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An Analysis of Computer Based Methods and Problem Based Learning in Mathematics

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ABSTRACT

Like most other professions, engineering has evolved significantly in the last two decades. It is continuously changing to reflect the needs of the 21st century. The engineering profession is re-examining its relationship with its scientific roots. This is an exciting time to invigorate the curriculum and its educational approaches.

The curriculum and educational practices must be responsive to rapid economic and technological developments as well as emerging global environmental and social problems. Students' personal needs must be balanced against changing requirements of industry and professional accreditation bodies. It is therefore of paramount importance for educators of engineers in the 21st century to recognise changes in the engineering profession and to modify subjects to suitably cater for new requirements.

The purpose of this research paper is to bring to light some of the more prominent teaching methods and strategies currently used to teach mathematics to engineering students in various universities worldwide. Emphasis is given to the effectiveness of these methods and strategies.

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Why is Mathematics Education Important for Engineers?

Mathematics education is of much importance to the engineering curriculum because it helps to lay the foundation for good analytical and problem-solving skills often required in traditional engineering work. Mathematics subjects are prerequisite to a number of engineering subjects. The need to reinforce these mathematics skills is further highlighted by a recognised engineering skills shortage.

Most civil engineers believe that only few mathematical concepts are used at work, Kent and Noss propose an explanation as to why this is so. It has been suggested that this is because mathematics has become wrapped up in engineering practice. As an example, geometry and trigonometry have become so much embedded in engineering practice such that a structural engineer tends to think about say, a simple plane curve, in terms of what they mean in structural terms rather than in mathematical terms.

Furthermore, Blockley and Woodman claim that with the advent of computers, emphasis has changed from the ability to perform engineering mathematical calculations to the ability to interpret the meaning of mathematics in engineering. This is especially true in the use of computer software applications. Blockley and Woodman's argument is supported by Hadgraft and Kent and Noss. It has been established by Kent and Noss that manipulative skill is less regarded than the "holistic" understanding or interpretation of mathematics and in identifying which areas need mathematical applications in an engineering context.

The importance of solid mathematical education for engineers is stressed by a number of practitioners and argued by Blockley and Woodman. It has been highlighted that mathematics is needed in engineering because "all mathematics is the ultimate form of logical rigour. It is the language of scientific communication, hence without a facility in mathematics engineers are cut off from scientific change and development."

The Need for Improved Performance in Engineering Mathematics Education

It is claimed that mathematics skills are in fact not strong in many professional engineers and should be strengthened. Engineering students are seen to lack the necessary mathematics skills when they enter traditional technical occupations.

According to Henderson, surveys of widespread practices in software engineering show that many engineers do not have sufficient skills to use discrete mathematics and logic as tools in performing their work. In the case of Civil Engineering, Blockley and Woodman found that while it is paramount for engineers to understand structural behaviour, practising civil engineers have been known to make incorrect assumptions in finite element modelling whereby non-existent boundary conditions and degrees of freedom have been set. This clearly illustrates a lack of understanding in interpreting mathematics as a tool to model physical and engineering conditions – a substantial part of what a young engineer's work may require.

Pollock and Springer have also expressed concern over students' mathematical preparedness even as they enter higher education. This highlights the need to strengthen engineering mathematics education at the university level.

Methods used to enhance learning should respond to issues such as technological and other changes that impact engineering mathematics education in the 21st century. This is hoped to be achieved through improved teaching methods.

Prominent Non-Conventional Teaching Methods Currently in Use

From a survey of recent (from 1995 up to the present time) literature in mathematics education for engineering students, the following are notable means for teaching and learning to adapt to 21st century needs and conditions:

Advanced computer based methods – web based interactive, software applications

1. Multidisciplinary approach

2. Problem Based Learning (PBL) strategy

These methods and features are discussed in more detail in the succeeding sections.

Advanced Computer Based Methods – Use of Web Based Interactive, Software Applications

With the rapid progress of computer technology in the last couple of decades, software applications and the web have become important elements of our daily activities. This reality is also evident in engineering mathematics education. Computer technology and its applications have been incorporated in engineering mathematics subjects at most universities worldwide. Hence, while one or more other teaching methods are employed, it may be observed that they are often used in conjunction with web technology or software applications.

