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Mathematics for Engineering Education

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ABSTRACT

This paper presents author's experience in teaching a course of Applied Mechanical Engineering Analysis at both undergraduate and graduate levels in two public universities in the U.S. and Canada. This course synergistically integrate the math that students learned in previous years to solve mechanical engineering problems on rigid body dynamics, fluid mechanics, heat transfer and mechanical vibrations. Statistics is used to handle quality control of products by mass production. The teaching of the engineering analysis course in his current university covers Junior and Senior year undergraduate students satisfying prerequisite courses in calculus and differential equations, as well as upper division courses of dynamics, thermodynamics and fluid mechanics. The course covers a 15-week semester and is offered in both the Fall and Spring semesters.

1. Introduction

Mathematics and physics are two principal pillars for all engineering disciplines including mechanical engineering. Indeed, courses in mathematics and physics dominate the Lower Division engineering education in both freshman and sophomore years in most engineering programs worldwide. Many engineering schools offer a course on engineering analysis that follows math courses on pre-calculus, calculus and differential equations. Engineering analysis is also offered at the entry level of graduate studies in many universities in North America.

The wide acceptance of engineering analysis to be a core curriculum by many engineering educators is attributed to their conviction on a real need for students to synergistically integrate all mathematical subjects that they learned in earlier years and apply them to solving engineering problems. However, the pedagogy of "engineering analysis" or alike, and its outcome have rarely been discussed in open forums. Most universities offer these courses as a terminal math course with advanced math subjects. Consequently, all textbook vendors that the author has contacted with had consistently offered books published by their companies on "advanced engineering mathematics" for the textbook for the course on "engineering analysis." Few such books are listed in References [1-5]. If one takes a close look at these books one will notice that almost all these books are authored by applied mathematicians who have little exposure to other upper division engineering courses and the engineering as a profession. Additionally, all these books are bulky in size with more than 1000 printed pages, and they present detailed and elegant mathematical treatments to mostly mathematical problems that may not be essential for professional practices by engineer in problem-solving and decision-making.

As most engineering problems in "real world" are of physical nature, disjoint in teaching mathematics and physics in Lower Division engineering curricula has resulted student's inability in using math as "tools" for their solving engineering problems of physical nature. Many students in the engineering analysis classes are equipped with sound experience and skill to perform math manipulations, including solving given differential equations; either use classical solution techniques that they learned in previous math courses, or use modern tools such as electronics calculators and computers. However, they are not capable of deriving proper differential equations for solving particular engineering problems they have in their hands. Many more students could not apply integrations to determine common design engineering properties such as volumes, centroid and moment of inertia of solids of 2- and 3-dimensions. The situation has worsen in recent years with rapid advances in information technology, which offers students with ready accesses to turn-key hardware and software packages such as finite element and finite difference codes to solve many engineering problems with little knowledge and experience in realistic interpretation of the output of their analyses that make sense in reality. These readily available commercial computer codes have actually further disconnected engineering students from understanding basic engineering principles in an already serious situation of disjoint of math and physics in the current math education in engineering.

There appears an emergence of consensus among engineering educators that students need to be educated on how to relate physical situations to mathematical modeling that often involves deriving appropriate math tools such as differential equations with relevant boundary and initial conditions to solve real-world problems.

2. Author's Teaching Philosophy on Math Education for Engineering Students

The author believes that it is fundamentally important to treat the course "engineering analysis" to be an "engineering subject" but not a terminal math course with advanced math subjects. Students in the Junior or Senior year have already acquired sufficient math in their earlier years. What they need at this level of their undergraduate studies is "how to effectively use the math that they learned in past as the tool to solve engineering problems." Teaching engineering analysis following this principle would not only offer students powerful math tools for their future professional career, but it would also stir up their interest in learning engineering as a profession.

