Technology’s Role in Student Understanding of Mathematics in Modern Undergraduate Engineering Courses

Andrew Phillips, The Ohio State University

Andrew H. Phillips graduated summa cum laude from The Ohio State University in May 2016 with a B.S. in Electrical and Computer Engineering and with Honors Research Distinction. He is currently finishing his M.S. in Electrical and Computer Engineering, and then he will pursue a Ph.D. in Engineering Education. His engineering education interests include first-year engineering, active learning, learning theory, and teaching design, programming, and mathematics. As a Graduate Teaching Associate for the Fundamentals of Engineering for Honors program, he is heavily involved with developing and teaching laboratory content, leading the maintenance of the in-house robotics controller, and managing the development of the robotics project.
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Abstract

This paper seeks to identify important implications on the use of technology in the teaching of mathematics in modern undergraduate engineering courses. These are used to create a big picture of the current situation of engineering mathematics teaching based on the developments over time. Certainly, the use of technology in engineering and mathematics is necessary in the modern world. Technology is integrated into everything engineers do, and engineering students must develop skills with learning and using various forms of technology.

For mathematics, utilizing technology leads to faster and larger quantities of calculations that can be performed, which are clear advantages. However, it has been shown that the theoretical mathematical ability of modern undergraduate engineering students has mostly decreased over the decades. Part of this decline is due to the focus in classrooms on application-based teaching and using technology to perform calculations instead of allowing students to think through mathematical problems. This can lead to engineers who can crunch numbers but not solve new conceptual problems.

Mathematics is a vital skillset for engineering students. Its many forms are required of students to some degree in every engineering discipline, and higher-level courses may make extensive use of mathematics. Additionally, a good mathematical ability is often needed after graduation in industry or in graduate school. Thus, it is important to foster the conceptual mathematical understanding of undergraduate engineering students for their futures. However, students often make use of technology as a “black box” in that they get an answer for a particular problem but do not understand the concepts underneath and have difficulty applying the math to different situations. Due to this, there is a need for teaching strategies which expose students to technology without replacing analytical and theoretical ability.

Thus, a literature review is conducted for articles describing the role of different technologies in teaching mathematics and student understanding. The collected articles come from engineering education and mathematics education sources. Specific technologies referenced include personal graphing calculators, programming software, and Virtual Learning Environments (VLEs). The results of using these reported different technologies and methods are compared. Advantages and disadvantages for student use and understanding are discussed.

From this bigger picture, it is seen that there are ways to leverage modern technology appropriately to take advantage of the speed and power of calculation but not impede conceptual understanding and learning. As technology continues to change, it is important that engineers retain the conceptual understanding so they can adapt to new tools and still solve future engineering problems. It is hoped that through this literature review, good practices for properly using technology to supplement and improve mathematics education in undergraduate engineering can be compared and expanded upon.
Introduction

The mathematics ability of undergraduate engineering students has seemingly declined over the decades [1, 2]. Due in part to the increased role of technology in their studies as well as the increased focus on application of mathematics instead of conceptual understanding, modern undergraduate engineering students have more difficulty with even basic algebraic and numerical analysis. In addition, engineering students do not always see the relevance of learning mathematics to their future careers or even to their future college coursework [2].

However, these same students are still graduating with engineering degrees and going to work in industry or in research. One possible reason for this is the potential slipping of mathematical standards in universities. A study comparing the mathematics performance of students at a certain university in 1997 and in 1990 found that students with average grades in 1997 performed just as poorly as students with very low grades in 1990 [3].

This change in engineering mathematical standards is sometimes combated by the role of pure mathematics instructors. Often, these mathematicians are perceived to teach math too theoretically and not in a practical manner [1]. Although these mathematicians argue that it is important for engineers to understand the mathematics they are using, most engineering programs still focus only on applications of math and contend with the mathematics instructors on course content [1].

Thus, it is often argued that engineering department faculty should be the ones teaching mathematics to engineers for them to see the relevance [2]. In addition to the possibility that mathematicians are the experts in teaching math, many math departments also receive significant funding from teaching engineering students, and they may not like the idea of engineering departments teaching math instead [2].

Because of this contention among engineering and mathematics instructors, often a “just in time” [1] approach is used in engineering courses like physics and chemistry. This refers to the introduction and use of specific mathematical concepts only when they are needed in the general course of learning the physics or chemistry. Unfortunately, although this may increase students’ practical sense for mathematics, it decreases their appreciation and understanding because they are only using concepts sporadically. Additionally, this disjointed presentation of mathematical concepts often leads to a decrease in the amount of total time to teach basic undergraduate mathematics because lecturers simply show a technique once for its immediate application and then move on [1].

