricula continue to place heavy emphasis on science, there is a growing recognition that, since design is at the core of being an engineer, engineering education must include design experience. This new trend is reflected in the ABET 2000 standard that all accredited engineering programs in the United States must conform to.

Teaching design effectively can be much more difficult than teaching the engineering science courses. In fact, many educators continue to insist that since design combines both art and science, it's essentially impossible to teach. In this view, design skill can only be learned through long apprenticeship to skilled designers in practice. Another common response to the challenge of teaching design is to assume that teaching students to use design *tools* such as CAD and FEA software will suffice. The idea seems to be that once the students have the tools, they will somehow pick up the necessary but ill–defined design *skills* by osmosis.

We take the point of view that while engineering design is both an art and a science, engineers at every stage of their development can profit by looking closely at engineered objects. Ferguson has shown how the early history of engineering was dependent on the transmission of ideas through collections of detailed drawings of machines [1]. Engineers have always learned from the intelligent inspection of other designs. What we attempt to do is to make this process an integral part of the classroom experience for our students.

While the subject of this paper is a particularly well–engineered artifact, the Kodak single–use camera, we would point out that students learn from examining badly designed products as well [2]. The crucial point is that students should be encouraged, from the beginning of their education as engineers, to look at the world through "engineering eyes", and ask questions such as:

- Why was this object designed the way it was?
- What was the intent of the designers?
- Was this intent carried through to manufacturing?
- What were the primary constraints on this design? How well were they met?
- Do all parts of the design cohere, or does this artifact look as if it were "designed by committee"?

We have found that when students are given guidance in looking at real artifacts, the educational experience becomes both deeper and richer. In effect, the student learns how to peel away the layers in a design, starting with the most obvious questions, (e.g., what materials were used and why, what manufacturing processes were most appropriate, etc.), and ending up at the level of subtle design details. Along the way, the student begins to gain some appreciation for the *art* of engineering as well as the science, and also gains some understanding of how severe constraints can often lead to a truly elegant design.

Finally, we have found that it is very useful to have more mature students look at families of products created by a single firm. In this way, they begin to understand both the difficulties and the advantages of developing a product portfolio, and how firms can leverage common platforms and components across many product lines without blurring product identities. These important concepts are not at all obvious to engineering students, but are very much on the minds of engineers in industry.

3 THE SINGLE–USE CAMERA

In our experience, an ideal device for teaching engineering design is the single–use camera that is available around the world. These cameras are made by several different firms, including Eastman Kodak, Fuji, Konica, and Agfa, are generally available for less than eight USD, and are invariably highly engineered artifacts. Our work at Ohio State University has been with one family of cameras developed by the Eastman Kodak Company.

The Kodak FunSaver© Camera was originally developed in 1987 in response to the introduction of the Fuji Quicksnap© Camera [3]. The FunSaver© camera, which was a basic outdoor viewfinder design, later evolved into an entire family of inexpensive single–use cameras that have been adapted to a variety of specific uses. The original camera, which did not include an electronic flash, became the platform on which the next two derivatives, a wide–angle camera known as the Panoramic©, and a waterproof version, the Weekend©, were based. By 1990, Kodak introduced the first one–time–use camera with a flash, and subsequently developed a large and varied product family. All of the cameras in the family used identical components to transport the film and to trigger the shutter and flash. In more recent years, Kodak has developed a new single–use camera for the Advantix© film system, and has also introduced cameras that employ the Ektanar© lens. All of these cameras are part of Kodak's extensive recycling and re–use program; over 300 million cameras have been recycled and reused since 1990.

At Ohio State University, we have used the cameras in the classroom since 1998. We first introduced them in our Introduction to Engineering course sequence for first–year students, and subsequently used them in an upper–division course, Fundamentals of Product Design, which draws students from a wide range of engineering and design disciplines. In the following sections we examine several contexts in which the cameras have been useful for teaching design.

4 USING THE CAMERA WITH BEGINNING ENGINEERS

Our work with these cameras in the classroom began in 1998, with the creation of a new series of courses for our first–year engineering students. This course was the result of a college–wide discussion of our longstanding retention problems in engineering. At that time, internal studies had shown that we were retaining less than 40% of all of our entering students to graduation within five years. The general feeling in the College of Engineering was that at least part of the problem was due to the fact that our students did not encounter actual engineering until after they had completed almost two years of basic science courses. We felt that by getting students involved in engineering early on in their academic careers, they would have a better understanding of what engineering is, and would know whether or not they wanted to pursue an engineering degree.