The very first thing that the instructors need to do is to "relate" math of what the students have learned in previous courses in the Lower Division to the physics that they also have learned from their Lower Division education, and to the engineering courses that they have taken in the Upper Division classes. This would include illustrating the roles of common math terms such as functions and variables play in real-world physical situations. The same should be done for understanding the physical nature of discrete-values and continuous varying functions with respective variables. Students need to learn how some well-known physical phenomena can be expressed by math terms such as derivatives and integrals of functions. Relevant math expressions for the "laws of nature or physics" such as the Newton's laws for engineering mechanics, Fourier law for heat conduction, the first law of thermodynamics, etc. would be helpful in relating math and physics. Such exposures would make it easier for students using the math tolls that they learned in earlier math courses to determine the areas, volumes, moment of inertia, etc. in their engineering design, and also be able to derive their own differential equations to solve engineering problems. Students are often amazed by the "power" of the first and second order ordinary differential equations that they have learned before in solving a variety of problems in rigid body and fluid dynamics, heat transfer and mechanical vibration problems related to their day-to-day lives after they have learned how to relate math with physics.

3. Selection of Topics for Engineering Analysis

As mentioned in the foregoing section, the author is of the opinion that what lacks in the math education to undergraduate engineering students in this country today is their ability to synergistically integrate the math that they have already learned from previous years with the physics that enables them in solving engineering problems. Consequently, no additional math topics are viewed to be necessary in this engineering course. What is required is to develop adequate course syllabi that will educate engineering students to relate math and engineering which is of physical nature.

The course syllabi in the author's engineering analysis class were developed on the basis of satisfying both the course goals and student learning objectives as presented below.

A. Course Goals:

1. To learn the relationships between engineering (the "master") and mathematics (the "servant").
2. To learn how to derive mathematical (analytical) models for the solution of engineering problems.
3. To learn how to formulate mathematical models, e.g. derivatives, integrals and differential equations for mechanical engineering problems involving various sub-disciplines.
4. To learn how to interpret mathematical solutions into engineering terms and senses.

B. Student Learning Objectives:

1. To fully understand the physical (engineering) interpretations of fundamentals of mathematical terms such as functions, variables, derivatives, integrals, and differential equations.
2. To acquire experience and skill in basic methodologies in differentiation, integration and solving linear ordinary and partial differential equations.
3. To be able to relate special tools such as step and impulsive functions, Laplace transform and Fourier series for modeling engineering phenomena and facilitate mathematical solutions
4. To be able to establish mathematical models, such as differential equations with appropriate boundary and initial conditions for mechanical engineering problems in fluid

mechanics, vibration and heat conduction/convection of solids, and be able to solve these equations.

5. To be proficient in finding solutions of integrals and related information from available "tool" such as mathematical handbooks, spreadsheets and computer software such as Mathcad and Matlab.
6. To learn the basic principles of linear algebra and its application in solving large number of simultaneous equations often required in advanced engineering analyses.
7. To understand the basic principles of statistics and its application in quality controls in mass productions in manufacturing processes.

Syllabi of the engineering analysis course that the author teaches are listed in Appendix 1. A special printed lecture notes under the title "Applied Engineering Analysis" was developed by the author and they are sold to students in his class at the cost of printing. This set of printed notes [6] adequately covers a semester in 15 weeks with 2.5 hours/week, including two lecture slots spent on two quizzes with 75 minutes each.

As presented in Appendix 1, the course is primarily focused in the first three subjects with Course subject 1 on the linkage between the math and engineering and the following two subsequent Course subjects on the applications of the first and second order differential equations with examples on how these equations may be used to solve a number of problems involving several sub-disciplines of mechanical engineering in rigid body dynamics, fluid dynamics, heat transfer and mechanical vibrations. Appendix 2 presents a number of typical problems that students learn to solve with the first three course subjects. The course subject on Laplace transform is included in the course to refresh students' experience in using this transform technique to solve differential equations with the functions involving variables that covers semi-infinite domains, and the subsequent Course subject on Fourier series offers math expression for periodic phenomena such as crank-slider mechanisms used in many machines and internal combustion engines. The subject on partial differential equations intends to usher students to math modeling of more complex engineering problems involving more than one variable. Matrices and solution of large simultaneous equations are necessary math tools for handling engineering problems of great complexity, and they are the key elements of modern analytical tools such as the finite element method. The course concludes with the fundamental principle of statistical process control on products produced in mass production.

