# A Need for Change in Engineering Education

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**Abstract:** We discuss modifications that need to be made to engineering curricula as a response to changes in student attitudes and the decline in student performance. Both these phenomena are closely related to societal changes, as well as on the proliferation of computers and information technology. We propose changes that involve more hands-on learning, more laboratories, wiser use of computers, integration of experimental and computational techniques, better textbooks that contain several and realistic examples, and a way to communicate with students in a way that addresses their frame of mind.

## I. INTRODUCTION

It has been said, "the only permanent thing in engineering education is change." This statement reflects the influence of science and technology on our society and the response of academia to meet new societal needs. For example, many engineering curricula nowadays include several courses on computational technology where few such courses were around 25 years ago. Recent advances in manufacturing, materials, and other subjects are making their way into engineering curricula. ABET requirements for accreditation keep changing every 10 years or so. Such change is, of course, healthy and it should lead to better-prepared engineers. Recognizing this, a large number of universities have undertaken extensive reviews of their undergraduate program in recent years. The Association of American Universities (AAU) conducted an extensive Survey of Undergraduate Education Activities in 1994 [1]. According to that survey more than half of the responding universities (53) had begun comprehensive reviews of undergraduate education on their campuses, or were in the process of developing plans for improvement of undergraduate education. Engineering schools are definitely part of this change (e.g., [2,3]).

One can loosely categorize changes to engineering curricula depending on the need for the change: On one hand, we have changes introduced as a result of research and development. Examples to this include new materials, biotechnology, telecommunication networks and the like. On the other hand, we have changes introduced in response to societal needs and evolution.

Examples to this include the ongoing debates on humanities courses, the overwhelming public interest in technology and computers, and the demands of the workplace.

It is my contention that it is now time for yet another overhaul of engineering curricula. Because of the proliferation of computers and information technology and societal changes which are in part caused by them, we have to adjust our educational system to address student needs, concerns, and most important of all, student attitudes and expectations. Clearly, this need for change is fueled by societal needs. I am concerned that if we do not soon change the way we educate engineers, the quality of graduating engineers will decline.

## II. THE PROBLEM

I believe that we need to make modifications to engineering curricula in view of recent technological advances as well as changes in student attitudes and expectations. I became aware of this need gradually over the last seven years, as I began to notice a decline in student performance, especially at the undergraduate level. Based on discussions with colleagues across the country and in different disciplines, I learned that this decline was not confined to a region, a university or a certain subject matter. Students who come to college these days are not as well prepared as their predecessors. Their understanding of and familiarity with fundamental concepts from science and mathematics is not as strong as before. This adversely affects student performance in college, and it reduces understanding and application of major fundamental concepts. This deficiency is more visible in science and engineering curricula, which rely on prerequisites more than other subjects.

Not only has the transmittal of knowledge from one course to another weakened, but there is also a change in student attitudes towards courses, especially towards subject material that students deem not useful toward their future. More and more frequently, students keep asking the question “what is in it for me?” Sometimes quietly, and at other times not so quietly.

This phenomenon that I have observed through personal experience and conversations with colleagues is beginning to show itself through national testing. Recent test scores indicate that the math and science aptitude of American high school students has gone down again, reaching historically low values. For example, from the 2000 National Assessment of Educational Progress test, conducted on 12$^{th}$ graders from 40 states, it was found that the test scores went down on average by three points compared to those in 1996, a decline considered "morally significant" by Education Secretary Rodney Paige [4]. Ironically, up until 4$^{th}$ grade, American students do well compared to students from other countries. The decline begins after that.

When I first began to observe the decline in student performance I thought it was a temporary situation, or a cyclical one. However, the more I looked and the more I talked with people, I began to realize that it was for real. In addition, a recent experience confirmed my fears. Two years ago, I was assigned to teach a senior level course in vibrations that I had last taught 10 years before. The basic material covered in this course has not changed too much over time. At my institution, as in most others, there is unrestricted access to computers, which are packaged with sophisticated software that makes programming much easier.