Many practitioners have asserted that computer based teaching should be supported in the delivery of mathematics subjects to engineering students. This complements the equally large proportion of engineers' professional work being reliant on computer software applications.

Taraban highlights the importance of examining computer-based learning because it represents a leading progression in contemporary teaching. There are reasons why "engineering mathematics courses have not undergone wide scale changes towards IT. These are the high cost of moving 'chalk and talk' mathematics teaching out of lecture rooms and into computer laboratories, and the lack of a common grounding in mathematical technology in school mathematics curricula".

Electronic learning (e-learning) is often thought to be the new way to communicate mathematics. It is also believed to enhance comprehension and stimulate interest. Particularly for engineering students and practising engineers, familiarity with a number of software packages is said to be vital for effective problem solving. Some practitioners suggest that the use of interactive mathematics can provide more engaging learning materials. This will consequently attract more students to study mathematics in engineering courses.

Aside from using packages, interactive mathematics may involve personalised, interactive documents on the web. It may also include the use of the web as an unconventional calculator using numeric, graphic and symbolic mathematics interactively.

As well as assisting learning, computers can also be engaged in assessment by way of “computer aided assessment” (CAA). CAA has been reported to increase students’ confidence and to reduce their stress levels. Furthermore, some practitioners have suggested that it would be beneficial for educators to explore the potential of using technology (software tools) to improve the interrelation between mathematicians and engineers and for bridging their individual knowledge in a fresh manner.

Brenner assert that computer programs for engineering students must be simple to understand and easy to use. They should also be capable of achieving straightforward results. This will prevent the technical details of the computer program from taking away the focus of learning from the main subject matter. Waldvogel has communicated along the same lines. He supports the appropriate use of modern mathematical software in teaching engineering but cautions that software cannot take the place of basic understanding. He is a proponent of MATLAB, which is believed to be a transparent and versatile in numerical work. Most mathematics subjects for engineering students introduce students to MATLAB.

Kent and Noss put forward Mathcad and MATLAB as useful tools for engineers for constructing models and for their own specialised applications. This is primarily because these tools allow accelerated prototyping. This means that, “initial modeling ideas can be investigated by the potential users, and the resulting interaction often leads to an improved match between the model and the users’ requirements”.

Mathematica or Maple is thought to be less useful as they are more difficult to understand without thinking in “explicit mathematical terms”.

Karady and Nigim maintain that Mathcad is easily grasped by students. Part of the reason for this may be because formulas in Mathcad worksheets appear in the same form as they are seen in textbooks.

MATLAB has been widely chosen firstly because it is widely used in industry, and secondly because of its “pronounced Linear Algebra orientation”. MATLAB is believed to help make the theory more transparent to the engineering student by allowing the student to follow the theory’s operation in a wider range of applications. Whereas mistakes in manual linear algebra exercises can slip away unnoticed, MATLAB also acts as an effective teaching tool by refusing to process incorrect statements. MATLAB is also said to be very useful when demonstrating graphs of functions and discussing limits.

Brenner and Morgenroth envisaged the inclusion and effective use of modelling and simulation in the fields of environmental, chemical and biotechnology engineering through the application of POLYMATH. POLYMATH is a numerical computation package used for modelling and simulation, particularly created for engineering students and engineering professionals. It is generally used for interactive problem solving involving algebraic equation systems, differential equations and regressions. With the application of a few elementary rules, POLYMATH models can be transformed to MATLAB functions. POLYMATH is easy to understand and simple to use. It requires only minimal user intervention in the technical details of the solution process.

