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Online Learning Resource for Smooth Transition from High School to Engineering Education

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Abstract

Although high school mathematics curriculum documents in Ontario, Canada have, for the past two decades, made calls for classroom practices involving both modeling and applications, students still experience difficulties in moving into a university engineering program. This paper discusses a new initiative in online learning and the teaching of mathematical modeling and applications in engineering education at the University of Ottawa, Canada. In particular, we explore how modeling and Internet technologies can enhance progress in engineering education.

Key Words: *Online learning, Engineering mathematics, Modeling and applications, Internet technology.*

1. Introduction

Over the last decade or more there have been growing concerns in higher education regarding the shortage of candidates with adequate knowledge in mathematics for undergraduate degree courses in science and engineering [1-7]. Students moving from high schools to mathematics-related programs at universities, such as engineering, often have difficulty applying their mathematical knowledge to new situations. They find that there is a gap in the knowledge and skills expected of them in a university program. The gap seems more pronounced in mathematics. Usually, these university programs depend critically on students' experiences of learning mathematics and on their ability to make connections between the mathematics they learn in high school and the practical situations presented later in the university. Mathematics education at the high school level (ages 14-19 years) faces a variety of challenges including: a broad range of students' needs; a shortage of qualified mathematics teachers; and constantly changing curriculum and assessment practices.

Technology is playing a key role in the teaching of science, engineering, and mathematics in a variety of ways. The use of the Internet and its learning capabilities is growing rapidly as a dynamic and engaging learning environment that offers the potential for creating exciting learning opportunities for students.

Promising Internet-based learning is possible when mathematics, foundations of engineering, and human-computer interaction design experts work together taking into account sound modeling pedagogy.

In this paper, we will discuss the details of the first unit of an engineering learning resource (ELR) currently under development at the University of Ottawa in Canada. The ELR focuses on modeling a number of elements and characterizations of applications in a learning environment that will facilitate a smooth transition for students from high schools to engineering programs. The first unit of the ELR is a module that involves constructing models of electric circuit elements and interconnecting them to form electric circuit models of practical systems. Although this unit emphasizes the skills required to model circuits, it also allows students to be able to engage, outside of the classroom, in the practice of electrical engineering, and most importantly in problem solving.

2. Mathematics for Engineers

Mathematics is present in all disciplines of engineering. An understanding of key mathematical concepts together with a skill to apply them effectively to solve engineering problems is an essential ability that every engineering student must acquire. Traditionally, mathematics has been taught to year 1 engineering students at the University of Ottawa by lecturers from the Department of Mathematics. Formal lectures present theory and students practice by solving problems. Although this method of teaching may meet the needs of students with high competence in mathematics, formal lectures do not appear to be the most effective method for teaching mathematics to engineering students for several reasons. Many students learn to solve theoretical problems without being able to apply that knowledge and further, are exposed to pure rather than applied mathematics. As well, a pure mathematician's perception of mathematics may be different from an engineer's and the teachers' perception of mathematics clearly affects the manner in which it is presented. This, in turn, affects students' perceptions and understanding of mathematics. While some perceive mathematics as a body of established knowledge to be internalized by the learners; others see mathematics learning as a complex activity. Bruner [8] suggests: "We teach (mathematics) not to produce little living libraries on the subject but rather to get a student to think mathematically for himself". Current thought on mathematics teaching and learning suggests that the goal is to develop students who are able think mathematically rather than learners who simply memorize and apply procedures. Similarly, Ward [4] says "In many ways we have, in the last 10 years, been teaching too much mathematics and been teaching the wrong mathematics. Much of the mathematics taught to engineers and scientists is rarely seen or used again in their future careers. This state of affairs has been 'driven', to a large extent, by the requirements laid down by the engineering institutions in order that engineering programs are suitably accredited. Dare to say that those mathematicians who advise the engineering institutions do not have their finger of the pulse of modern developments in this area? What we wish to focus on is what mathematics we should teach to engineers and scientists, and what electronic aids we should be using to teach that mathematics."

3. Applications and Modeling

The term 'applications and modeling' has been increasingly used to denote many relationships between the real world and mathematics. Using mathematics to solve real world problems is often called applying mathematics, and a real world situation which can be tackled by means of mathematics is called an 'application' of mathematics [9]. The term 'modeling', on the other hand, is the process of representing the behavior of a real system with a mathematical model, or collection of mathematical equations. That means it focuses on the direction from reality to mathematics while application focuses on the opposite direction from mathematics to reality. Engaging students in modeling reinforces mathematical concepts through their connection to real-world applications. Mathematical models also help in the understanding of practical systems, which is why they are so important to engineering. Simulation tools are very appropriate for expanding the range of options for approaches to teaching modeling and applications. They enhance the students' experience of mathematising situations, designing and conducting simulations, and engaging in applied problem solving.

