Int. J. Engng Ed. Vol. 17, Nos. 4 and 5, pp. 332–335, 2001
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Design Engineers—Fast, Cheap, or Good—Pick Any Two of the Three*

FRANK J. FRONCZAK
Mechanical Engineering and Biomedical Engineering Departments , University of Wisconsin-Madison, 1513 University Avenue, Madison, Wisconsin 53706 USA. E-mail: fronczac@engr.wisc.edu

This paper presents the argument that Engineering Design is a complex process requiring knowledge, skill, and attitude. While knowledge can be taught, skill and attitude cannot. Instead, skill can be developed and attitude can be cultivated and nurtured. It is argued that the development of design skills, and the cultivation of the attitude needed for successful design require much more effort and a more individual approach than that which is needed to merely pass on knowledge. This is a necessarily time consuming and costly process. Consequently, if our goal is quality, we must be willing to expend considerable time, at necessarily considerable cost, in order to achieve this goal.

INTRODUCTION

ENGINEERING DESIGN is a complex process requiring knowledge, skill, and attitude. For purposes of discussion here, knowledge is factual information. It is *relatively* easy to pass on knowledge, and, over the course of time, we have developed effective and efficient means of doing so. Skill and attitude are fundamentally different from knowledge, however, and this fundamental difference requires a substantially different approach when educating our students. Skill is the ability to use the knowledge that we have access to, and attitude is the mindset that gives us the will and determination to use our knowledge and exercise our skill. Neither skill nor attitude can be *taught*; rather skill can be developed and attitude can be cultivated and nurtured. Although we are bombarded by motivational material that says, 'Attitude is everything', and while this may be adequate for some fields of endeavor (perhaps motivational speaking, for example) the evidence clearly suggests that successful design engineering requires all three: knowledge, skills, *and* attitude.

It is my contention that the development of skill, and the cultivation of attitude require much more effort and a more individual approach than that which is needed to merely pass on knowledge. Furthermore, while developing design skills and cultivating an appropriate attitude is costly, it is certainly worth the expense.

KNOWLEDGE

Engineers who do not know the laws of nature and the engineering principles that govern their designs certainly are doomed to produce devices or structures which provide little value at best, or result in dire consequences at worst. In most of our engineering schools, we are indeed fortunate to have intensely bright, energetic, and highly motivated young men and women who are easily taught knowledge with relatively little need for individual attention. Even concepts as fundamentally difficult as Einstein's Theory of Relativity are regularly, successfully taught to students in lecture halls filled with hundreds of students. Furthermore, we can assess the students' learning of the material (or at least their short-term retention of it) by relatively straightforward means such as exams.

It shouldn't come as much of a surprise that engineering schools are very adept at passing on scientific-based knowledge, even that which is quite advanced. Our engineering schools have been heavily influenced by a governmental research support philosophy that almost exclusively favors the development of new knowledge, rather than the application of this knowledge. Consequently, our engineering faculty have been heavily populated by those whose stock-in-trade is the development of scientific knowledge. Most engineering faculty have spent much of their lives acquiring, developing, and passing on the knowledge that they have found useful. It seems to be only natural that if smart people spend a lot of time doing something that is relatively straightforward, (such as teaching knowledge) that they will get to be pretty good at it, and so we are.

Even teaching knowledge has some limitations when it pertains to engineering design, however. Certainly engineering design requires a much broader base of knowledge than just that grounded in basic and engineering sciences. In addition to this engineering-science knowledge, it is imperative that design engineers also have a base of engineering knowledge based on *technology* as well as knowledge of engineering design methodology principles and practices.

Design methodology has been the subject of

* Accepted 1 April 2001.

much intense scrutiny over the past couple of decades and a fairly well-accepted structure of the design process has been identified and promulgated throughout the engineering design community. While the details of the approaches of various authors on the subject may differ, the design methodologies presented by French, Cross, Hyman, Pugh, Thompson, Ullman, Dym, and even Bietz, [1–8] to name just a few, share a common fundamental approach. While much design is still done in a rather ad-hoc manner, it is becoming ever clearer that particularly young and inexperienced design engineers can benefit greatly from following a more structured approach to the design process.

It is also clear that much engineering practice is based upon *technology* rather than scientific principles. As discussed by Kline [9], the term technology includes:

- hardware (machines, products and devices);
- the techniques or processes by which these products are made;
- the complete systems involved in the production of the hardware.