Thus, the standards and time allotted to ensure mathematical understanding are decreasing, and there is a need for new techniques to solve this problem. However, simply raising the standards or giving more time for traditional mathematics lectures are not sufficient because they do not address all the aspects of students’ poor mathematics performance. One possible solution is to appropriately leverage modern technology to find a balance between conceptual and applied learning.
Certainly, in the modern world, the use of technology in engineering and mathematics is necessary. Technology is integrated into everything engineers do, and so, engineering students must develop skills with learning and using various forms of technology. Also, technology allows mathematical computations to be done much faster and in larger quantities. There is no denying the importance of using technology in engineering mathematical education.

Despite the clear advantages and the current student preference to use technology whenever it makes a problem easier, its misuse can decrease student understanding of mathematics. One common misuse of technology in a classroom is to use it instead of any kind of theoretical or paper-and-pencil analysis. If instead, technology can be used to supplement student conceptual understanding and analysis or as a check or visualization tool after analysis is complete, then students gain the benefits of modern technology while still going through conceptual processes.

Within this lens, the literature review uncovered three main uses of technology to supplement student mathematical learning that are being used today. The specific technologies referenced are graphing calculators, programming software, and Virtual Learning Environments (VLEs).

**Graphing Calculators**

A common current tool for undergraduate students is the graphing calculator. It is widely used due its mobility and small size, relatively high computational capability, and interactive graphical capabilities. Graphing calculators are often used by students on homework problems and sometimes even during in-class activities and examinations. Because of their widespread use, a study was done to determine the ways in which a graphing calculator has meaning in a pre-calculus course [4].

The focus of this study [4] was on the interaction between the teacher and the students in terms of using the graphing calculator. The teacher’s own knowledge and use of the graphing calculator impacts the meaning constructed for the tool by the students. Results showed that for this particular class, the instructor had extensive experience using a graphing calculator and often encouraged students to use it to help with understanding and not just computation. In addition, the instructor emphasized to students that graphing calculators also have limitations. Admitting that calculators do not always tell the whole truth was important for the students to think of using the calculator as one tool that needs to be checked and not the only tool.

In addition to the findings that the teacher’s own competency influenced the meaning constructed by this tool, the study [4] also identified four areas in which students use the graphing calculator and create meaning. First, the students saw the calculator as a computational tool. This view raises issues like the limitations of rounding and the need for students to enter calculations correctly. Second, students used it as a transformational tool. That is, with encouragement from their instructor, the students used the calculator to create global understandings of functions which they analyze locally on paper. This combined the paper-and-pencil analysis with the computational advantages of the calculator. Third, the calculator was used as a visualization tool. Students utilized the graphical capabilities to do more than just graph functions. They changed equation parameters to see the effects on the graphs and to link the visuals to the physical problem situations. Fourth, students used them as checking tools. Again,
with leadership from the instructor, students would conjecture a particular graphical fit for a set of data and then use the graphing calculator to graph the fit and check its accuracy. All of these uses imply supplementing prior thinking and consideration of limitations with the advantages of technological computation and visualization. Thus, these showcase appropriate use of a graphing calculator for the improvement of student mathematical understanding and investigation. The study noted that these four views generally led to students investigating the meaning of the calculations and graphs with significant input and encouragement from the instructor.

However, the study [4] also uncovered some negative aspects of using graphing calculators in the classroom. One limitation was its use as a personal device. Students would conduct computations or look at graphs privately on their own calculators. This often led to students not paying as much attention in class or withdrawing from communicating with others. The second limitation was the use of the calculator as a “black box”. Although the four views listed above generally led to students investigating the meaning of the calculations and graphs, this was done with significant input and encouragement from the instructor. Thus, in certain cases and when using it on their own, students continued to simply plug in numbers and read out the answer from the calculator screen without thought as to why that was the answer or if it was correct. Additionally, some students got caught up in understanding a particular random number generation function available in the calculator and did not realize that it is just one tool for solving the problem instead of it being the only possibility. Both limitations support the concerns addressed in the introduction that students can tend to use technology for mathematics without regard to understanding the full meaning.

This study unveils that graphing calculators can be used in conjunction with analytical practices to improve student mathematical understanding and ability. However, it also reveals current issues with their use and highlights the importance of guidance from an instructor with a working knowledge of the tool.

**Programming Software**

In addition to the graphing calculator, engineering students have access to powerful programming software packages. These programming software packages can do similar things to a graphing calculator, but programming software can do them faster and at a much larger scale. Of course, these packages also include unique graphical manifestations, models for specific engineering discipline work, and different programming syntaxes which separate them further from calculators. For example, one such programming software package which is often utilized in engineering curricula is MATLAB. A study was done in Australia to look for similar effects on student learning when using MATLAB to complement mathematics [5].