Applications and modeling problems have been an important subject in mathematics education as can be seen from the wealth of literature on the topic [9, 10]. Over the past two decades, high school mathematics curriculum guidelines in Ontario, Canada (Ontario Ministry of Education [11]) have suggested that classroom practices should involve both modeling and applications. The mathematics guidelines issued by the Ontario Ministry of Education present a curriculum that focuses on modeling, the use of technology, communication in mathematics, learning through inquiry, and the use of investigations in which students explore new problems in unfamiliar settings. However, although the curriculum focuses on modeling and applications, the activity of modeling is not as prevalent as one would expect in high school mathematics classrooms. High school teachers often do not have a sufficient understanding of modeling, nor appropriate contexts for modeling problems that are required to facilitate a modeling curriculum. Hence, students arrive in a university engineering setting without sufficient exposure to using mathematics for modeling and applications and often do not recognize the mathematics that they should know within that context.

4. Needs Analysis

Initial steps were taken to determine the interests, abilities and experiences of students who will use the ELR, as well as to gain some students perceptions of initial prototypes. This was done through a focus group of high school students attending a mini-course, as well as a short individual survey of high school students attending an engineering open house.

4.1. Group survey

In designing the first unit of this project, an initial step by the Centre for e-Learning was to conduct a needs analysis through informal interviews with 2 focus groups of high school students (12 students, each) interested in pursuing university studies. The students were attending a 5-day course on electrical engineering offered by the first author at the University of Ottawa in May 2004. The objective of the interviews was to gain insights into the students' strengths and weaknesses and areas of interest for the development of an innovative online resource to aid students in improving their mathematical skills for their first year engineering program.

Students were first given some background information about the engineering program and the objectives of the online learning resource under development. Prior to the interview, the students were supplied with a document on fundamentals of electricity to read. Every student was asked the following questions:

1. What is your favorite subject? What would you like to study at the university?
2. Do you enjoy mathematics? What is your career goal? Why do you think some students have difficulties in mathematics?
3. Are you computer savvy? What do you use the Internet for?

4. What did you like about the document on electricity? What would you like to see more of to improve this document?
5. If you could study engineering or mathematics online, what type of course or activity would you like to see? How would you design the course or the activity?

The majority of students showed interest in pursuing science, mathematics, and engineering. All students responded that they enjoyed mathematics. Some reasons they feel students have difficulties in mathematics include: they do not see how mathematics relates to their career ın general or life as a whole; teachers teach too much theory and not enough hands-on; sometimes students do not pay attention; teachers should give more explanations; some students are lazy; and some students do not like mathematics.

All students said they are very familiar with computers and the Internet and use them daily for playing games and/or chatting and/or for conducting research projects for school. Regarding the document on fundamentals of electricity, the students liked the diagrams because they are related to electrical circuits and the many equations. They found the review and summary very helpful and asked for more examples and activities.

The students stressed the need for an interactive online resource with email quizzes, games and a chat room to discuss equations; clearer diagrams that relate examples to mathematics; and a glossary to explain difficult words. They also suggested that it should be more colorful and asked for problems to be solved step-by-step, especially those related to electric circuits.

4.2. Individual survey

Another group of students was individually surveyed to evaluate the components of the ELR after attending a presentation describing the main features of the resource. Table 1 shows the results of the survey for 54 high school students. As shown in Table 1, more than 50% of students see “math” and “engineering” as a way to solve problems; 40% of the students recognized math as a tool for everyday life, while 53% of the students recognized engineering as a tool for everyday life. Students showed great interest in taking a course with an online component. Also they seemed to be self motivated or need some sort of help to enhance the motivation.

5. ELR Development

With the explosion of the Internet and the desire of many institutions to disseminate courses across the world, many students look to online education with promise [12]. To help address the needs of the many students who are joining or are already at year 1 engineering, the Faculty of Engineering worked with the Faculty of Education to develop the Internet portal Engineering Learning Resource with Essential Math (http://www.site.uottawa.ca/mathasatool). We have developed the first unit of the resource as a pilot project to be followed by other units that cover various fundamental subjects in engineering. This online portal is referred to as ELR and the first unit as the “unit.” The unit is related to the modeling of electric circuit elements. It is comprised of 13 topics. Each topic includes a number of special features designed to make learning easier and to let students explore the subject matter in better depth, if desired. The main features of the unit are listed below:

Table 1. Survey responses for target audience of 54 K-12 students.

