From Computers to Mechanisms – the Demand for Teaching Skills the 'Reverse Way'

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ABSTRACT

A growing number of students enters universities having spent considerable amount of time with computers and other devices that expand only visual interaction and combination skills. How do they do with their digital understanding of a largely analog world that surrounds us? What difficulties do they encounter learning traditional tools and machines? Analysis of usefulness of these skills in today's workplace, and what else must be taught. Results given by the "let's try and see" experimental attitude in various lab and classroom courses. Analysis of tests and observations of students having different backgrounds and levels of skills.

1. INTRODUCTION

Evolution of technology and society demands education of people who are equipped with knowledge and skills that are useful in the surrounding environment. New professions are created and some traditional ones become obsolete. Blacksmiths, professionals that once were on the leading edge of technology, became extinct. Advances in technology transformed their trade, created multitude of related specialties and demands for new skills based on higher level of scientific knowledge. About 55% of Americans used computers at home or at work at the end of year 1995, the highest level of all nations [1]. This number is constantly growing for the overall population and is already close to 100% for high school graduates. Most adults in industrially developed nations have a limited understanding of basic sciences, yet they use a wide array of technologies at home or at work. This limited understanding of basic sciences does not prohibit them from being very productive users of high-tech devices but only as long as the devices operate flawlessly. At a first sign of malfunctioning, an operator is usually helpless and cannot continue to work (almost proverbial power outage at a cash register and the cashier cannot calculate percent discount or change). Although the dependency on increasingly complex devices will continue to grow, some knowledge principles and basic skills need to be taught in order to prevent a total dependency on many narrowly specialized professionals. Narrow specialization inevitably brings about a risk of not thinking in terms of a whole system and a difficulty in communication with specialists from other disciplines. There are strong voices in academic community calling to provide solid interdisciplinary knowledge to all graduates [2].

Technical rationality, the traditional base of engineering knowledge and skills will still remain a corner stone of all technology-related professions [3]. However, ways of teaching this engineering knowledge base have undergone substantial changes in recent years. Starting in primary school, there is a tremendous shift in ways of delivering technical knowledge. It is often dictated by tools used in the industry (variety of digital equipment), by current fashion (multimedia) and popularity among students (sit back, watch and enjoy). Certain traditional educational outcomes such as manual skills, are therefore accorded lesser importance and not given a chance to get developed. On the other hand, some subjects are being increasingly taught through physical contact with real objects of study, for example, growing popularity of field trips in biology classes.

2. TECHNOLOGY CHALLENGES AND REALITY OF TEENAGERS

The social and economical realities of the US society, open to outside exports and constantly searching for lower cost production and new markets, necessitate education of a very flexible professional, easily adoptable to new challenges. How do today's teenagers fare in their readiness for university education and challenges of the future workplace? Widely publicized predictions estimate that today's university graduates will change careers 3 to 6 times before they retire. They certainly will face accelerating changes, which already can be seen by examining the history of industrial progress in the last two centuries alone. The pace of changes will most likely to be the fastest in the United States which for the past 6 to 8 decades leads the world in innovation and basic research [4].

It has been observed in the past three years that young people enter college with lower manual skills (but higher computer skills) than their predecessors. Is that only because of more time spent in front of a computer and less in physical contact (both manual and visual) with real 3-dimensional objects? The answer seems to be a simple 'yes', but the reality is more complex. Each generation of young people acquires skills that are demanded by the surrounding environment and the society they function in. Successful people adopt easily to the surrounding world that was created by preceding generations. In order to improve quality of life and increase work productivity, previous generations have created a 'throw away society', a complex, yet easy-to-use equipment, devices that are difficult to disassemble and too costly to repair. As compared to peers of twenty years ago, not many teenagers of today have repaired their own bicycle or watched a parent repairing a toy or a kitchen appliance. How many have repaired a car or measured pieces for precision fit while rebuilding an engine? These activities became substituted by computer games, hence many manual and simple technical skills do not have a chance to be developed. On the other hand, in today's developed economies, people who are competent in high-tech areas and possess interdisciplinary and communication skills have the highest potential for a successful career. We need to remember though that successful engineers and engineering technologists must not only be well versed in the use of computer tools, but also possess understanding and feel for physical nature of processes and functioning of mechanisms that goes beyond graphical representation on the screen.

