A New On-line Testing and Remediation Strategy for Engineering Mathematics[1]

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Abstract *- It is well documented that there is currently an unsatisfied need in industry for more qualified engineers, and a disturbing decline in college students opting for technical degrees. Part of the problem is the high attrition rate among engineering majors, which can be attributed, in large part to problems with mathematics. In addition, the Accreditation Board on Engineering and Technology (ABET) has adopted a new set of criteria for evaluating engineering programs, which is outcome-based rather than course-based. The ABET 2000 criteria require that the institution formulate educational objectives, then assess their educational strategies.*

We are currently developing a strategy using web-based mathematics examinations, tutoring and advising to help improve retention of engineering students and to address ABET's outcomes-based assessment. This paper describes the software used in our on-line testing and the exam questions we designed based on electrical engineering applications.

I. Introduction

There is currently an unsatisfied need in industry for more qualified engineers [1]. For example, according to the Bureau of Labor Statistics [2] jobs for electrical engineers are projected to increase between 21 to 35 percent through 2006. In addition, a recent study by the American Electronics Association reports a disturbing, decline in college students opting for technical degrees [3].

Part of the problem is attrition among those who begin a technical major. Currently, about 50% of UNR engineering students drop out or change majors in the first two years of study, some without actually taking a single engineering class [4]. This high dropout rate can be attributed in part to a misunderstanding of what a career in engineering involves and a realization that such a career does not meet the expectations of the student. Nevertheless, many of these students drop out because of problems with mathematics [5]. In addition, the current educational environment does not allow them to remedy their deficiencies in mathematics at their own pace. Another problem is that some students who do decide to stay with engineering programs achieve only minimal proficiency in mathematics. This is later a serious handicap to their education and is the cause of endless problems for them and for their instructors.

For the reasons above, among others, the Accreditation Board on Engineering and Technology (ABET) has adopted a new set of criteria for evaluating engineering programs, which is outcome-based rather than course-based. The ABET 2000 criteria [6], [7], require that the institution formulate educational objectives, then "evaluate, advise, and monitor students to determine its success in meeting its program objectives." The institution must devise "a process that ensures the achievement of these objectives and a system of ongoing evaluation that demonstrates the achievement of these objectives and uses the results to improve the effectiveness of the program." The criteria also state that "Engineering Programs must demonstrate that their graduates have (a) an ability to apply knowledge of mathematics, science, and engineering, and (b) an ability to design and conduct experiments, as well as to analyze and interpret data."

II. Addressing the problems

Engineering programs at the University of Nevada and the South Dakota School of Mines and Technology have received NSF funding to develop a strategy comprising web-based mathematics examinations and tutoring to help students achieve the desired competency in mathematics and to encourage students to continue in their engineering programs. The strategy includes monitoring and verifying the progress that students make as they receive tutoring and take on-line tests. We will then assess the use of these web-

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based examinations to complement the existing mathematics curriculum for engineers to achieve these goals.

Note that while both web-based testing and tutoring are well known means of mathematics instruction and assessment, we are suggesting critical modifications in the way it is used. First, we are combining their use in a supervised strategy that seeks to maximize student learning and minimize dropout. Second, we are allowing students to familiarize themselves with the test environment through dry run tests. We therefore hope to minimize the probability of student failure due to unfamiliarity with on-line testing.

Here are some specifics:

- Students (especially those who do not make an "A") may not retain much of the knowledge they acquired in a math course. They often "cram" for exams and a few weeks later have forgotten most of it. Testing them on the concepts later will provide an opportunity to refresh their knowledge and to do so in an engineering context.

- Students who can differentiate a polynomial often cannot apply that skill in the context of an engineering problem. Therefore, an important feature of the questions is that they will frequently be presented in the context of engineering applications. We will develop a bank of questions in the main topics covered in math courses required for engineering majors with the assistance of students who have excelled in those classes.

- Finally, we have also observed that even students who have completed calculus persist in making certain canonical elementary errors that interfere with their ability to solve problems. Examples of these errors are

$$\frac{1}{x+y} = \frac{1}{x} + \frac{1}{y}$$

$$\sqrt{x^2 + y^2} = x + y$$

and $(x+y)^2 = x^2 + y^2$.

The proposed tests will help to address this problem.

III. The Testing Software

Drs. Jeff McGhough of the South Dakota School of Mines and Technology and Jeff Mortensen of UNR have already written a prototype program that constructs both multiple choice and free response questions at random to build an exam, which is then delivered to the student. The student may then answer the questions and submit the responses. The system will grade and record the results. It does not require any special software for the student; all of the processing is done on the server. Dr. McGough has successfully used the prototype in academic classes during the 1998-1999 academic year. The interested reader may contact Jeff McGough or Jeff Mortensen for a more detailed description of the latest version of the software and its status.

The interface to the test system will be a Web Browser. Currently, the test system consists entirely of a server-side program that interacts with a web server and a relational database. Eventually, some aspects of the system may be moved to the client side -- most likely in the form of Java applets to maintain platform independence.

There system recognizes three types of users: students, proctors, and instructors.

- Students will (after authentication if it is a proctored exam) be able to take exams and later review their scores and exams.

- Proctors will assist in authentication.

- Instructors will be able to perform test configuration and review their student's results by performing pre-configured SQL queries on the database.