4. Challenging Issues in Math for Engineering Education

The author has taught engineering analysis to mechanical engineering students at both undergraduate and graduate level in two major universities in Canada and the U.S.A. since 1972. He has faced with two major challenging issues relating to the teaching this course in both countries, as will be presented below.

Challenge 1: Student's preparedness

Engineering students in this country are generally good at learning by free-spirits necessary for being creative and innovative, as well as by hands-on experience. However, a well-known fact is that they are significantly lagging behind in math skills in comparison to their peers in many other countries in the world. Many students enrolled in author's undergraduate course on "Applied Engineering Analysis" have clearly shown this deficiency despite the fact that they all have passed the prerequisite courses on pre-calculus, Calculus I, II and III covering four semesters, and an additional course on differential equation. Syllabi of these prerequisite courses are presented in Appendix 3. Students satisfy these prerequisite courses either from the Lower Division education at author's university or from the community colleges with course articulations approved by the university. However, many of them are not accustomed to apply math in solving engineering problems. The course on applied engineering analysis with the course syllabi presented in Appendix 1 appears very difficult for them. One major reason for this is their ill-preparedness in basic math skills.

The author conducted an aptitude test for incoming students to his class on engineering analysis in 2004. As shown in Appendix 4, there were 5 problems relating to student's basic math skill in differentiation, integration, multiplication of simple matrices and solving a simple first order ordinary differential equation. There were 49 students participated in the test and the results of the test were summarized following the problems on the same sheet. Distribution of marks scored by the students is shown in Figure 1.

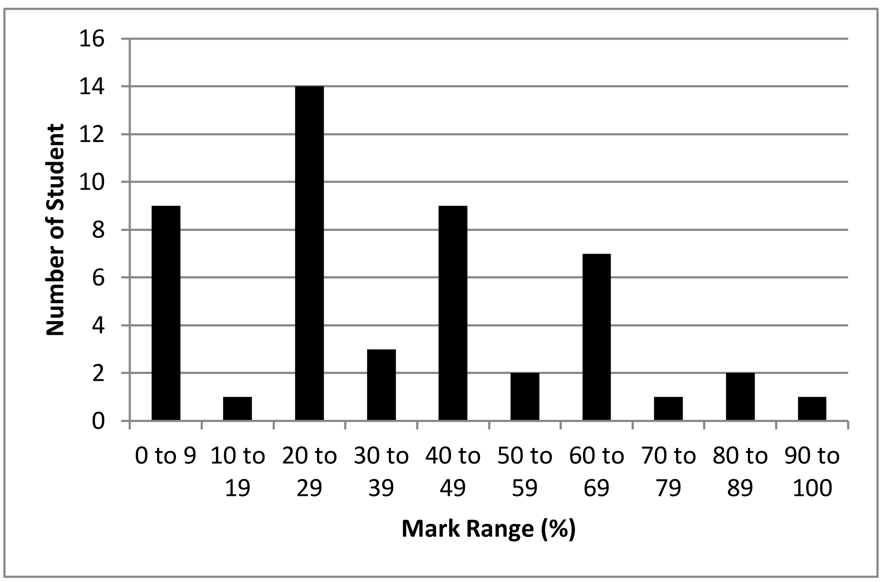

Figure 1 Mark Distribution of an Aptitude Test on Student's Math Skill Learned from Lower Division Education

The result of the aptitude test as illustrated in Figure 1 was anything but disappointing. On may argue that the outcome of this particular aptitude test may not reflect the true level of math skills of American college students in general because of the small database, it nevertheless sends an alarming signal to math and engineering educators with the following observations:

