The Arts and Engineering

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τῷ σοφῷ ξένον οὐδέν.
Antisthenes (444–371 BCE) [1]

γηράσκω δ' ἀεὶ πολλὰ διδασκόμενος.
Solon (ca. 640–558 BCE) [2]

We are often told, almost always by nonengineers and nonscientists, that instruction in the Liberal Arts and the Fine Arts should be an important part of the education of engineers. The position of the nontechnical person is that a liberal education will make engineers better people and better able to understand and respond to the needs of society. American Engineering students, however, are unconvinced and mostly greet such assertions with ridicule and scorn. Both sides are wrong. Exposure to the Liberal and the Fine Arts is important to the education of engineers, but not just to make them better members of society. Such exposure is important, because it will make them better engineers.

There have been many studies of the value of the Arts in primary and secondary education, particularly as a motivational device, and there have been even experimental studies which show that intense exposure to art develops superior spatial-visual coordination and other basic skills. I'm not sure, however, how much these studies will influence a secondary-school student who asks, like the illiterate dance student in the 1980 Alan Parker film *Fame*, why he must read the book when he can watch the video.

Digital Object Identifier 10.1109/MCS.2008.924881

I have no interest here in Art as a motivational device or as an aid in neurological development, valuable though these aspects of Art education may be. What I wish to propose are the propositions that creation in Art and creation in Engineering have much in common, and that the study of the Liberal Arts and the Fine Arts in tertiary education demands creative participation on the part of the student, while the study of Engineering most often does not.

Contrary to the misconceptions of most nontechnical people and, probably, of many Engineering and Science students, Engineering, Science, and Mathematics are not purely deductive disciplines. Innovation in these disciplines, certainly, is not. Deduction tells us nothing about how to determine the assertions we wish to deduce or by what deductive path we will deduce them from basic principles. At a still higher level, deduction does not tell us how even to choose our basic principles. Deduction is important to mathematical disciplines like Physics and Engineering, because we cannot accept a theoretical assertion which cannot be deduced from basic principles. An inability or unwillingness to carry out the deductive process fully and rigorously often leads to very bad research. I have seen this many times. But deduction is probably not the most important activity of Science or Engineering research. The most important activity is *induction*, how we determine the things we wish to prove (or discover or design or invent) and how we are going to prove (or discover or design or invent) these things from observation, analogy, and the magical element we call intuition. Stated in other words, the most important part of research is not finding the solutions but finding the problems. Unfortunately, we cannot teach induction, senior-year projects to the contrary. So we teach Engineering and Science courses as deduction with an occasional dollop of historical and physical motivation, and we give the misimpression to our students and to the world that ours is primarily a rational deductive discipline.

For the largest segment of successful Engineering graduates, it is sufficient that they be good deducers, since their work will consist largely of the application of existing methods. At the risk of seeming elitist, I assert that not all good engineers are suited by temperament to research, and the vast majority do not engage in it. Research is also not necessarily the most important quality for judging the value of a career in Engineering, although many researchers may not be able to accept this. Some of this writer's most satisfying work has been outside research doing development work, what many call "real engineering." Research is often a very frustrating activity. I do research, lofty motives aside, because I am driven to do research, much as a runner is driven to run his daily mileage. Many universities were once criticized for giving too much emphasis to research rather than to teaching. Now universities have focused primarily on funding.

The other misconception is that Science and Engineering deal with immutable truths, which also is not exactly the case. We believe that such truths exist, of course, but not

 1066-033X/08/$25.00©2008IEEE

necessarily that we know them. In Science and Engineering we never have a complete theory, and often we must revise our ideas as our experience increases. The majority of people do not understand this. Far too large a fraction of our population, when a scientific idea turns out to require revision, thinks the need to revise a theory justifies the belief in such absurdities as intelligent design, creationism, or astrology. The true world of Science and Engineering is cloaked in ambiguity and doubt. Our job is to find the best approximation of truth amidst that ambiguity.