In contrast to the gradual decline I have been observing in courses that I teach more frequently, the difference between now and 10 years ago was clear. The amount of material I could cover was less, the level of coverage had to be lower, I had to review the prerequisites longer. Students were not grasping the basic concepts as well as before, even though I solved more examples. The computer projects I assigned were similar to the ones I gave 10 years ago, and they could be done by writing fewer lines of code, thanks to new software. But, fewer students submitted their projects on time and did them correctly. Even though students had more exposure using computers and information technology, their programming skills had gotten worse. Abstract concepts, such as coordinate transformations, flew right over their heads.

So, the decline is real. Interestingly, this decline is evident even in institutions where standardized test scores and class rankings of entering students is increasing, as is the case in my university. This warrants taking a closer look at the reasons behind this phenomenon.

## III. THE CAUSES

Why is there a negative change in student performance and attitude? It is difficult to pinpoint the exact cause of such a phenomenon. Even if a major sociological study is conducted, there will still be disagreements about the cause. I personally believe that there are three major reasons:

1) The generation of students currently of college age has been brought up in a society of unprecedented prosperity, comfort and peace. These kids were less than 10 years old when the Berlin Wall came down, many families prospered with the booming economy and moved into better homes, and, until the terrorist acts of Sept. 11, 2001, there were few military conflicts that directly affected the United States.

Students coming into college have had a much easier life than students say 20 or 40 years ago. They have more resources at home and they have more money. Up until very recently, they felt much safer. This feeling of safety and prosperity has led to a more relaxed attitude, including at school.

Today's students have an attitude of expecting more to be done for them than in previous generations. This is because at the home, as well as at a societal level, more has been done for them. Students now have access to equipment and gadgetry that give them answers instantly and without working hard for it. This has changed how students think and what they expect from an education, from their parents, from schools and universities, and from society.

Contrast this attitude with what happened to math and science education in the United States in the late 1950s, after The Soviet Union first put a satellite on orbit and then sent a manned flight into space before America could do the same. The concept of modern mathematics was born after the public reaction to these events.

2) The proliferation of computers and information technology. In 1983, in K-12 institutions, on average, there was one computer for 125 students [5, 6]. By 1995 this ratio dropped to nine students. Today, it's probably half that. We are now used to quick results using canned software or from the web. We feel no need to memorize information (even things like sin 30˚); the answer can be looked up instantaneously. If students need to research the life of Albert Einstein, they no longer need to go to the public library and check out books. They can find most of the information they want on the Web. This has changed the way students think, learn and visualize, as well as what they expect from life and from an education. Students want to see the results of what they are doing in front of them in order to understand what is going on, whether they know the basics or not. Abstract concepts that require deeper thought do not get much attention. Independent thinking has come to a low level.

Tools supplied to students have also followed this trend of multimedia, gloss and instant answers. For example, in second or subsequent editions of many engineering textbooks there is more color and a larger number of figures, while exposure to fundamental concepts has been cut down. This brings science and engineering education to superficial levels. When students don't understand the basics, they have even a harder time in a subsequent course that has a prerequisite. At the end of several texts, there are CDs, which provide canned software. Some books even list the computer code to solve homework problems. The situation is not too much different in graduate school. More and more students are taking courses in which canned software is readily available, and interest in fundamental subjects is decreasing.

About two years ago, I read an interesting letter to the editor in the New York Times, in which the link was made between the decline in the math aptitude of American students and the introduction of the calculator. In my view, a second such reduction is taking place right now. The vast availability of computers, software and the Internet is having a dumbing-down effect. The Internet explosion, together with substantial declines in computer prices, began about six to seven years ago. The kids who were in grade school then are our college students now. An extensive Educational Testing Service (ETS) study [7] using 6,227 fourth-graders and 7,146 eighth-graders points out that, while higher-order thinking skills are affected positively by frequency of computer use, lower-order thinking skills are affected negatively. The study, which looks at both home and school use of computers, concludes that home use of computers has a positive effect, but "the net effect of school computer use is negative." The study does not conjecture why this decline took place, rather it makes some recommendations that we will discuss later on.