This study focused on the “skills, feelings, attitudes, and beliefs” [5] of first semester engineering students in an algebra and calculus class which used MATLAB. A survey questionnaire looked at the relationships among factors like computer confidence, mathematics confidence, math-tech attitudes, and math-tech experience. From the low correlation found between computer and math confidence (0.11), it was determined that those are separate dimensions [5]. This finding supported previous results [6] and is important because it allows the comparing of student computer use with their mathematics ability. Cretchley, et al. also report
high correlation between math-tech attitudes and math-tech experience, indicating that more experience with programming software led to better attitudes about it.

Most of the students in the study [5] expressed positive reactions to using MATLAB for most of the assignments, and any early frustrations with learning to use the software dissipated after time. Some of the specific advantages students listed are: graphing functions, three-dimensional graphing, matrix computations (a specialty of MATLAB), visualizing and calculating integrals, and checking analytic work. These are similar to the findings about the graphing calculator in that students enjoyed being able to gain new information from the software instead of just plugging in numbers. However, intense computations that require understanding of memory storage and computation time received less favorable reviews from students, indicating that learning new computer information was not seen as productive.

There were some issues with certain students not liking to use the software or becoming distracted by using a big computer. Also, students in the study who were distance learners had more difficulty due to fewer support resources [5]. Even students who expressed positive use of MATLAB did not usually go above and beyond the suggested exercises, though. This indicates that there is a balance between the use of programming software and the amount of additional learning or technological savviness required.

Nevertheless, Cretchley, et al. showed that using MATLAB can help student mathematical interaction and understanding. Galbraith, et al. also support that confidence with using computers, such that students are not bogged down by technical issues, can help increase mathematical confidence and ability.

Virtual Learning Environments

The internet is now a vast multimedia communication tool that has seen increasing use in classrooms. However, using the internet as a mode of instruction for a course involves changes in presentation as well as teaching. Engelbrecht and Harding state that despite the early issues with representing mathematical symbols and procedures on the internet due to programming limitations, mathematics is increasingly being taught on the internet [7]. This is because the internet now offers new “visual facilities and exploratory opportunities” [7] not available even with graphing calculators or programming software.

One influential method of the internet in teaching undergraduate mathematics is using a Virtual Learning Environment (VLE), also called a Learning Management System (LMS). These systems act as course websites with features such as content pages, quiz and survey tools, student tracking, file management, and assessment packages [7]. Engelbrecht and Harding cover multiple instances of VLEs and condense their use into certain categories based on their use in mathematical courses [7]. These categories include sites being used for mathematical resources, exercises for practice, communication with peers and instructors, and the dissemination of the full course.

Engelbrecht and Harding have seen advantages of the use of VLEs in that students can interact on their own time with the material. For example, courses could be setup to allow students to
work through modules or quizzes at their own pace online. Additionally, students can track their progress online and potentially see how they compare to the average progress of other students in a class. Overall, Engelbrecht and Harding sought to categorize the extent of use of VLEs in terms of interaction and material. They found that while not many sites are used with both full interaction and full material use in mind, the combination of some online interaction with peers, visualization tools, and quizzes along with constant online access to course material and progress generally worked well for specific courses under study [7].

Thus, although VLEs are relatively new, there are advantages to using them to increase student interaction and learning with mathematics.

Discussion

All three forms of technology discussed above, the graphing calculator, programming software, and VLEs have been shown to have both advantages and disadvantages for teaching undergraduate engineering mathematics. In studies from the referenced journal articles, students seem to identify similar positive uses of the technology. These include the ability to graph and visualize functions, increase the speed or magnitude of computation, and to check analytical computations. Additionally, the ability to go back and redo these procedures, whether on a calculator, in software, or in an online VLE, gives students exploratory skills within mathematics to increase their interaction with the material.

However, despite these advantages, studies have shown some disadvantages or hurdles in technological use. There is the fear that students use these technologies in a “black box” way so that they do not actually understand the mathematics but only how to mechanically get the answer. The above studies show, though, that careful combination of technology with prerequisite analytical work can keep the conceptual benefits and the computational benefits. In addition, the studies imply that instructors must have a good knowledge of how to use the technologies, as well. It is important for instructors to be able to warn their students of limitations of technology and to be available to help with the learning curve of using computers and software. The technology must also not separate students into their own “bubbles” of learning but allow for interaction to enhance investigation and learning.

Conclusion

Modern undergraduate engineering curriculum is sure to continue and expand its use of technology, including some which are not yet known. If students use these technologies in appropriate ways and do not forsake the analytical, investigative, and interactive elements of mathematics education, then these technologies can have positive impacts on student mathematics confidence and ability, such as improving visualization, computation, and interaction abilities.

Overall, slow progress has been made for the advancement of appropriate technology implementation for engineering mathematics education. This paper has shown a subset of the recent advances and successful studies and indicates that the historical decline of mathematical
ability and importance is starting to turn around. Engineering mathematics curricula will need effective technological use more than ever to best prepare engineers for their careers.

References