We think of math in different ways. Select the two ways that would best describe the way you see math	
A tool for everyday life	40%
A set of rules and procedures	24%
An abstract game	13%
A way to solve problems	54%
A tool for science/engineering	35%
A form of language	9%
A way of explaining the world	20%
We think of engineering in different ways. Select the two ways that would best describe the way you see engineering	
A tool for everyday life	53%
A set of rules and procedures	9%
An abstract game	22%
A way to solve problems	50%
A scientific tool	20%
A form of language	6%
A way of explaining the world	30%
We think of online learning in different ways. Select the item that would best describe your interest in taking a course with online components	
I am very interested in taking a course with an online component	41%
I somewhat interested in taking a course with an online component	48%
I would prefer taking a course that is not online	11%
We think of personal motivation and self-discipline in different ways. Select the item that would best describe your personal motivation and self-discipline	
I feel proud that I can motivate to achieve my goals	56%
I sometimes need the help of my friends or other people to encourage me	40%
I often need guidance/supervision to achieve my goals	4%

5.1. Topics selection and preparation

In typical university teaching, a large emphasis is placed on the fundamental theory, with a number of applications to stimulate the theory. Therefore, the guiding principle in designing the topics of the unit was to introduce the basic theory of electrical engineering and the realization of basic modeling with many practical examples so that the students have an understanding of concepts they need throughout their engineering studies. The complete list of topics covered in the unit is as follows:

- Charge and Coulomb's law
- Electric current
- Voltage
- Resistance
- Ohm's law
- Power and energy
- Elements of electric circuits
- Kirchhoff's laws

- Series circuits
- Parallel circuits
- Analysis of combination circuits
- Capacitance
- Inductance.

Pedagogical processes are arranged in two major directions: modeling of electric circuit elements and problem solving. To accomplish the process of modeling, all related rules of physics are presented and mathematical formulations are identified and explained. To promote problem solving, the usual pedagogical processes are followed: defining the problem; finding possible solutions, evaluating the solutions and implementation.

The authors found that the process of developing the content far exceeded the time required for developing a traditional university course. As preparation time can be a serious obstacle to creating quality online material, the authors recommend that faculty and/or online course developers ensure that they have set aside enough time for the process.

5.2. Focus on math

Each section of the unit includes "boxes" titled "Focus on Math." The content of these boxes, which are set aside from the main text summarize significant mathematical techniques and procedures for the modeling of common electric circuit elements. They usually consist of gradually-built instructions, and are written in a systematic way of solving problems. The unit includes the following "Focus on Math" boxes:

- Linear and nonlinear systems
- Scalar and vector
- Derivative and integration
- Numbers and signs
- Percent
- Graphing a linear equation
- Slope
- Numerical expressions
- Function
- Fraction
- Voltage-current relationships for the capacitor
- Voltage-current relationships for the inductor.

5.3. Learning resources

The unit provides several resources and professional development activities which are designed to give learners and teachers technical competence in implementing modeling activities. The following is a list of the resources:

- System of units.
- Brief profile of early history of electrical engineering.
- Practical applications of electrical circuits.
- Analogy between a water pipe and a resistor in an electric circuit.
- Categories of electrical quantities.
- Standard color code system and Ohm's law chart.
- Summary of main electrical concepts.
- End-of-unit problems and multiple choice questions.

5.4. Technology considerations

Some of the technical options considered for the ELR included HTML only; HTML synchronized with audio; and flash animations. HTML with audio and animation results in presentations that can be streamed over slow Internet connections yet remain quite attractive.

Providing an Internet-based learning resource must have a means of two-way communication. Current options available for such interaction include e-mail and newsgroups although many other modes of interactivity are possible. Large screen slides are used to effectively convey written and graph presentations. Figure 1 shows a screen shot of the ELR front page.

5.5. Testing the ELR

Six electrical engineering students have individually tested and evaluated the design methodology of the ELR on November 2004. Table 2 shows the summary of feedback written and oral comments obtained from testing the ELR. Students were asked to rate eight qualities including: clarity of learning objects; presentation of content; visual presentation; tables and diagrams; level of interest and satisfaction; ability to use the ELR; the most interesting part of the ELR; and parts that need improvement.