For the first course of the two–course sequence, we developed five laboratory experiences using the Kodak single–use cameras. The students were required to buy a camera and use it during the first week of the term. The students began by taking photographs of a bicycle moving at a known speed. By measuring the "blur angle" of the bicycle spokes captured in the photos taken without using the flash, students were able to come up with a rough estimate of the camera shutter speed. Using these estimated shutter speeds as sample data, we introduced the concepts of the mean and the standard deviation, and explained their use in engineering experimentation. For most of our students, this was their first exposure to statistical concepts.

In a follow–up lab, the students disassembled the cameras and measured the shutter speed more precisely. For this exercise, the students worked in small groups and used a light source and a light sensor, attached to a "virtual oscilloscope" on a computer, to obtain a measurement of the shutter speed and the flash duration within a range of a few milliseconds. By comparing their initial estimate of the shutter speed from the photographs to the more precise measurement, the students gained an understanding of how engineers often begin with rough estimates and work toward higher precision. By comparing the standard deviation of the two sets of measurements, the students gained insight into how statistical analysis is used to attack real problems.

In the succeeding camera–based exercises, the students were introduced to basic electronics (based on an analysis of the flash circuit), mechanism design (the shutter design), manufacturing processes (the injection molding process used to make most of the camera) and a basic optics exercise.

In succeeding years, we have refined some of these exercises and replaced others. One of the more successful of the follow–on activities is an assembly exercise, where the students assemble the cameras using both "push" and "pull" production lines. In this case the students begin to appreciate the complexity of assembly processes, and learn that engineers are responsible for designing processes as well as products. While the use of actual artifacts such as the cameras requires considerable time in developing and preparing the laboratory exercises, we feel that it has been successful in helping the students find connections between what they are learning in the classroom and products with which they are familiar.

5 USING THE CAMERAS IN UPPER–DIVISION COURSES

In the upper–division course in product design, the single–use cameras are the skeleton around which a set of lectures on meeting customer needs, developing product portfolios, designing system architectures, and designing for manufacture, assembly, and disassembly are constructed. This course attracts students from a wide range of engineering and design disciplines, and takes the students through a series of exercises that begin with determining customer needs, and culminate in construction of prototype products. The cameras have been used for a variety of tasks, and in every case have proven to be quite useful.

At the beginning of the term, interdisciplinary student teams purchase several variants of the cameras, and are required to use them over the course of a week to photograph examples of good and bad design. The students return the film for developing, but keep the cameras for later analysis. For the second week's exercise, the students meet as focus groups, and analyze what they liked or disliked about each particular camera variant. At the conclusion of this exercise, the students as a group brainstorm a new variant on the camera design, and present their design to the larger class.

As part of the lecture material, students read a brief history of the camera, based on the narrative in Wheelwright and Clark [3], and relate the camera's development to lectures on concept generation and especially product portfolio development. Students at this stage of their development are ready to begin to look at the larger world of industry and commerce that they are entering upon graduation. While some of these concepts are more closely related to business than engineering, students are very receptive to the idea that they need to understand how the firms most of them will work for develop entire portfolios of products. In this regard, it is difficult to think of a product more suited to this discourse than the family of cameras developed by Kodak. Because the cameras all use the same internal components, with minor modifications, students can see how it is possible for a firm to intelligently develop a portfolio that can attract a very large market share, without spending massive amounts of capital on dedicated production lines. In course evaluations, students quite often remark that this material is one of the most valuable experiences they gain from this course.

Perhaps the most useful application of the camera at this level is in teaching the basics of functional decomposition and system architecture. Functional decomposition is a very powerful tool for understanding complex systems, but at present it merits little attention in typical engineering curricula, if it is mentioned at all. Students are not accustomed to dissecting systems in terms of layers of functionality, and the concept of system architecture, in the context of mechanical design, is generally overlooked in mechanical design textbooks. Nevertheless, these concepts are widely used in industry, particularly in complex environments such as the aerospace industry. NASA, for example, bases their entire design process around this concept, as shown in Figure 1, taken from the NASA Systems Engineering manual [5].