The 'engineering feel' of processes, components and entire systems is difficult to describe in terms that apply universally to every professional. All new designs or improvements originate in human brain and are one of multiple fruits of human intelligence and creativity. Computers are not in position to create anything new yet, some say they will never be. Today's computers are very sophisticated but still are not more than just tools. What are we getting by giving the best computer to the best-trained operator? Will he or she be able to deliver a final product without first conceptualizing it, gathering adequate information, hand sketching on a piece of paper, quickly analyzing different concepts and what-if scenarios? All successful designers and inventors proceed along that path and do not use computers on conceptual stages because they can substantially slow these activities. 'Engineering feel' being an essential functional part of a good technical professional helps make fast and accurate judgments, define initial conditions, set up experiments etc. It is largely based on one's experience which starts building in early childhood by playing with objects, disassembling, destroying, repairing and using them again in a manner to avoid or cause another destruction. Information used by brain comes from seeing 3D objects, hearing sounds, feeling texture, hardness, resistance, motion, heat, vibration, etc. Today's explosive evolution of computer applications in the field of virtual reality aims at providing such interface of man and machine simulating real world without use of physically existing objects. But it is still years ahead before virtual reality can compete with real toys. Some engineering programs implement activities aimed at development of engineering skills through in-depth investigation of various products or failures of products [5, 6].

During senior projects, I have observed a very common student approach to conceptualizing and describing design ideas. After a verbal description (difficult to understand and visualize), students spent days, if not weeks, putting their ideas on paper by using the best software available. As a rule, these drawings were not self-explanatory and still needed extensive verbal clarification. Almost never conceptualization started with hand sketching, writing down key words that describe ideas, constructing flow diagrams, brainstorming over a hand sketch or using any available object to help visualize the concept (something like using Lego cubes). Few students were easy to steer into that path of work and all of those who were, had at least 12 years of industrial experience.

There was an interesting IBM ad aired during 1997 Baseball Playoffs. A twenty-something years old employee explains to his middle-age boss new ideas of using the Internet to reach customers and promote business. Using the computer screen, he shows different looks of company logo: flashing letters, letters in fire, etc. The unimpressed boss calmly starts talking about his vision of designing something that would provide customers with responsive and timely service, help them in managing inventory, production, delivery, communication with other customers … The young employee thinks for a long while and says that he has no idea how to go about it. Isn't education process putting little too much emphasis on fashionable appearance and not enough on the content and outcomes of activities? New revisions of ABET requirements [7] place greater emphasis on engineering problem solving and applicability of educational outcomes. Outcomes-oriented education that reflects industry demands is expected to replace presently dominant activities-oriented education.

3. PERSPECTIVES OF YOUNG STUDENTS

Some perspectives on the surrounding world displayed by young students are not in line with the way the surrounding world functions. The below listed problems pertain to behaviors and beliefs of young students, as well as, technical aptitudes and were observed in 3 types of academic activities:

- in-class lecture with homeworks
- hands-on laboratory
- design project (involving information search)

3.1. Behavior and beliefs related shortcomings of young students.

The following problems in behaviors and beliefs were observed among around 20 years old engineering technology students during learning process and completion of assignments:

1. attempt to apply same style of learning to all subjects (highly cognitive tasks as well as mostly manual skills)
2. prefer learning through 'hacking' rather than a systematic approach
3. little note-taking ability
4. little self-organization skills when facing multiple assignments in laboratory
5. difficulty in formulating assumptions and questions (prefer to guess)
6. lack of self-verification
7. attempt to solve all problem through 'plug-and-chug' or 'how was it before?' methods instead of defining the core of the problem
8. have little interest and ability to solve open ended problems
9. think that Internet has all answers
10. "image is everything" (look is more important than substance)
11. good talkers but bad listeners
12. no desire, sometimes up front animosity, to work in groups
13. prefer to be told exactly what to do yet have little respect for following established procedures

Most of the above listed problems are found in overall student population regardless of discipline of study. Some of the problems may result in failure to acquire discipline-related knowledge and skills, and impede effective functioning as an engineering technology professional. Problems 1 and 2 can have especially dangerous consequences when 'let's try and see' approach (good for learning menu-driven software) is used around machine tools or measurement equipment. Problems 3 and 4 have a potential to become a big shortfall during professional life, especially in dynamic work environments that allocate little time for documenting successful or unsuccessful steps and procedures. It is worth noticing that although note-taking and self-organization problems tend to fade with experience, they are not as easy to correct as advertised by some organizers of "two hour seminars in note-taking". My instructional experience suggests that it takes two to four years before improvements are visible.