IV. Exam Questions

We designed a set of exam questions for students in precalculus classes that review concepts we deem essential for success in the electrical engineering curriculum. The questions are all context-based so that students who pass the test demonstrate an ability to apply mathematics to engineering problems rather than simply regurgitate memorized formulas. The topics covered in the questions include: circuit analysis, electronics, electromagnetic fields, fiber optics, power systems, machines, as well as engineering mechanics. At this stage, the questions target students at the precalculus level. Our experience and others [8], show that mastering precalculus mathematical skills is essential for students to succeed in their engineering

programs. In fact, lack of these basic skills is the main reason for the fatal mistakes alluded to in the Section II.

We now provide examples of the questions included in the test. We also discuss how the questions can be repeatedly used by randomly varying the data in the questions and answers. The testing program performs the latter task without the need for the intervention of an instructor or proctor.

Circuit Theory

1. The resistance of an electric wire depends on its material and geometric properties and is given by

$$R = \frac{lr}{A}$$

where R is the resistance in Ohms, r is the resistivity in Ohm-meters (a property of the material), l is the length of the wire, and A is the cross-sectional area of the wire. Determine the resistance of copper wire of length two meters and cross-sectional area .0001 m^2. Use the table below.

Material	Resistivity Ωm
Copper	1.7×10^{-8}
Aluminum	2.8×10^{-8}
Rubber	10×10^{-8}

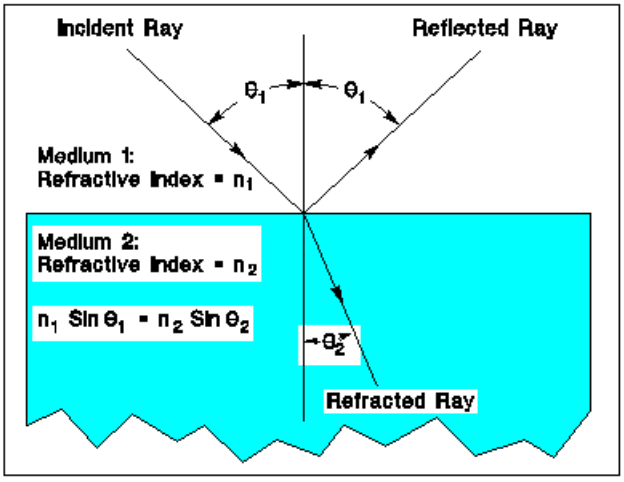
Question Variations

The calculation of the resistance depends on two geometric properties and one material property. The program can generate the length and area of the wire randomly within specified ranges. The program will also generate the material at random from the provided table and lookup its resistivity to generate the correct resistance. The student must look up the appropriate resistivity from the table, then calculate the resistance. Additional questions can be generated by providing the student with the resistance and two properties and asking for the third property.

Optics

2. The bending that takes place when a light ray strikes a refractive boundary (e.g., an air-glass interface) at a non-normal angle is governed by *Snell's law*. It states that $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ where n_1 and n_2 are numbers called the *indices of refraction* of the two media respectively.

   If the angle $\theta_1 = 30°$ and the index of refraction of medium 2 is one and a half times that of medium 1, what is sin (θ_2)? (or θ_2 ?)



Snell's law

Question Variations

New questions can be generated by varying the angles and material properties in the question.

Acoustics

3. The speed of sound in air depends on the air temperature as follows

$$c = 20\sqrt{T + 273}$$

   where T is the temperature in degrees centigrade. Determine the temperature of the gas in a furnace if the speed of sound is 700 m/s.

Question Variations

Here two quantities can be randomly varied to generate different questions. The proportionality constant, given as 20, is actually dependent on the density and the specific heat of the gas. The temperature can be generated at random in a specified range and the proportionality constant can be varied based on physical parameters provide to the testing program. Additional questions can be generated by providng the speed of sound and using it to

calculate the temperature of the gas. The latter type of question is the basis for acoustic pyrometry.

V. Conclusions

For many undergraduates, poor mathematics skills are a major obstacle to completing their engineering programs. The situation is typically worse for electrical engineering because of the high level of math proficiency required for some of the required classes. In most universities, there are a few students whose mathematics skills are so weak that they should consider other career options. There are also a few who are highly motivated and possess all the skills needed to succeed. The majority are somewhere in between the two extremes. While many of us may dream of better students or of students of days gone by, the reality is that we need a strategy that will allow the marginal student to succeed and improve the skills of the average student.

We have developed a strategy based on on-line computer test combined with tutoring to allow students to learn critical basic concepts and skills required in their engineering classes. Our experience is that tutoring by itself, or testing by itself, will not produce the desired results in many cases. However, a combined tutoring and testing program appears to offer great advantages. Trial tests reveal to the students and tutors areas of deficiency. These are remedied by tutoring tailored to meet the student's needs. On-line testing allows the student to take exams as many times as desired until, with appropriate tutoring, enough progress is made to pass the test.

Another feature in out new testing strategy is that the questions used are based on engineering applications. Formulating questions derived from engineering applications provides students with a justification they nowadays demand for the mathematics portion of the typical electrical engineering curriculum. This allows an institution to realize some of the benefits of an integrated curriculum with all its benefits [9]. While such a strategy may not achieve all the benefits of an integrated curriculum, it offers the advantage of avoiding implementation obstacles such as faculty resistance, intra-university politics, organizational difficulties, and cost that a new paradigm necessarily requires.

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