Much of technology-based knowledge is based on experience; it employs concepts, materials, and processes that are used because they have proven effective. Often the scientific basis for technology is not sufficiently understood or developed to be able to be used by design engineers. Certainly researchers are hard at work codifying and trying to develop a more fundamental understanding of technological knowledge. However, its shear enormity (as well as its ever expanding nature) defy attempts to effectively and efficiently transfer this knowledge to our students. One means which is *effective* (although not necessarily efficient) is to have students work on a design project which requires them to acquire and use some of this technological knowledge as it pertains to their design project. Usually this requires guidance by an experienced mentor, a design engineer who can help the apprentice engineers through the maze of information so that they can identify and begin to understand the technology appropriate for their problem. While this can be a somewhat daunting task, the acquisition of even technological knowledge is still relatively straightforward.

SKILL

Skill, however, is another matter. It requires the exercise of judgement, and judgement requires the wisdom that comes only with experience. Unfortunately, the most potent experience seems to derive from the exercise of poor judgement. We certainly learn more when our mistakes rise up to smack us in our faces (presuming that we survive the experience) than we do when everything seemingly goes according to our (apparently) well-laid plans. The Scottish poet Robert Burns (1759–1796) recognized that 'the best laid plans of mice and men often go awry'. We can couple this to another important fact of life that was expressed by the Japanese author and philosopher, Ihara Saikaku (1642–1693) namely, 'There is always something to upset the most careful of human calculations.' Certainly this is why we must continue to thoroughly test our designs before we unleash them on the public, but I digress from the main point. These lessons seem to tell us that there is more to success than just well though-out plans and thorough analysis. I believe that an additional essential element to successful design is the exercise of good judgement.

The exercise of good judgement is an intellectual skill that cannot be *taught*, but must be developed. Just as with physical skills such as throwing a curve ball, it is a relatively straightforward matter to identify and teach the knowledge that is required to successfully have a pitcher hurl a baseball so that it bears in on the batter's rib cage, only to break down and out into the strike zone as the batter is bailing out on the pitch. But it is quite a different proposition, indeed, to help even a gifted athlete develop the skill to throw a curve for strikes without hanging one more often than not. Only by extensive coaching involving careful attention to every step of the process can a good coach hope to develop a superior pitcher.

How much more attention then, is needed to develop an even more demanding intellectual skill such as that required for engineering design? By working closely with individuals or small groups of students, an experienced design-engineering educator can delve more deeply into the thought process of the students. In this way, the educator can identify areas where errors have been made and where poor judgement has been exercised, as well as recognize which design skills the student is totally lacking or particularly deficient in. Just as a good coach does, the educator can then provide prompt, appropriate feedback to the students. The students can see the error of their ways and hopefully have an opportunity to recognize how they went wrong and how they can do better next time. It must be understood that this is a long-term process of continual improvement. Also, the task of developing skill is very challenging and complex. Only by going over the process again and again, and then again some more, can we hope to develop a student's design skills to even the most rudimentary level.

While we certainly cannot produce a truly accomplished design engineer right out of school, we can instill in them the fundamental understanding of the process. Furthermore, we can hopefully develop their design skills to a level of 'critical mass' which will enable them to continue to develop on their own. Furthermore, by going through the problem *with* the student, the student has a chance to observe and participate in the thought process first hand and see the messiness that it involves. This leads naturally to the other required element, namely attitude.

ATTITUDE

Henry Ford said, 'The man who says it can't be done and the man who says it can be done are both right.' In order to design something—to create something new, you must possess a confidence that it can be done and that you are the person to do it. To be successful as a design engineer you need to have faith that even though eminently qualified people have addressed the same problem, you or your team can do a better job; there is a better mousetrap to be made, and you are the one to make it. Furthermore, design, by its very nature requires venturing into new, uncharted territory. This involves taking risks and a willingness to accept failure as a real possible outcome of your efforts. In order to successfully deal with these issues takes a certain attitude. And while we can identify certain characteristic traits that are desirable in design engineers, we have to recognize that some of these traits must be cultivated—that is the seed must be planted and the developing plant must be nurtured if it is to survive and flourish. Each individual has different traits and a good design instructor will identify the strong points of each student as well as the traits that interfere with a productive attitude. The instructor can then turn their attention to helping the student adjust their attitude to bring it into line with that needed to face the unique challenges that design engineers face.