1) The mark distribution of the aptitude test by incoming students to author's engineering analysis class in Figure 1 shows a peculiar phenomenon; while there was one student who achieved a full mark of 100%, the majority student population or a whopping 77.55% scored less than the nominal passing mark of 60%.
2) This mark distribution has clearly shown a lack of basic math skills by Upper Division college students in American engineering institutions. The university in which the author has been teaching in the past 23 years is a major public institution in a state known for leading science and technology. One would also notice that 43 of the 49 students who took this aptitude test were in their senior year, yet their performance in solving basic math problems appeared much less than one would have expected.
3) Problems associated with student's dismal performance in the aptitude test appear in Figure 1 is that the problems involved in the test were covered in all the four prerequisite math courses they had successfully passed in their Lower Division math education, as indicated in Appendix 3. Their poor show in the giving aptitude test makes one to wonder how these prerequisite courses were taught by the Lower Division math teachers. The same may apply to how the high school teachers taught the basic math to their college-bound students.
4) Lack of basic math skill compounded with lack of experience in relating math and physics at all level of math training has led to a serious question on the adequacy of math education to American engineering institutions.

Challenge 2: Adequate textbooks for math education for engineering students

There is virtually no adequate textbook available in the current marketplace that would satisfy the course goals and student learning objectives stipulated in Section 3 of this paper. Textbooks adopted for post-differential equation classes by many engineering schools in the country such as those cited in Reference [1] to [5] have little to offer students how the math tools that they learned in Lower Division can be used to solve engineering problems as typified in Appendix 2, and hence relating to problem solving and decision making in their future professional practice. Additionally, these books are all grossly overwhelmed with contents, which cannot be covered in either a 15-week semester or a 10-week quarter, which are what most engineering schools can afford with their already over-crowded curricula.

5. Applied Math vs. Engineering Math

Many engineering subjects, such as thermodynamics is regarded by many to be "abstract" yet the applications are "real." Mathematics, being a branch of science, is very different from engineering; Albert Einstein once said that "Scientists discover what was. Engineers create what was not." Indeed, engineers create what was not; they are expected to solve problems that no one else has solved, and making decisions that often bear major consequences. The tools that engineers need to perform all these tasks are math tools. In theory, mathematicians and applied mathematicians concern with mathematical methods that are "typically" used in science, engineering, business, and industry. Their main concerns are in elegance in solutions that they develop for many applications that do not require. The relevance of applied math to engineers has diminished in recent years due to the rapid advances in, and availability of information technology with many turn-key software packages to the engineering profession. This trend has resulted in a major paradigm shift in math education to engineering schools. One obvious example for such shift is that the “solution techniques” for differential equations, whether they are ordinary or partial differential equations, have become less important to the engineering profession. The ability in “deriving” the relevant differential equations and interpreting results obtained from turn-key numerical analyses to real-world situations become vital experience for engineers. This new trend in math education to engineering students requires closer correlations between basic math skills and relevant physical phenomena applicable to the engineering profession.

One essential element that engineering students in this country needs in this new trend of math education is adequate teaching material – suitable textbooks. Books that can relate math subjects and complicated math analyses with physical situations will not only enhance student’s learning of the subjects, but it will also stir up much needed interest in learning by the student. A noticeable example for such textbooks is the availability of several textbooks on engineering dynamics, for instance in Reference [7]. These books, though appear bulky in size, but are specifically designed for classes covering one-semester, with abundant examples of applications to person’s day-to-day life, with vivid graphical and pictorial depictions.

It is author’s ongoing effort to develop a textbook from the experience gained from years of teaching this subject of engineering analysis that will offer the students much needed knowledge and experience in linking math and engineering in their professional practices in a similar form as in Reference [7].