Problems 5, 6, 7 and 8 are also very common among seniors. Especially troubling is their difficulty in defining the core of the problem at hand, which leads to neglecting of that, probably the most important, step in solving problems. As a consequence, work becomes disorganized, and tends to follow many guessing steps due to unidentified goals, priorities, known and unknown pieces of information. It was observed that students usually try to match problem-solving tools known to them (equations, procedures, software, etc.) to the problem at hand without reflecting on the nature of the problem. If the answer obtained 'looks good', they conclude that the problem is solved and usually do not verify solutions. Another very commonly used problem-solving approach leading to unnecessary work is matching of problem at hand with previously solved problems in order to follow the previously used procedure. Quite often simple rewording of a problem leads to a complete stalemate or time consuming tries and searches for similarities with previously solved problems. However, these shortcomings can be overcome through multitude of problem-solving exercises and by examining results of a problem through 'what-if' games that change inputs to the problem. Recently, there have been many publications on importance of providing more training in solving open-ended technical problems [8, 9, 10, 11]. In solving open-ended problems, young students usually embark on guessing process and stick to one answer they like without proving that other answers are less valuable. Assumptions are very seldom stated and self-verification is rarely done.

Problem number 9, is the wide spreading belief that everything can be found on the Internet, and if not found there, it is nonexistent. Students have little practice and desire for finding information through more traditional channels such as library search for books and articles in journals. They neglect possibility of using wrong information from web sites that are not peer reviewed. The dominant mode of searching the web seems to be use of one (at most two) favorite search engines and site to site links. The amount of available information and rapid access seem to encourage random, fairly disorganized way of work. At its present stage of development, the Internet is not as well structured as library search tools, therefore missing a valuable site is still highly probable. In one recent engineering technology senior project course at CCSU students were actually forbidden to use the Internet in literature search for the first four weeks and had to show results of more traditional library search conducted in that period of time. Although difficult to quantify and too early to assess, the benefits of such approach seem to be threefold:

1- better self-organization in conducting each next search
2- fast establishment of knowledge base in the area investigated and its historical development (through available books and journals)
3- later searches done on the Internet were exploring more possibilities and stayed more focused (less hacking and more up-front planning)

A positive side of using the web is high enthusiasm of students, rapid access to information and a very appealing tool. As suggested by early results of the project, before using the web there is an absolute necessity of doing preparatory work: defining the scope of search, listing basic ideas what to look for, learning about basics of problem on hand, establishing key words, etc.

Problems numbered 10, 11, 12 and 13 have roots in the overall upbringing of young people, influence of peers and media, prevailing general culture and social values. Having little influence over these issues, university education must take advantages brought by the other side of some of these problems. Lack of interest in group work and lack of respect for authority do have some positive notion in them. They are typically associated with principles of western culture, such as independence, individualism and self-reliance. The overlying challenge for engineering educators is how to harness these positive personal characteristics into skills of team work, efficient communication and high work ethic which are among the skills valued the highest by the industry [13]. Problem number 10 tends to be less visible with the growth of basic engineering knowledge and experience.

3.2. Technology related shortcomings of young students.

Technical and hands-on shortcomings observed among around 20 years old engineering technology students:

1. marginal 'feeling' of physical units other than inch, foot and pound
2. little practice in manipulating physical units when solving equations
3. problems with sketching or manually replicating more complex 3D shapes
4. no feel for variability and uncertainty when taking a measurement
5. very small hands-on skill with simple hand tools (screw driver, wrench, etc.)
6. recklessness in learning how to run machine tools (want to learn fast through trial and error method only, many seem to neglect the fact that safety comes first)
7. marginal knowledge of SI units

It is worth noticing that today's list of technical and hands-on shortcomings does not contain "lack of computer skills" as it would have even 3 years ago. It is observed that teenage students have acquired considerable computer skills either in high school or at home. What still needs to be taught is that a hardware plus software is just a tool to accomplish a task, not an intelligent problem solver. Therefore, up-to date freshman classes on introduction to computers or information processing should comprise of not just examples of how to use spreadsheets, word processors or databases but also more involved, engineering oriented problems in plotting, calculations, data organization and retrieval. Knowing what is a right graph for a given application and how to create clear and easy to read graph is more important for a technical person than knowing all about how to make the graph colorful.

A very simple project of grinding proper shape of lathe tool bit from a solid HSS blank is used during freshman/sophomore course in metals machining at CCSU to enhance hand-to-eye coordination and viewing of 3D objects. As expected, students with hands-on experience of any kind (not necessarily machining) complete the assignment in less than 20 minutes. Students without such experience or with less developed abilities to switch between 3D and 2D views, achieve poor results even after 2 hours of work and need to be repetitively instructed on how to look at the master and what motions to use for replicating it.