How do we make our students (and ourselves) better inducers and better able to deal with ambiguity? Here, I believe, the best laboratories are the Liberal Arts and the Fine Arts. Serious novels, poetry, paintings, sculpture, pieces of music, and other products of artistic expression are not quantitative, and their art derives in no small part from ambiguity. My claim is that the Liberal and Fine Arts accustom us to working amidst ambiguity and uncertainty. This is not to say that professors in the Liberal Arts or Fine Arts can teach us how to deal with ambiguity or how to be inductive. But they can expose us to many tantalizing examples of ambiguity, and to a lot of sensations and to forms of perception which don't exist in the normal realm of Science and Engineering. As engineers and scientists, we generally brush off the Liberal and the Fine Arts, because they are not quantitative and lack any kind of repeatability except for trivial copying, but this quality of Art is insufficient justification for neglecting it. Actually, there are repeatable truths *related* to the Arts, which come from the application of Science to the Arts, as in the computer-aided statistical analysis of literary texts, but this is repeatability in Science rather than in Literature. What makes literature art is lost in the noise of such analyses. The truths of the Arts are not quantitative, nor are they universal principles, but the experience of increasing our understanding through examination and reexamination is more accessible in the Arts than in Science and Engineering. The appreciation of a work of art is truly an inductive experience. Regretfully, my efforts to cultivate greater contact of engineers with the Arts have yielded only bitter fruit. I always told my Engineering students that they would become better engineers if they would read a poem every week, especially a non-narrative poem. You can imagine their response.

When we confront our students with a work of art, whether it be a poem (preferably non-narrative), or a sculpture or painting (preferably non-representational), that experience requires a creative (and often inductive) effort on their part, not the creative effort of the artist who created these works, but creative nonetheless. The student must somehow go beyond the superficial form in order to appreciate the work. It is not simply a bunch of words, notes, colors, lines, curves, and surfaces. An artistic painting or photograph is not the same as a snapshot from the beach. A novel or a poem is not the same as a newspaper article or a product description. The key to appreciating a sculpture by Michelangelo will never lie wholly in an atlas of diffeomorphisms describing its shape.

Some students, whether would-be engineers or humanists, cannot "get" what a work of art is all about, and we are unable to teach them how to "get" art. At best they learn a lot of vocabulary and how to recognize different periods or different artists, but they never truly experience art. They can only repeat what they have been told. The first person to say "your eyes are like the stars" was a poet. The first person to repeat it was trite. It is that way in Science and Engineering too. Perhaps, many of our Engineering students and many of our Liberal Arts students are like this. Engineering and Science research, I claim, are the more difficult professions. In some ways, significant research in Science and Engineering, not simply repeating experiments for different substances or applying the same technique over and over again to different systems, is more demanding than "artistic creation," because one must be able to do both induction and deduction well. The very best scientists and engineers are often artists as well if only secondarily to their technical profession. Einstein, a poet of Physics, also played the violin and made amateur art films. Akito Arima, former president of Tokyo University and a notable nuclear physicist, is one of Japan's better known *haiku* poets. Few poets of the English language can solve even elementary problems in Mathematics or Physics.

Art is not the only part of the Liberal and Fine Arts which has this benefit. I claim that so does the learning of a foreign language, especially a language very different from one's own, whose vocabulary may have different semantic ranges and whose grammar may exhibit very different morphological and syntactic forms from one's own, and which may differentiate words according to conceptual categories which seem beyond exotic. Languages most separated from one's own either in space or in time (or both) are likely the best. The puzzling out of meaning in such languages is not a very different exercise from puzzling out the meaning of Engineering results, and, certainly, it is a constant exercise in induction. Listening attentively to serious music, reading serious literature seriously, examining works of pictorial or plastic art, or even watching foreign films, all have something to contribute to our education as engineers. Better still is to engage oneself in the creative side of the Arts, however poor the results. My own pitiable experience has been that writing a short story feels rather like writing an article in Engineering or Physics, while writing a poem feels like proving a theorem in Mathematics. I note with satisfaction the belief stated by many pundits that much of Mathematics is simply good grammar.