6. Summary and Conclusion

The author has made relentless effort in assessing the adequacy of math education to engineering students in his university. His observation appears less than optimistic based on his accumulated experience gained in teaching a course on Applied Engineering Analysis to his students in junior and senior years in two major universities in both Canada and the US in the last 20 years. Following are few of his findings:

1) Students at the junior and senior levels appear inadequately prepared for the class of engineering analysis despite their satisfying the prerequisite courses in their Lower Division education. The dismal performance in the aptitude test with problems presented in Appendix 4 had led to this observation.
2) Student’s dismal performance in the aptitude test may be attributed to the inadequacy of the math that they learned prior to their math education in their pre-college education. The problem is thus even more serious than it appears. It warrants a thorough review of the adequacy of math education through K-12 schools.
3) Engineering educators are commanded for their insight for offering a follow-up engineering analysis course for engineering students after their passing the math courses in Lower Division. It offers engineering students the last chance to learn how math that they learned in previous years may be used to solve engineering problems.

4) The course on Engineering Analysis should be taught as an Engineering subject rather than another math course with advance math topics. This course should serve a purpose of developing engineering student's ability in synergistically integrating their knowledge and skills that they learned from their previous math courses with their solving real-world engineering problems.
5) There is lack of adequate textbook to facilitate engineering students to acquire the knowledge and experience in solving engineering problems using the math that they learned in previous years.
6) The author strongly recommends serious effort by engineering educators to initiate in-depth research in the adequacy of current math education to engineering students.
7) The rapid advances in information technology has resulted a major paradigm shift in math education to engineering students, and the way how this education should be delivered to them. There is an urgent need for engineering educators to look into this paradigm shift and developing curricula of math education to engineering students accordingly.
8) Frequent and open forums organized by professional societies such as American Society for Engineering Education (ASEE) or major funding agencies like the National Science Foundation (NSF) will provide much needed dialogues between the instructors of the Lower Division math courses and those of the Upper Division engineering courses. Such dialogue will definitely facilitate the development of closer relevance of math education to engineering students.

Engineering educators and senior executives of industry and business have consistently advocated the dire needs for American engineering institutions to place strong emphases on the "fundamentals" in its educational programs. Math and physics are the two "fundamentals" of the "fundamentals" of engineering education. Strong relevance of math to engineering in American engineering institutions should be viewed to be a top priority in nation's engineering education reform. Only then can engineering educators produce the engineers that can satisfy the needs by the nation's industry and business.

References

[1] Kreyszig, E., Kreyszig, H., and Norminton, E.J., "Advanced Engineering Mathematics," 10th edition, John Wiley & Sons, Inc., Somerset, NJ, ISBN 978-0-470-45836-5, 2011 (1113 pp)

[2] Jeffrey, A., "Advanced Engineering Mathematics," Harcourt Academic Press, San Diego, ISBN 0-12-382592-X, 2002 (1159 pp)

[3] Zill, D.G. and Cullen, M.R., "Advanced Engineering Mathematics," 2nd Edition, Jones & Bartlett Publishers, Sudbury, MA, ISBN 0-7637-1065-2, 2000 (926 pp)

[4] Greenberg, M.D., "Advanced Engineering Mathematics," 2nd Edition, Pretice-Hall, Upper Saddle River, NJ, ISBN 0-13-321431-1, 1998 (1324 pp)

[5] Wylie, C. Roy and Louis C. Barrett "Advanced Engineering Mathematics," 6th Edition, McGraw-Hill, Inc., New York, ISBN 0-07-072206-4, 1995 (1362 pp)

[6] Hsu, T.R., "Applied Engineering Analysis," for internal distribution for San Jose State University students, Spring 2013 (218 pp)

[7] Hibbler, R.C., "Dynamics," 13th Edition, Pearson, Upper Saddle River, ISBN 13:978-0-13-291127, 2013 (736 pp)

Appendices

Appendix 1 Syllabi of an applied engineering analysis course
Appendix 2 Typical problems solved by the first and second order differential equation
Appendix 3 Prerequisite Courses for the course on applied engineering analysis
Appendix 4 Aptitude test problems and results on student's math skill