Brenner offer some reasoning behind their conclusion stating the positive effects of the use of POLYMATH. They also demonstrate its effectiveness by describing how it was applied to the modelling and simulation of a classic problem in “Water Pollution Control”. Similarly, Mtenga and Spainhour provide sound arguments to support their claim about the benefits of using Mathcad. They also illustrate the functionality aspect of Mathcad by presenting a problem ("Stepped Column") where it has been implemented. Naimark uses his observation to compare topics with and without MATLAB support. He explains that topics incorporating MATLAB are grasped well, with nearly all of the exercises solved correctly by the students. Colgan bases his conclusions on student grades. But contrary to Naimark's results, student grades indicate that mathematical knowledge and skills gained in subjects with MATLAB are comparable to those gained in subjects without MATLAB. It is the ability to program in MATLAB that increased significantly. Lee and Lin showed how MATLAB might be integrated into an electrical engineering subject for the purpose of visualising and appreciating its application in a real environment, and only declared the associated relevance of measurement and analysis based on it.

Taraban recently conducted a case study comparing the effectiveness of software implemented interactive (active) learning compared to computer based plain text (passive) approach. Results from the Taraban case study indicate that computer based learning is much more effective when it is interactive than when it is passive. However, it is not categorically shown in their study that computer based interactive learning is superior to the traditional lecture and textbook based method.

The integrated approach has been used in a number of American universities. This approach encourages active learning and combines different models mostly consisting of the physical model, mathematical model and computer simulation model. Nirmalakhandan present recent findings involving independent evaluations of the success of using these active learning environments in engineering classes. Evidence shows that the integrated approach, promoting active learning, helps to improve engineering education with 81% of students confirming the effectiveness of the computer model.

Multidisciplinary Approach

Several practitioners recommend that mathematics subjects to engineering students be delivered within an engineering context. One way to help students integrate their knowledge and be able to see mathematics in the context of engineering is to design a subject where collaboration between engineering and maths departments (and other staff) is a fundamental principle. Additionally, Haryott suggests that for a good working engineering syllabus to succeed, collaboration should be accomplished not only among academics but it should also include accrediting bodies and recent engineering graduates.

Maths and engineering collaboration is undoubtedly consistent with the arrangement in modern industrial working practices. It has been identified (and success noted from student comments) that interface between engineering and mathematics subjects can be achieved through the multidisciplinary approach. This was evidenced by the noted success (based on student feedback) of this program at the Edinburgh University and at Canterbury University.

In the Canterbury model, each week generally contains lecture and lab sessions handled by the Department of Maths and Stats. Lab sessions are used for problem solving. However four out of the twelve weeks (four weeks are nonconsecutive) are devoted to engineering case studies that are taught by staff with an engineering background. The case studies are carried out in groups of two students. Development and delivery of the subject is accomplished jointly. Different departments present each lecture and each lab session jointly. Positive feedback has been received from student survey results as well as from staff-student review meetings.

These approaches may be effective because materials are presented in different ways (lecture, lab and case studies) within a short time frame and this enables the students to obtain thorough and in-depth knowledge/skills of the subject matter. The presence of regular lab work (weekly) is useful because the students' lab experience will support and complement what has been learned in the lecture each week. This will also reinforce learning and provide hands-on opportunity with MATLAB and other computer packages.

There are various ways in which collaboration between maths teachers and engineering departments benefits students. Practical examples given in class are also taken from engineering fields. Taking practical examples and problems from engineering has also been suggested for technological colleges in Japan. Waldvogel in his presentation 'Workshop on Mathematics in Engineering' proposed additional improvement by focusing on and extending linear algebra and numerical analysis with possible inclusion of discrete mathematics, due to the fact that practical engineering problems "are rarely solvable in closed form".

Incorporating guest lectures by engineering staff is an innovative teaching practice for mathematics subjects and this can potentially improve engineering students' appreciation of mathematics. This is because the engineering staff can reinforce the importance of maths and better relate mathematics to the engineering concepts, practical problems and even work requirements.

Problem Based Learning (PBL)

Active learning is "learning by doing". This occurs when students play an active role in their learning. The problem based approach is a form of active learning where learning is driven by the problem. Haryott advocates that in order to support the creative nature of engineering, the use of problem-based learning should be explored further for teaching mathematics to engineering students.