I am concerned that if we do not use computers wisely, the decline in student performance is bound to continue. All this is coming at a time when substantial resources are being used (and there is tremendous public pressure) to add more computers to K-12 schools, many times to the detriment of other science equipment. I fear that such exposure will have a harmful effect, if proper teacher training, quality software, an education plan that emphasizes the fundamentals, and proper perspective do not accompany such exposure. The most significant recommendations of the ETS study are to increase "efforts to ensure that teachers are properly trained to use computers" and to "focus on using computers to apply higher-order skills…" Another recent study also highlights the need for additional research and development in educational technology [8].

3) The reduction of hands-on science education at K-12 levels. Go to any school district and ask how much money they have recently spent on computers and peripheral equipment, and how much money they have spent on lab equipment. The answer may surprise you. On top of this, I have heard of anecdotal evidence that many K-12 schools are reducing the number of science experiments for fear of accidents and litigation that follows. A colleague recently estimated the average cost of such litigation at about several hundred thousand dollars per accident.

Another major problem that science education is facing is the shortage of teachers. Considering the demographics of the teacher population, this problem is bound to get worse in the future. On a positive note, state and federal officials have noticed this shortage and nationwide efforts are in place to develop talented science teachers.

I published my initial findings on this subject in an engineering journal [9]. After my article was published, I got feedback that mostly agreed with my position. One e-mail that I received is worth quoting:

> I just finished reading your article in the October Prism magazine. I could not agree more with your assessment on computer use in education at the K-12 level.

My company produces laboratory equipment (wind tunnels, engine test stands etc). I recently visited a high school in our area that had been given a large grant to start a pre-engineering program by a former student who had done well for himself. They spent the entire grant on a computer lab and did not see the need to purchase any equipment. They could do all of the experiments with software.

We are getting ready to release a new line of vehicle dynamics trainers geared toward the pre-engineering physics market. When I showed the teacher our lesson plans for vehicle dynamics his comment was "We are a college prep school, we do not have an auto shop to train grease monkeys."

I applaud your courage to speak out on the negative effects of computers in education. All I have heard is we need more and faster computers. I haven't heard exactly why.

The author of the above e-mail is not alone. Larry Cuban, education professor emeritus from Stanford, recently published a book that analyzes computers, their use by students and teachers and their impact in schools as instructional tools [10]. The book investigates K-12 institutions in the Silicon Valley, by far one of the most affluent and technologically aware locations in the United States. His findings are chilling. Apart from the fact that much of the equipment donated to schools comes from companies that don't need the equipment and may not be suitable for the needs of the schools [11], Prof. Cuban found that less than 10% of teachers used their classroom computers at least once a week. Professor Cuban points out that school administrators and politicians are under tremendous pressure from society to spend large sums of money to purchase computers and to network them, even though their use so far as teaching tools has been less than minimal. Somehow, society has decided (with no data, information, and historical perspective) that the way to overcome poor performance of U.S. students in science and mathematics is to add more computers to schools and more integration of computers in teaching. It is as if we have a mass hysteria on computers and the Internet.

Professor Cuban's research finds no evidence that the use of information technology leads to increases in academic achievement. I think that this is one of the reasons why the ETS study found out that use of computers at home were more beneficial to students than use of computers at school. Professor Cuban questions the excessive spending for computers and networking equipment and the culture that measures computer adeptness by the number of computers. He recommends that administrators involve teachers in the planning and implementation of computer related activities and allow them more unstructured time, technical support, and professional development.

## IV. PROPOSED SOLUTIONS

The problems discussed above need to be tackled both at the K-12 as well as college levels. I am an engineering educator and as such will primarily address here what we can do at the college level. At the K-12 level, there must be proper teacher training and the need to continuously emphasize that computers and information technology are extremely useful tools for accomplishing several tasks but that they are not solutions themselves. There has to be improvements in children's educational software. Software should push students to think independently. A quote from Prof. Cuban's book sums things well: "Without a broader vision of the social and civic role that schools perform in a democratic society, our excessive focus on technology use in schools runs the danger of trivializing our nation's core ideals."