The single–use cameras are an ideal tool for introducing the concepts of functional decomposition and system architecture. The camera contains several subsystems, such as image capture, media protection, film transport, and illumination. Students are tasked to break down the total system into subsystems, and map the flows of mass, energy, and information through the system. Beginning with a top–level "black box", the students develop the functional structure of the camera, and then map individual components to particular functions. At this point, it becomes clear to the student which components perform a single function, and which perform many functions.

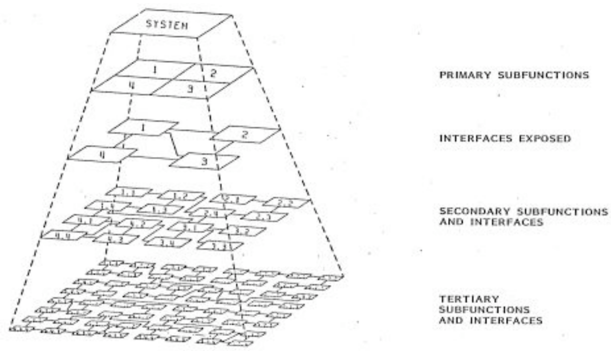

Figure 1. NASA Functional Decomposition Pyramid (from [5])

Having arrived at a detailed functional map of the assembly, it is a small step to the notion of the system architecture. Students begin to understand the two extremes of integration and modularity, and can appreciate that one system can contain a mix of highly integrated and modular components in the same platform, an architecture which the cameras employ. This architecture enables the manufacturer to use many of the same internal components across the entire product line, and reinforces the ideas of product portfolio that were introduced earlier in the course. We should note here that the cameras have been used to teach systems thinking in continuing education courses taught at NASA by one of the authors (Lilly) with great success.

Finally, the cameras are also used in introducing the students to the basic ideas of lean manufacturing. Several hundred cameras have been disassembled into their component parts. In a laboratory exercise, the students first assemble the cameras completely, using a predetermined (and deliberately inefficient) production system. They very quickly spot the inefficiencies in the layout, and it is often difficult to persuade them to complete the first product run and collect the relevant data before they begin to make changes. We ask the students to calculate the *takt* time required to build a camera, and measure the work in process (WIP), and the number of rejects (cameras are considered to be rejects if the shutter does not trigger the flash). The students are then allowed to re–design the production facility, which at this point is still configured as a classic "push system", where every station produces product as quickly as possible, without regard for inventory levels.

Following this exercise, we introduce *kanbans* into the system in the form of sheets of paper between each station. Students are forbidden to complete their specific build task until their *kanban* is empty. The production line is run again, the product is "pulled" from the end of the line, and the results compared to the original "push" layout. The students are given the opportunity to optimize the pull system, run the assembly line a fourth time, and the results are recorded for the four runs. Typically, the students are amazed to discover that the pull system, when done correctly, results in more product coming off the end of the production line, with fewer defective cameras. In post–course evaluations, students very often choose this particular laboratory exercise as the most valuable. While many of them, particularly the students in industrial engineering, have done similar exercises with paper airplanes, etc., they asssert that assembling an actual product is much more effective in understanding the intricacies of the lean production system.

Figure 2. Camera assembly exercise

6 CONCLUSIONS

We have found the single–use camera to be an exceptionally flexible and useful tool for teaching engineering design at many levels and in many contexts. By using well–designed artifacts in the classroom, in effect we allow the students to apprentice themselves to highly skilled designers. While they do not have the opportunity to work directly with these designers, they nevertheless can profit by closely examining the results of their efforts. The instructor's task is to choose engineered artifacts and devices that provide a sufficient level of detail to hold the students' interests, but not so much that the complexity of the device becomes overwhelming.

We have found single–use cameras to be an especially effective tools for teaching design for these reasons. The cameras are very highly engineered devices, containing several subsystems, and afford the instructor many possible avenues for teaching design, some of which we have explained here. This brief overview by no means exhausts the possibilities for using the cameras in design classes.

We firmly believe that design classes are enhanced when students are exposed to real engineered artifacts in a logical, systematic way. We hope that this short paper has shown some interesting ways in which appropriate artifacts can play an important role in design education.

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