Using Reverse Engineering in the Classroom to Teach Creativity

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Abstract

Successful engineering is the creative execution of both art and science. As educators, teaching science is something we do quite well. Teaching creativity, the art of engineering, is another matter entirely. Students may successfully complete an engineering education while never having the opportunity to learn or even considered the need to learn creativity. The creation of art requires talent. We all possess creative talents in some degree and although talent is innate, we can help students to develop and expand the talent they do possess. Learning to intently focus on a problem is one key to developing creative talent. In the history of technology, a great many stunning developments have resulted when ordinary individuals have relentlessly focused on the problem at hand. This paper reports on a simple reverse engineering project, part of a capstone engineering design course, that helps students focus their creativity. The results of this exercise over the last few years has been encouraging. Students have used the skills they have learned to critically examine and hone their own creative skills and to appreciate the creative skill of other engineers.

Introduction

No topic in engineering causes more consternation to educators and students than creativity. We all recognize that the exercise of creativity is essential to the success of any engineering project. Indeed, one of the paramount factors distinguishing great engineering is creativity. However, opinions concerning the teaching of creativity in engineering education range between two extremes. One extreme holds firmly that since creativity takes talent, and talent is innate, it is essentially futile to attempt to teach creativity to anyone, including engineering students. Many of these people subscribe to the left-brain – right-brain dichotomy first proposed by Nobel laureate, Roger Sperry [1]. According to this construct, those individuals favoring the right hemisphere of the brain are characterized as verbal. They are artistic, creative, impetuous, imaginative, risk takers and, in general, more apt to "think out of the box". Essentially, the right-brained among us are the artists. On the other hand, those favoring the left hemisphere of the brain are characterized as non-verbal. They are detailed oriented, given to linear thinking, rely on logic and reality rather than feelings and are less given to creative thought. Clearly, these are some of the characteristics of the archetypical engineer.

Of course, like any stereotype, there are numerous exceptions. For example, one of the greatest artists of any age, Leonardo DiVinci was a gifted engineer. Also, Isaac Newton, besides being without equal as a scientist was rather creative. And even if as Sperry suggests, 80 percent of the population clearly favors one hemisphere or the other, the deterministic notion that you either have it or you don't strikes many people, including engineering educators, as odd or even unacceptable.

The opposite opinion on the teaching of creativity, led by Hazlerigg,[2] Suh, [3] and many others, suggests that creativity is essentially about making decisions and that the correct decisions are found by the use of certain universal axioms. Known as Decision Based Design or Axiomatic Design, its proponents believe the production of an optimum design (and by extension creativity) may be reduced in practice to the rigorous application of a given formula, much as A + B + C = D. Although the simple application of design rules and decision matrices, (for example Pugh [4] charts) have been successfully used for many years, there is doubt that a rigorous mathematical basis for creating the optimum design will ever be found or even exist in a useful form.

Cross [5] has suggested that design is a human activity and design knowledge, if it is a science, is more akin to the soft sciences of economics and physiology than the hard sciences of chemistry and physics. According to Cross,

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first, designing is a natural human ability, not done by other animals and not (yet) done by machines, Second, design knowledge resides in the processes of design – primarily modeling like sketches and drawings and lately computer models. The point here is that models themselves do not design. They are simply the tools by which humans accomplish the design function. Third, design knowledge resides in the product. The form, function and finish of a product embodies the essence of the design. Moreover, to the trained observer, much of the motives of the designer and the constraints that evoked the design are also apparent. The promise of this third notion is what prompted the heuristic exercise reported in this paper.

What is and is not Reverse Engineering

Reverse engineering, by definition, is the thorough and methodical examination of a device, product or process in order to understand as much as possible about its material, manufacture, function and use. Once something is produced, it is *frozen in time,* in the sense that it presumably reflects the current state of the technology - the most economical mix of resources and constraints - and the design reasoning that prevailed at the precise time of its manufacture. Reverse engineering is as old as technology. One could easily envision a primitive man examining the chipped flint edges of a spear point lost by a more technologically advanced hunter.

Although reverse engineering, as a sub-specialty of design, continues to be a useful tool, [6] its fuller application currently suffers from two related problems. First and unfortunately, the notion of reverse engineering conjures up images of the theft of intellectual property. In a world of free trade but hard to enforce property laws, it often happens that a product that required a substantial investment to develop may be reverse engineered for a fraction of the development cost to produce a competing product as good or better than its original. Second, much of the current literature on the subject deals primarily with the reverse engineering of software as if the theft of computer software is somehow less a moral issue than the theft of computer hardware, for example. Perhaps the ephemeral nature of software makes its theft easier to conceal. Not withstanding the abuses of reverse engineering, it remains a powerful tool and has much to teach engineers and engineering students.

There are many good reasons for reverse engineering:

a) A company may own a piece of vital equipment that must be rebuilt or maintained. It is no longer in production and replacement parts or service is no longer available. The only alternative may be reverse engineering.

b) A competitive product is suspected of using patents or products without the proper licensing. In this case, reverse engineering is both prudent and proper.

c) A terrorist or criminal group or enemy state has developed a weapon or counter weapon. The best defense is reverse engineering to learn the weapon's weaknesses and develop countermeasures.

d) Reverse engineering is quite common in forensic studies and may be required to help reconstruct events leading to accidents or the results of natural disasters.

e) Reverse engineering is frequently employed in archeology to understand the development of technology over time.
f) Companies often reverse engineer their own products in order to improve performance and/or reduce cost.