Many articles and books have covered the issue of how the surrounding environment influences intellectual development of a young person. In my opinion the main factors contributing to the development of the above listed behavioral and technological shortcomings of young students are: lenient high schools, low level of social interest in sciences, ready-to-use everything, E-Z-everything, throw-away items used in everyday life, abundance of ready-to-play-with toys which leave no time for their in depth exploration, mass media pounding new information on viewer without giving time for own reflection, and overwhelming amount of readily accessible knowledge. Regardless of who is to blame for these shortcomings of young students, there is a growing pressure from industry to equip university graduates with the required knowledge and skills. Universities must therefore adapt academic activities to the student population, focusing on the achievement of demanded learning outcomes as the underlying objective.

4. HOW YOUNG STUDENTS APPROACH PROBLEMS

The above stated observations and conclusions were verified in two simple tests in manufacturing laboratory during early stage of a freshman/sophomore course in metals machining technology.

4.1. First test.

Four groups (each having 11 to 14 students) were given vernier calipers with dual scale (metric and inch), 0.4000" gage block and very similarly looking steel pins 2" to 4" long, 0.4" to 0.5" in diameter. The pins had very similar surface finish but different diameters and had roundness and cylindricity errors invisible to a naked eye. Prior to the exercise, students were instructed in reading the calipers and had few weeks of hands-on experience. Each student was given one pin and was asked to provide answer to the question "what is the diameter of the pin in millimeters?" The exercise was carried out without any further explanation or possibility of conferring with other students and without specified time limit.

Measurement procedures used and answers delivered by the students were classified into 2 groups: measurement (M) and result (R), giving 9 categories for both groups together:

M1 Measured in one place only.
M2 Measured in more than one place and picked the 'best looking' value.
M3 Measured in at least 3 places and reported average diameter from all measurements.
M4 Measured in at least 5 places and reported max, min and average diameter from all measurements.

R1 Gave correct answer.
R2 Reported diameter value in centimeters thinking that it was in millimeters (e.g. reported 1.148 mm for 11.48 mm pin).
R3 Reported diameter value in inches thinking that it was in millimeters (e.g. reported 0.452 mm for 11.48 mm pin).
R4 Reported diameter in inches instead of in millimeters (e.g. reported 0.452 inch for 11.48 mm pin).
R5 Reported result with a gross error (like in categories R2, R3 or R4) and tried to convince the professor that they either delivered what they were asked for or misunderstood the task which was not their fault.

Table 1. Percentage of students giving answers in the above-described categories during the pin measuring exercise.

Category	% of students giving answer in the category
M1	24
M2	16
M3	52
M4	8
R1	40
R2	26
R3	10
R4	10
R5	14

As indicated by the results (Table 1), one in four students did not consider that a pin could have some form errors because pins ‘looked good’. One in six students picked a ‘best looking’ value without a logical explanation for such a choice. All answers falling into category *M2* were given uniquely by recent high school graduates with no work experience and none of them gave answers falling into category *M4*. Answers falling into categories *R2*, *R3* and *R4* indicate lack of feel for physical units of length and were given by students with and without work experience. Particularly troublesome observations of lack of responsibility for own work and results are seen in category *R5*. Students who gave these answers seem to be well educated in subject of different learning styles, can convincingly talk about black being actually white, yet make little or no effort to verify their own work. In the past few years, many newspapers, weekly magazines and other news media have extensively covered the subject of pre-college education and lack of personal responsibility fostered by some social developments in the American society and its judiciary system. The ‘anything goes’ attitude, widespread in many high schools, which entitles students to ‘feel good’ about their effort, about the value of personal achievement and learning in general, is the breeding ground for such behaviors [12]. Some media reports indicate a growing moral acceptance of cheating among high school students. These unacceptable ethical behaviors of a student can be easily transferred into a workplace. The importance of professional ethics has been highlighted in the results of a study recently conducted by ASME among senior-level technical managers from US industry [13]. The results show that 85% of respondents placed professional ethics among the top 20 skills required from engineering graduates, 5th place overall among the top 20 skills. Skills that scored higher than professional ethics were in descending order: teamwork, communication, design for manufacture and knowledge of CAD tools (94 to 86% of respondents placed them among the top 20 skills).

4.2. Second test.

Students who participated in the first test were given digital calipers (displaying in millimeters and inches), 4.0000” gage block and 4.100” long turned round shaft made of steel. The calipers were intentionally zeroed at 0.100” (but students were not made aware of it) and handed to the students with jaws at about 4” mark. Each student was asked to provide within 1-minute time frame an answer to the question “what is the length of the shaft in inches?” The exercise was also carried out without any further explanation or possibility of conferring with other students.