PBL has been claimed to be the "natural technique" to use in teaching engineering because it duplicates work situations most engineers find themselves in. Workplace situations hold similarities with small group, PBL in the classroom. This is evidenced by the fact that in engineering work, people team up in small collaborative groups and encounter problems that are open-ended and often with conflicting elements.

Litzinger proposes a revision of engineering curricula to include multiple learning experiences that challenge students to cultivate self-directed learning skills. PBL subjects have been studiedin connection with this and positive correlation was obtained between PBL and readiness for self-directed learning.

Aside from multiple learning experiences, some practitioners have suggested PBL based programs include more student participation. It has been proposed that there are many opportunities for engineering students to work on projects requiring their collaborative skills. Group work and report writing are included in mathematics subjects for engineering students. These subjects are intended to be problem-based, with students encouraged to acquire additional knowledge on top of what was covered in lectures. They also require group work and report writing to assist in developing skills associated with working cooperatively, time management and investigating "real applied problems". This is supported by the PBL experience described by Johnson in a hydraulic engineering class.

Morgenroth have suggested the usefulness of PBL in understanding and appreciating mathematical modelling. This claim is supported by Thomas with the success (based on feedback) of a game show format for PBL classes in mathematical modelling. Projects undertaken by students have been argued to enhance learning. Karady and Nigim report on a proposed problem solving method in power engineering at Arizona State University which has been tested for four years claim that this method, which also utilizes Mathcad, has helped improve grades and has also lifted student interest in the subject matter. It is postulated that the success of this problem solving method can be attributed to the interactive nature of the process. This signifies that it is effective for students to discover the trends, meanings and interconnections in an interactive way.

An integration of studies from 1980 to 1999 was accomplished by Springer. This pertains to small group learning's effectiveness with undergraduate students of science, mathematics, engineering or technology (SMET) in North American educational institutions. The main effect of small group learning on achievement, persistence, and attitudes among undergraduates in SMET was significant and positive. The significance of this analysis to PBL cannot be ignored if small group PBL is utilised.

It is noted that while interactive and PBL are both forms of active learning, they are not exactly the same as each other but only contain common elements. Innovative teaching methods being used in a number of American universities are consistent with an integrated approach characterised by active learning environments. This approach encourages "learning by doing". Projects are often required of students working in small groups, challenging them to "rationalise, reconcile, predict and validate" theoretical knowledge against the physical model. Active learning can take several forms and one of these is PBL. This integrated approach can therefore be thought of as an extension of PBL.

Nirmalakhandan present recent findings involving independent evaluations of the success of using these PBL based learning extension in engineering classes. Evidence shows that this integrated method helps to improve engineering education, with 92.1% of respondents attesting to the effectiveness of this teaching strategy.

CONCLUSION

An engineering mathematics subject should be a part of a well-designed engineering curriculum for its full benefit to be realised. This has been suggested by the European Society for Engineering Education's (SEFI) proposed hierarchical engineering curriculum.

It can also be seen that if based primarily on learning enhancement, a combination of various effective teaching methods may be the best strategy in teaching mathematics to engineering students since that can capture the value of each method. Some combinations reported to be effective are PBL-computer based, multidisciplinary-computer based-part PBL and PBL-multidisciplinary computer based. It is essential to be able to combine the methods effectively; but in an effective subject design, these methods (computer based, multidisciplinary and PBL) merge well.

Moreover, having three models which can be viewed in three different perspectives, helps students better recognise the interrelationships between the problem itself, the theory and the physical and computer models. This improves their understanding especially if the integration is accomplished over several semesters. In earlier years, there are mathematics subjects that require abstract concept development.

It would be interesting to investigate more closely the combinations of approaches. A better comparison of their achievements can then be performed. It is also worthwhile considering a comparison of the effectiveness of two or more individual methods particularly in a measurable and controlled manner.

While small-group PBL, computer method or integrated approach may be most effective in enhancing learning, their full implementation may be limited by their associated costs, implementation time and resources. Although many practitioners argue the merits of innovative methods of teaching, it cannot be suggested that the traditional lecture method has unconditionally lost its usefulness.

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