It should be kept in mind that exhibiting an appropriate attitude is not sufficient by itself to successfully face complex design challenges. Recent changes in educational philosophy have perhaps focused extensively on raising the self-esteem of our nation's youths, often, apparently at the cost of teaching them the requisite knowledge, and developing the skill needed to successfully utilize that knowledge. If we spend all of our efforts on making our students feel good about themselves, they will fearlessly go forth, only to find themselves overmatched by the challenges that they face. We need to strive to achieve a balance within the effort that we devote to knowledge, skills, and attitude. If our students are deficient in any of these areas, they will be hard pressed to be successful. By working closely with our students, we can identify where our efforts are most needed and thus where they can do the most good. In this way, the senior capstone experience can be considered a 'finishing school' of sorts, where the deficiencies that have slipped through are identified and hopefully rectified, and the strengths are polished and refined.

GOOD OR CHEAP?

How can we hope to accomplish these ends? As the old saying goes, 'You can have it fast, you can have it cheap, you can have it good; pick two out of the three.' When we apply this adage to the education of design engineers, we realize that our part of the process is limited to a very short time, so we have no choice but to be fast. That leaves us with a choice of only two options. We can have it be good, or we can have it be cheap. And this certainly leaves us with no choice at all. We must be sure that the education our students receive is 'good'. This comes at a cost—a cost of faculty time and resources devoted to the individual attention that the development of skill and the cultivation of attitude demand.

For as long as I can remember, there has been a sign in the window of Fronczak's Hardware on the South Side of Chicago that says, 'There is nothing that cannot be made cheaper, and sold for a lower cost by a man who is not concerned with quality, and the person who buys on a basis of price alone is that man's fair prey.' Applying this dictum to the education of design engineers, we can probably find ways of reducing the costs associated with this education, and this approach certainly has a large, eagerly receptive market. However, the intrinsic importance of a high quality education that addresses the acquisition of knowledge, the development of critical engineering design skills, and the cultivation of a fundamentally sound attitude is certainly of great importance. Thus it is imperative that we do not find ourselves acting in the role of the man who is selling our goods cheaper, but at a cost to their quality. As engineering design educators we are entrusted with the responsibility to maintain the standards of quality, and so we must be resolute in continuing to resist the ever-present pressures to trade off quality for cost. Fast, cheap, or good—which two will it be?

REFERENCES

1. M. J. French, *Conceptual Design for Engineers,* 2nd ed., London: Design Council, 1985.
2. N. Cross, *Engineering Design Methods,* London: Wiley, 1989.
3. B. I. Hyman, *Fundamentals of Engineering Design,* Upper Saddle River, New Jersey: Prentice-Hall, 1998.
4. S. Pugh, *Total Design,* Wokingham, England: Addison Wesley, 1990.
5. B. S. Thompson, *Creative Engineering Design,* 4th ed., Okemos, Michigan: Okemos Press, 1998.
6. D. G. Ullman, *The Mechanical Design Process,* 2nd ed., Boston: McGraw-Hill, 1997.
7. C. L. Dym and P. Little, *Engineering Design,* New York: Wiley, 1999.

8. G. Pahl and W. Bietz, *Engineering Design,* Berlin: Springer-Verlig, London: The Design Council, 1988.
9. S. J. Kline, Innovation Styles in Japan and the United States: Cultural Basis; Implications for Competitiveness, *ASME 1989 Thurston Lecture, ASME Winter Annual Meeting,* Stanford University, Department of Mechanical Engineering Report INN-3, December, 1989.

Frank J. Fronczak is a Professor of Mechanical and Biomedical Engineering at the University of Wisconsin-Madison. He teaches in the areas of machine and product design, dynamic systems analysis, and fluid power. Dr. Fronczak's research includes work involving the design of hydraulic hybrid vehicles, hydraulic-mechanical-electrical systems, and rehabilitative equipment. He has also consulted with industry on dozens of design projects. He received a BS degree in General Engineering and an MS in Theoretical and Applied Mechanics from the University of Illinois, and a DE (Doctor of Engineering) degree in engineering design from the University of Kansas in 1977.