Most important of all, we must remember that Engineering research is a creative act, and creation is always an expression of the imagination. Following someone else's mathematical proof or the progression of equations in Engineering or Physics is not an expression of the imagination. Creating that proof or those equations for the first time *was*. (Your eyes are like the stars!) The closest we come in Engineering courses to helping our students learn induction is in their homework problems, but not if these problems are only substitution problems, or repetitions of the text, or carefully guided problems of connecting the dots, which is the general case, especially in the more recent textbooks. If the problems do not require significant nonrepetitive effort from the good students, then they are really of no value except to enhance short-term memory. Unfortunately, we opt too often for homework problems which do not require much thought, perhaps, because so few students can be expected to solve any other kind. As in the well-known sports maxim, the *art* of Engineering is learned in the *struggle* to get the answer, not in simply being shown it. (Interestingly, the homework in advanced courses in Pure Mathematics is generally of the inductive variety and requires some imagination.) The activity of research in Engineering has far more in common with artistic creation or even with the appreciation of a work of art than anything which we usually teach in our Engineering classes. If we share his mother tongue, we might, if we were sufficiently talented, learn far more of an Engineering graduate student's promise as a researcher by having him write a poem or a short story than by examining him on Fluid Dynamics or Finite Element Analysis. This is not to say, as one colleague has already chosen to misinterpret my remark, that we should not test out students on their competence in Engineering but only on their ability to write poetry.

We must also keep in mind that problem solving of any kind, whether it be in Mathematics, Physics, or Engineering, or working out the best fingering or phrasing for playing a piece of music, achieving a desirable rhyme and meter in a poem, developing technique in a sport, creating tension or resolution in a musical composition, literature, painting, or the plastic arts, understanding a work or even only a word in a foreign language, planning a trip, or achieving a certain taste and texture in a culinary dish, is valuable in itself and valuable also for us as engineers. If we focus our attention too strongly on solving problems in only our chosen discipline, in which the range of perception and expression is limited—especially so in Engineering and Science—then we lose suppleness in our thinking, as well as the insights that often come from obscure analogies. The ancient Greeks knew better and saw Art in everything. So should we.

A recent study [3] by the National Academy of Science, the National Academy of Engineering, and the Institute of Medicine has proposed a large investment in our K–12 and university Science, Mathematics, and Engineering programs in an effort to compensate for decades of erosion. Missing from that program, however, is any effort to improve the education of future engineers, scientists, and mathematicians in the Liberal or Fine Arts. If the purpose of that investment is to enhance innovation in technical fields, then it may be very short-sighted to invest only in technical areas and exclude those areas which bring us into more direct confrontation with the creative process, with ambiguous concepts and data, and with more diverse avenues of perception. Innovation and creativity are most often the province of those with strong interests outside their profession. Standardization, even at a high level, does not usually lead to greater creativity or innovation. Accrediting organizations for university Engineering programs have done considerable damage to the education of engineers by forcing too much standardization. The success of our future scientists and engineers may lie in a greater diversity and liberalization of our education programs at all levels and in higher standards of performance rather than in rigid standards of technical content.

I do not practice the science of research but the art of research. *Ars gratia artis mechanicae,* Art for the sake of Engineering, to modify the motto of MGM.

AUTHOR INFORMATION

Malcolm D. Shuster (mdshuster@comcast.net) is a nuclear physicist turned rocket scientist, who has often wondered if he would have been happier making a career in Germanic Philology or Indo-European studies. He has published mostly on elementary particle interactions with nuclei and, especially, on spacecraft attitude estimation. He has also participated in the launch of several satellites and worked on submarine-launched ballistic missile systems and Geophysics. The article here is adapted from part of a keynote address [4], which he delivered at a symposium in his honor in 2005. This keynote address appeared subsequently in greatly altered form in a special issue of *The Journal of the Astronautical Sciences* [5], derived largely from that symposium. He makes his home in Germantown, Maryland. His Web site is http://home.comcast.net/~mdshuster.

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[2] As I grow old, I ever learn many things.

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