Table 2. Summary of feedback from written and oral comments obtained from testing the ELR.

Subject	**Summary of Comments**
Overall experience	favorable, students were able to complete tasks successfully and demonstrated interest in returning to the site.
Functionality	From a functionality standpoint, the students found it easy to complete the tasks and navigate smoothly. However, some students with less experience preferred to have explicit instructions on site navigation.
Look and feel	Students found the ELR to be visually appealing (simple, professional) and felt it added value to helping 1^{st} year students bridge the gap between math, science, and engineering. However, they would have preferred more interactive elements to further engage the users.

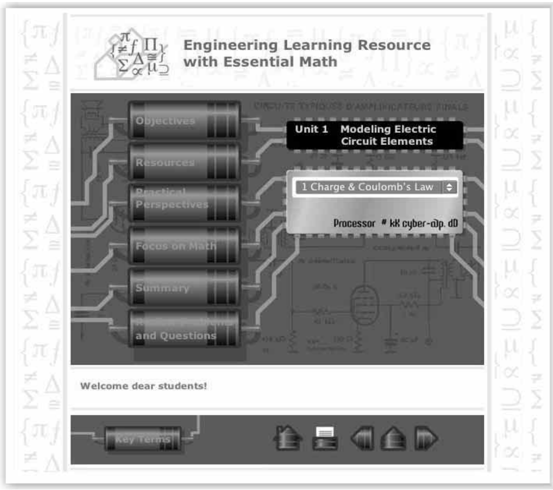

Figure 1. Screen shot of the resource front page.

The overall impression was favorable. Students were able to complete tasks successfully and demonstrated interest in returning to the site. From a functionality standpoint, the students found it easy to complete the tasks and navigate smoothly. However, some students with less experience preferred to have explicit instructions on site navigation. Students found the site to be visually appealing (simple, professional) and felt it added value to helping users bridge the gap between math, science and engineering. However, they would have preferred more interactive elements to further engage the users.

6. Tools for Modeling

Modeling of electric circuit elements requires mathematical tools to develop equations that represent the elements or circuits. Throughout the 13 topics of the unit, we highlight the following mathematical subjects for their importance in electrical engineering:

6.1. Linear algebraic equations

We emphasize simple matrix algebra and the definition of a determinant. Quite often, students struggle when confronted with different notations used in algebraic equations. Often, they had memorized algorithms that relied on one form of notation. Thus, throughout the resource we strive for students to understand the structure of the equations rather than memorizing the notation. This means encouraging deep rather than surface learning.

6.2. Scalar and vectors

We introduce vectors and their applications to the real world. The students should be able to differentiate scalar quantities from vector quantities. In the resource, we provided a list of scalar and vector quantities which the student will encounter throughout his/her study. For instance, force as a physical quantity in engineering could be a good example of a vector. One can consider the problem of calculating the force relative to two charges in a space. This problem may be easily visualized and students can recall their own experience in static electricity.

6.3. Calculus

Fundamental to calculus are derivatives, integrals, and limits. Based on our experience, students are not confident in the concept of derivative or integration. In the first unit of the resource, we provide basic information about integrals and derivatives. The process starts with rates of change, definition of derivative, and its use with simple functions. It is followed by applications of integrals. Finally, students can formulate problems in terms of integral and derivative with practical examples such as those of capacitors and inductors.

6.4. Ordinary differential equations

Differential equations seem to be a stumbling block for many students. They are used to construct models of various physical phenomena. Physicists and engineers are interested in how to compute solutions to differential equations. These solutions are usually used to solve various engineering problems. In the second unit of the resource we will classify ordinary differential equations: order; linear/nonlinear; constant coefficient.

7. Discussion

In spite of criticism of formal lectures [13] they still remain the main teaching method used in teaching mathematics in university. However, formal lectures alone are not particularly effective in teaching either mathematics or engineering for several reasons. Mathematics courses are built in such a way that if a student misses a key concept at the beginning of the lecture, the rest of the lecture can be lost for him or her. Besides, every student has his or her own pace of acquiring knowledge. The pace of the lecture can be too slow for some students and too quick for others. Also, formal lectures can deprive students from using their own initiative and sense of inquiry, encouraging surface or fragmented learning rather than deep or holistic learning. One way of overcoming many of these problems is to engage students in motivating learning activities and to use formal lectures as merely one component in a variety of teaching methods. These methods could include independent study and reading, small group learning and teaching, modeling investigations, and formative assessment. However, the use of the above methods for teaching mathematics to engineering students is currently rather limited in practice [14].