Preparing for the Assignment

Prior to the assignment of the project, students were presented with preparatory lectures on the subject of reverse engineering. The students were mid-way through the first of a two-semester capstone senior design course sequence in Biological and Biomedical Engineering at North Carolina State University. They were told that no design is perfect and all engineering solutions are essentially temporary. No design is "final" in the sense it cannot be improved. Even if it is considered to be perfect when it is first designed, changes in the technology of form, function, material or manufacturing will shortly render any design "sub-optimal". There are mature designs but the more mature the design, the less the likelihood for 'tweaking" and the greater the likelihood for major change. Often the simple application of new materials or manufacturing technology can reduce costs and/or add value to a product - which is mainly why reverse engineering is such a powerful tool. However, when critically examining any design, students are cautioned of design nuances that may be ignored or overlooked completely but nevertheless may be essential for the success of the design. One simple example given in class is the number, spacing and taper of the tines of a common dinner fork [7]. Having evolved over the last 500 years, the design of the dinner fork is a supreme example of an optimized design with very subtle yet essential features.

Another important lesson in preparation for reverse engineering is the understanding that creation is a deliberate act. In a mature design, it is wise to consider that every single property and attribute of every individual component involves a conscious selection from among all the possibilities, both known and unknown. In short, there is a reason for everything. Just because the reason is not known, does not mean there is none. Particularly in the mature design of a consumer good like a common padlock, there should be no useless features. Of course, there may be vestigial features like tooling registers on castings that are no longer needed because of CNC machining, but in this case as well as most others, the cost of removal is much more than it is worth. The saying common among interior decorators that "wherever the gaze falls, a decision must be made" is just as true with the design of a padlock as it is with a living room.

The final reason for this reverse engineering exercise is to train young engineers to not only look, but to see. We are all guilty of giving superficial glances when something more is required. However, in response, students often ask, "what am I looking for?" Or they ask, "how will I know when I see it"? This is a difficult question to answer because it depends on so many different factors. To get started, students are given a list of physical attributes such as strength, weight, shape, surface finish, lubrication, corrosion resistance, reliability, cost, wear, styling, etc. to identify. A better strategy, however, is to get the students to focus on one single attribute of one single part and ask, why is it made that way. For example, why is the shackle spring conical rather than cylindrical? Or why are some internal parts plated while others not. Take individually, these small observations seem inconsequential until one considers them in total and in light of, for example, functionality and ease of assembly.

The Assignment

After the preparatory lectures, the students were each given an inexpensive pad lock (Master Lock J No. 1) and were shown in lab how to carefully grind away the heads and remove the pins holding the laminated body together. Students were encouraged to proceed slowly, methodically and photograph each stage of disassembly. They were also advised to take very careful notes throughout the disassembly process. Once completely disassembled into the 53 individual components, the students were required to lay the parts out for display. Only then, if the students were able to re-assemble the parts into a working lock, were they given additional credit on the project. Additionally, the students were required to make a multi-level bill of material of the lock parts and to write a formal engineering report detailing the entire disassembly and re-assembly process. Students were encouraged to discover and speculate on non-obvious design features such as possible key combinations, automatic assemble methods, service life, etc. Students were given two weeks to complete the project.

The Results

The student work product from this assignment is a formal engineering report using the manuscript format guidelines published by the American Society of Agricultural Engineers. The report is generally eight to ten pages in length including figures, tables, a full multi-level bill of materials and a list of references. Most reports begin with an introduction that includes a history of keyed locks, the history of the Master Lock Company [8] and general information on the purposes of reverse engineering. A materials and methods section follows describing the disassembly of the lock, a description of the individual components and a discussion of the major sub-assemblies of the lock. To this point, most of the student papers are similar. At the section following, results and discussion, most of the similarities end. This is because students are encouraged to select one or more key aspects of the lock design and expand on them in detail. Students have been known to calculate the force required to pull the shackle from the lock body, model the forces acting on the lock from a bullet, develop an automated assembly and inventory control scenario, and calculate a probable service life for the lock. As expected, many students have attempted to devise ways to pick the lock or otherwise affect the opening of the lock in a non-destructive manner. A number of students have accurately determined the number of key combinations by the accurate measurement of key pins. A few students have actually determined that the insertion of the shackle is the last operation in assembly – a fact that is not obvious except by very careful examination of tiny stress cracks in one of the layers of the laminated lock body.

Since its inception in the fall of 2001, more than 150 students have completed this exercise in reverse engineering. Although our curriculum is ABET accredited and generally more than 85 percent of our students take and pass the fundamentals of Engineering exam, not all our students aspire to a career in engineering. Of the non-engineering careers sought by our graduates, medicine, law and management are the most frequently selected. Although this exercise in reverse engineering is frequently cited as one of the high points of their engineering education, one would expect that the non-engineers among the students would be less enthusiastic. In fact, this is not the case. Almost all the students consider this a very worthwhile exercise. As expected, the Master Lock Company nor anyone else provides much information on-line or elsewhere helpful in this assignment. What the students are able to learn about this common, yet surprisingly complex device, is primarily taken from their own persistence and methodical examination.

Conclusions

Unfortunately, the only assessment data we have at this point is subjective and antidotal. Later the same semester as the reverse engineering project, student teams are assigned a design project requiring critical thinking, creativity and attention to detail. It is not unusual to see insights gained in reverse engineering applied to these projects, For example, a student team in the process of designing a portable patient lifting mechanism, remembered to consider ease of assembly, the use of standard parts and the use of a single part for more than one function. These were lesson taken directly from the lock design. In the second semester, with much more complicated design projects that can require improvements to an existing device, students are more appreciative and less likely to discount a design they do not yet fully understand.

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