The continuous emphasis on computers and information technology being wonderful tools, but not solutions, must go on at the college level as well. In addition, I recommend that changes to engineering curricula should come in two (broadly classified) categories: 1) Changing the way we teach in view of the new student attitudes and preparedness, and 2) Changing the way we teach in view of the proliferation of computers, information technology (IT), and new scientific software that is available.

In the first category, educators need to recognize the changes computers and information technology have caused both in the understanding of basic concepts, student attitudes and student needs. A few colleagues disagreed with me after my initial article on this subject appeared, and I kindly directed them to compare what, how much and at what level they could teach 10 years ago in the same course they are teaching now.

By far, my most important recommendation is to give students more hands-on visualization. I say this because students who are used to getting instant answers need more than a teacher, a classroom, a textbook, and a computer to understand the material. Now, more than ever before, students need to see, feel and experience by themselves. Additional hands-on visualization can be accomplished by increasing the laboratory components of courses, as well as by emphasizing the need to conceptualize and to formulate problems. I recommend that every engineering course should have a laboratory component taught simultaneously with that course. Many times, experiments are taught in separate laboratory classes. This mode of instruction should be gradually eliminated. The main problem associated with implementing this change is that more personnel, especially teaching assistants, will be needed. Where will these resources come from? It is up to us as educators to convince university administrators and federal and state officials that added human resources are necessary to accomplish this task.

Additional emphasis on laboratory experimentation and bridging the gap between simulations and experimentation is not an original idea. Indeed, Buffinton et al. make the point of developing a curriculum involving simulation and experimentation [12, 13] and closing the loop on student learning by directly comparing simulation results with the response of actual physical hardware. Their motivation is that “simulations alone do not provide a fundamental understanding of physical systems.” Also, quoting them, “We additionally feel that recognition of the potential pitfalls in excessively relying on computer simulations in engineering education is a noteworthy observation, not only for the benefit of Bucknell students but for the engineering education community in general,...”

A key issue is whether students, and ultimately practicing engineers, have the ability to interpret, verify, and confirm their results. This can be approached by doing additional computational studies that analyze sensitivity, robustness and convergence, as well as similar results for similar problems, through experimentation with actual hardware, or by demonstrating that results are consistent with underlying theoretical concepts and principles. For the latter, students need, as a minimum, to have the skills to analytically and experimentally solve simple problems so that, in attempts to computationally solve complex problems, they can demonstrate that their computational approaches are at least consistent for special cases.

Next, consider the teaching tools that we use. I will address the computational tools later, in conjunction with the second category mentions earlier in this section. Here, I will primarily concentrate on textbooks and the use of examples in class. American students rely on their textbooks for studying more than their class notes. If you do not believe this, teach in class a solution approach different than the one in the book. Then, ask a question in the test that can be solved using both approaches and see which method of solution the students have selected.

The textbooks we choose should be as self-contained as possible and they should have lots of illustrative examples, making it easier for the student to visualize and understand the concepts. Recently, in a graduate level course, I made partial use of a textbook that had zero illustrative examples. The students thought it was torture to learn from that book.

Another issue to work on is in changing student attitudes on recitation sections and attendance. My department a few years ago tried an experiment with the sophomore dynamics class. Instead of teaching it in the traditional lecture format, we tried to teach the course as two lectures and one recitation, where the recitation was entirely devoted to problem solving. In addition, the recitation sections were taught in much smaller groups than the lectures. All the faculty members who taught in that format reported that attendance decreased considerably during recitation sessions. I assume it was those same students who skipped the recitations who wrote in the teaching evaluations that they were not exposed to a sufficient number of examples.

We need to communicate with students in a way that emphasize the fundamentals in a way that they can appreciate. We need to find new ways to reach the students' minds. We need to engage students both inside as well as outside the classroom. Assignment of projects, I think, will help in this area and promote independent thinking.

Next, let us consider the second category, that is, changes that need to be made to engineering curricula as a result of the proliferation of computers, IT and new scientific software. First of all, I should mention that I am one of the biggest proponents of using computers in education, contrary to what some may think. In this day and age, it is wrong to graduate engineers who are not proficient in computers. My point is that we have to maintain a balance between theoretical, experimental and computational work, and expose students to all three. We have to seamlessly integrate experimentation, analytical work and computation. I personally have a policy to assign a computer project in every course that I teach. However, students need to write their own code for the project and they rely on canned software as little as possible (I will not elaborate on complaints I get in teaching evaluations which say, in essence, that other faculty who teach the same course do not require computer projects). One problem with computer programming is that someone new to it can lose programming skills quickly. Hence, students should be exposed to computer programming every semester they are in school and preferably in every course that they take.