Measurement procedures used and answers delivered by the students were classified into 4 categories:

M1a Measured and reported result (without verifying zero setting). After being told that the result was wrong, measured again and showed the display indicating 4.000” again as a proof of being ‘right’ the first time.

M1b Measured and reported result (without verifying zero setting). After being told that the result was wrong, verified zero setting than measured again obtaining 4.100”.

M2 Measured, reported result than reflected on visible difference between the 4.0000” gage block and the shaft that got measured as 4.000” long. Verified zero setting and measured again obtaining 4.100”.

M3 Verified zero setting first, than measured the shaft.

Results shown in Table 2 indicate that only one in three students discovered wrong zero setting and delivered a correct answer without any help – categories *M2* and *M3*. Two out of three students did not provide a correct answer on their own – categories *M1a* and *M1b*. Half of that group (one in three students overall, predominantly recent high school graduates) did not even consider the possibility of doing something wrong during such a simple looking task – category *M1a*. When students from the last group (category *M1a*) were asked to put the 4.0000” gage block by the side of the shaft and find out what went wrong in their procedure, a third of them started defending their wrong answers instead of finding the cause of the wrong answer. Overall, the students whose answers belong to categories *M1a* and *M1b* had little hands-on experience and almost undeveloped 'engineering feel'. As later exercises and projects showed, many of them were very gifted and progressed pretty well.

Table 2. Percentage of students giving answers in the above-described categories during the shaft measuring exercise.

Category	% of students giving answer in the category
M1a	34
M1b	30
M2	26
M3	10

4.3. How students process and use information.

Woods and Crowe note that first-year students tend to solve problems by "playing around with the given symbols and data until they find an equation that used-up all the given information" [10]. These students do not attempt to gather any additional information for the assigned problems. As results of the above two tests indicate, if a solution looks acceptable, young students rarely attempt to use all the information available to verify their solution or to explore a possibility of other solutions. With the growing need for ability to work in teams and still a strong need to be able to act independently, students need to be given more open-ended problems and ill-defined problems [14]. Both types of brain teasing exercises foster practice in creative use and verification of information, search for information and validation of solutions. The problem definition phase that students accord to their problem-solving activities is usually very short. Atman et al. observed substantial truncation of this phase even among senior level students who finalize solutions without even considering end user of the product [15]. In general, such shortcomings of engineering and technology graduates tend to fade away with the growth of professional experience, which may take years. University role is to foster development of necessary habits and skills.

4.4. Trust in displayed results.

Use of digital displays is very common in everyday applications. Students with little hands-on experience believe that what the instrument displays is absolutely precise and has no likelihood of error and dismiss necessity of calibration against more robust masters. In my experience, the best way of teaching about simple concepts of variability, backlash in machine tools etc. is to let students discover results first through hands-on experience and then provide theoretical background. For initial machining experiences, manual machine tools and metrology equipment are also better suited than those numerically controlled because they provide a greater opportunity to feel the process.

5. CONCLUSIONS AND RECOMMENDATIONS

The 'Let's try and see' learning approach is an easy one to use, requires little rigor in pursuit of a goal and can be very time efficient, provided that results of actions are straightforward: YES or NO type. Learning menu driven software or using it for a new task are good examples of such use. After initial introduction, students fare very well, especially when they learn in a small group of 2 to 4 people. Mistakes can be made and repeated but they cost nothing and pose no risk to health. However, this learning approach is highly inappropriate when dealing with open-ended problems in analog-type environment, especially, when operating machines and measurement instruments. Great deal of up-front thinking about possible results of actions and some basic knowledge about the nature of a problem are required in order to prevent costly mistakes.

As incoming freshman and part time students are better prepared to deal with computer based tools, there is a growing need to teach the nature of engineering problems and how to solve them, treating computers as tools not the end result. Introductory courses in the use of computers need to be offered more frequently on remedial bases, freeing up the time for more in-depth courses in engineering applications of computers. In view of the growing volume of the required knowledge, it is difficult to envision any drastic reduction in time required for computer training of future students. However, due to substantially declining hands-on skills of the young generation, lack of contact with simple tools and mechanical pieces, laboratory activities involving hands-on exercises will become a more important part of engineering technology curriculum. Such activities could involve simple individual projects and repetition of some of these projects with given time constraints forcing students to do initial planning of activities, hence fostering learning by including some degree of repetition. Studies of failures, especially mechanisms and structures, are also a very valuable approach providing an insight on the nature of materials, manufacturing processes used and utilization of products and tools. Additionally, industrial coop will need to become a more integral part of engineering technology curricula.

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