Additionally, many of the problems in teaching mathematics to engineering undergraduates could be overcome through more prevalent use of mathematical modeling and applications at various educational levels. Although modeling, as generally viewed by the mathematics education community [10], has been a central theme in the Ontario mathematics curricula, not all teachers have adopted modeling techniques in their teaching. For modeling to become a focal point of the curriculum, there is a need for a significant shift in teachers' views of mathematics. Teacher education and professional development programs should include an orientation to applications and modeling in order to ensure that teachers will acquire modeling competencies and be able to teach modeling effectively. We would argue that the adoption of modeling as a central theme requires activities that allow teachers to personally experience modeling in new content domains. The ELR provides meaningful mathematics in context, is designed to accompany other pedagogical forms, focus on modeling, and takes into account the needs of the target audience.

Figure 2 shows a typical approach for the development of an online learning resource along with the details used at each step of development of the ELR. This learning resource is a supplementary reference for high school students in transition to engineering schools. We have recognized the specific needs of the audience through surveying focus groups of high school students. The surveys were very beneficial in making the resource development decisions.

The ELR could also be particularly essential for a large population of K-12 home schooled students. According to Farris [15]; “While home-schooled students do outperform the average students, they are weak in math”. One reason for the weaker math skills is that parents of these high school students often feel inadequate to teach the high school math and science [16]. We see future opportunities to utilize the ELR as a main curriculum for on-campus training sessions offered for students in the above transition. It may also serve traditional university professional activities through continuing education and/or distance learning programs.

The use of this learning resource for prospective and beginning engineering students provides an alternative way to address the challenges in teaching meaningful engineering with substantial mathematics. The ELR can provide engaging contexts and problems and complements a traditional lecture. Figure 3 shows approaches for the use of the resource as a supplement to engineering courses or as reference for a self study or a training session.

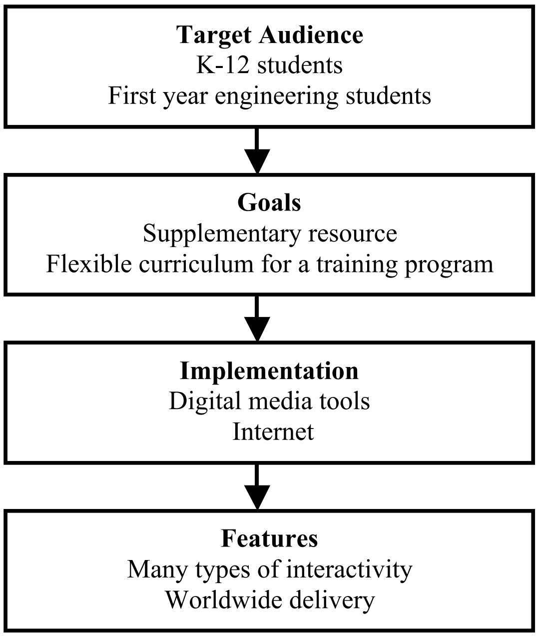

Figure 2. Development procedure of the resource.

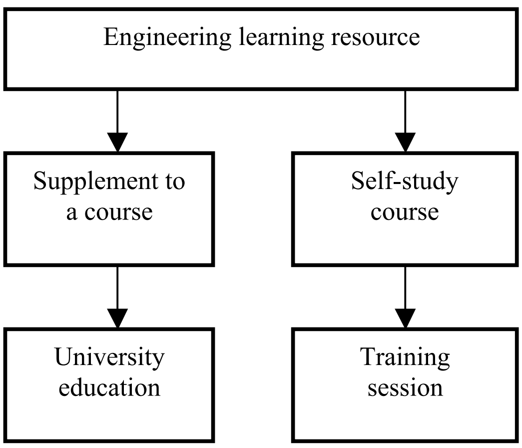

Figure 3. Two approaches for the use of the resource.

8. Conclusion

In recognition of the need to enhance mathematics learning, an online foundation/bridging resource has been developed at the University of Ottawa in Canada. We expect that this resource would serve as a tool to give students a level of mathematical sophistication and knowledge expected of them as they begin their engineering studies. We may say that this project represents the marriage of two major disciplines. The Faculty of Engineering brings concepts and physical laws, hands-on technology and engineering project expertise while the Faculty of Education brings its knowledge of teaching elementary and high school algebra and calculus, as well as its understanding of sound pedagogical practices. The result is a learning resource that helps smooth the transition for high school students moving to engineering education.

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