A more difficult issue is to judge how much canned software students should be exposed to and how much of the classical methods they should know. Every day, with improved computational tools reaching the market, the necessary skill sets to solve engineering problems come into question. One of the most pertinent examples in this is in control theory. Some of the most important tools in classical control are root-locus plots, Bode diagrams and Nichols charts. All three are graphical tools that help the analyst and designer evaluate how the control system behaves. When I took controls (many years ago), we spent weeks learning graphical techniques for constructing these plots. At the present time, with a single Matlab command, these plots are at our fingertips. Should we still teach our students the painstaking ways these plots are drawn or just refer them to the appropriate Matlab command? If we tell our students that this is the way of obtaining the plots, but that they can generate the same plot on their personal computers by just using canned software, how many of those students are going to study how to manually generate those plots? And, isn't it likely that students who just use the Matlab commands will have less of an appreciation and a lower level of understanding of the methodology?

We then need to consider the following:  Even if students have less knowledge when they graduate and less appreciation for what they are doing, will this change their job performance and their capability to carry out assignments?  Does it matter if engineering students graduate from college knowing less than their counterparts 20 years ago, if computational tools are there to assist them and make up the difference?  At this stage, there are differing opinions on this; it is too soon to know the answer, as data must be collected over a longer time span.  Are we likely to see people with nonengineering backgrounds doing engineering work, because they have the computational tools in front of them?  Are we likely to see engineers who cannot formulate and analytically solve simple problems but by clicking the right buttons, are able to computationally solve complex problems?  I personally hope not.  Will these engineers have the judgmental capability to determine if their computer-generated solutions are valid?  One thing for certain is that we will be facing such dilemmas more and more in the future.  Where to strike the balance is a key issue, especially if we consider that the next generation of scientific and engineering software will be much more powerful.

One point that I think must be made to students over and over again is that they cannot envision themselves only as users of software.  Students should also think of themselves as developers of software as well.  In addition, some engineers, albeit a minority, will be involved in writing computer code.

Recently, in a charity event I was seated next to two individuals from a big bank in New York City.  In the last seven years, several of our students, graduate as well as undergraduate, have found employment in banks.  I discussed with these gentlemen why banks were recruiting engineering students (they like us because engineers tend to think in a much more structured way, as opposed to nonengineers) and, expecting that banks would keep on hiring engineers, I asked them what software our graduates should be familiar with.  They both agreed that there was no need to know a specific software or computer language.  The students should basically know how to set up a problem and develop an algorithm to solve it.  They could learn the computer language later.  What the bank was asking them to do is to think and to develop.  Students will not be able to hone those skills by just sitting in front of a computer.  It certainly doesn't help if we ask students to use canned software all the time, if we do not ask them to de some programming themselves, or if the textbooks that we use have in print the source code for the computational tools students are using. We have to develop challenging assignments that make use of fundamentals as well as programming skills, never forgetting that computers are primarily tools.

Some universities, such as Drexel and Northwestern, are trying a new approach to engineering education.  They are introducing engineering subjects to students from the first year.

I find this idea interesting.  The results of this approach should be studied to see if it motivates and educates students better.

## V. CONCLUSIONS

We outline a theory that explains the decline in college student performance and changes in student attitudes.  Both of these phenomena are closely related to societal changes that are primarily due to the proliferation of computers and information technology.  We propose changes to engineering curricula that involve more hands-on learning, more laboratories, better textbooks that contain several and realistic examples, and a way to communicate with students in a way that addresses their way of looking at things. We emphasize the need to develop challenging assignments that make use of fundamentals as well as programming skills, never forgetting that computers are primarily tools and not a primary means of solution to engineering as well as other types of problems.

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## BIOGRAPHY

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