AC 2011-2537: ENHANCE ENGINEERING COLLEGE MATH TEACHING WITH GAMING AND VIRTUAL REALITY LEARNING MODULES

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Abstract

Traditional math teaching is insufficient in grasping students’ attention\(^1\). As a result, students are losing interest in learning mathematics and their performance is below that of students in other industrialized nations\(^2\). Surveys demonstrate that many engineering students feel math is boring and they don’t see the connection between mathematics and real life engineering problems. To address these issues, revamping college math teaching and incorporating modern technology into the classroom become crucial.

This paper presents a project that is currently conducted at Prairie View A&M University (PVAMU), which, through pilot math class teaching, proved to be efficient in increasing student engagement and supporting teachers’ instructional needs. The key strategy of the project is to develop innovative math learning modules and use them to enhance students’ performance. By applying cutting-edge computer graphics and virtual reality technologies, these modules can: (1) make mathematics learning interesting while still retaining the underlying contents; (2) make abstract and non-intuitive mathematics concepts “visible” and “touchable”, and thereby, easy to understand; and (3) bridge mathematics and engineering and motivate students to pursue engineering careers.

The goal of the project is to ensure that students, especially freshmen and sophomores, can benefit from the instructional strategies and develop a solid math foundation for their science and engineering careers. A summary of courses impacted, samples of the math learning modules, and student feedback are discussed.

Background

Mathematics serves as the foundation of all STEM (Science, Technology, Engineering, and Mathematics) programs. However, the weak mathematical knowledge base and prolonged preparation for mathematics readiness force many STEM students to either drop out or turn away from their STEM tracks. Many students have to repeat some of the required mathematics courses several times in order to pass them, especially for those admitted with relatively low SAT scores. This has serious and negative impact on the enrollment in the STEM programs and hurts the overall graduation rate. The problem is even worse at HBCUs (Historically Black College and University)\(^3,4\).

Students living in the digital age are visual and active learners to whom traditional mathematics teaching seems boring due to the lack of multiple ways to represent information using interactive text, images, sound and video to engage a broad range of learners. Survey results reveal that “math is boring” and “math is difficult” top the reasons of students’ losing interest in mathematics\(^5,6\). Studies also show that an important reason of STEM students losing interest in mathematics is that they don’t see the connection between mathematics and real science and engineering problems\(^7,8\). 81% interviewed students would like to know how mathematics is applied in music, sports, video, and engineering applications\(^6\). Therefore, how to effectively
engage students and how to easily deliver mathematical concepts become the key to address the issues.

To bridge mathematics teaching and engineering applications, the College of Engineering at PVAMU developed three engineering lab courses aligned with respective math courses (i.e. Lab I for College Algebra and Trigonometry, Lab II for Calculus I, and Lab III for Calculus II) to enable students to gain hands-on experience, deepen their understanding of math concepts, and improve their course performance. In synergy to these efforts, the authors, collaborated with mathematics department faculty, are exploring the uses of gaming and virtual reality technologies, developing new math learning modules, and investigating novel teaching methodologies to enhance student math learning.

**Goal and Objectives**

The overarching goal of the project is to create engaging math learning modules using gaming and virtual reality technologies, through which we can improve students’ performance in mathematics and make them well prepared for advanced science and engineering courses.

The specific objectives of the project include:
1. Develop game-like virtual environment and learning modules to bridge mathematics and engineering
2. Revamp engineering curricula; explore new approaches to make mathematics learning attractive while still retaining the underlying contents
3. Improve the delivery of laboratories and lectures, make abstract and non-intuitive mathematics concepts “visible”, “touchable”, and thereby, easy to understand
4. Increase STEM students’ math course passing rate
5. Foster students’ interest in mathematics, promote active learning, and motivate them to stay in STEM programs

To achieve the goal and objectives, the project consists of innovative technologies that enhance mathematics and engineering connection, simplify and speed up the process of complicated concepts delivery, as well as encourage critical thinking.

**Virtual Lab and Teaching Module Innovations**

1. **Gaming and Virtual Reality Learning Platform**

To help students in mathematics courses, researchers from higher education have invented a variety of approaches to facilitate students in study mathematics concepts and principles. For example, Wright State University introduced a freshman-level engineering lab course based on MATLAB\textsuperscript{9,10}. Taught by engineering instructors, the lab can show students how mathematic concepts are applied in fundamental engineering topics. Other educators also developed different software tools to enhance math learning\textsuperscript{11}. Based on our experience, however, most of these tools are still lack of ways in information representation, especially in making the learning environment fun and attractive.
The scholars at Prairie View A&M University started a project two years ago to renovate the mathematics curriculum. In our scheme, we develop an entertaining teaching environment using gaming and virtual reality technologies to stimulate student interests and enhance their learning effectiveness. By converting abstract concepts into vivid animation and providing game-like interactivities, the teaching environment possesses the unique features\textsuperscript{12,13,14} that traditional classroom teaching does not have: \textit{first}, it helps learners understand complex and non-intuitive subjects. Students often have difficulty in comprehending abstract concepts and multidimensional phenomena. Mastery of these concepts requires students to build mental models that incorporate invisible factors\textsuperscript{15,16}. The virtual learning system uses graphics and animation technologies to simulate dynamic physical phenomena and display intangible information, which make abstract concepts easier to understand. \textit{Second}, it enhances the learning by making the learning experience fun while still retaining the underlying content. Virtual reality teaching and learning environment is engaging and interactive. Students today have rich experiences with videogames. They can grasp and memorize the knowledge essence quickly when they are actively involved in playing and problem solving procedures. \textit{Finally}, it provides a better learning environment for those students who have difficulty in learning from the traditional classroom instruction.

In the first stage of the project, we developed both 2D and 3D learning modules using Vizard, a software tools with powerful graphic and multimedia functions. A virtual classroom created by Vizard is shown as in Figure 1. Through pilots teaching and students’ surveys, we have seen very promising results\textsuperscript{8}. Many students became to feel excited in mathematics learning. It truly encouraged us to put more efforts along this direction. Meanwhile, during the study, we also found that 3D modules typically are more effective in deepening student understanding by providing different view angles and showing object change. Therefore, in the second stage of the project, we focus on developing 3D modules to depict more intricate math concepts. To speed the courseware developing, we adopted 3DIVA Virtools software which provides a development platform for quickly constructing virtual classroom and creating 3D virtual reality applications.

\section{Learning Module Development}

All our learning modules are created based on real life or engineering problems. Generally, each module consists of two components: (a) lecturing/tutoring; (b) exercise and quiz. The lecturing/tutoring part is implemented as a virtual scene, in which the math topic is illustrated or animated in 3D graphics. Audio is integrated to emulate tutor explanation. Students can interact with the objects in the virtual world to observe and learn the mathematics/engineering concepts.
just like the way of game playing. The exercises and quiz are designed in similar ways for students to practice and verify their understanding. According to different course levels, we categorized the modules for College Algebra and Trigonometry, Calculus I, and Calculus II. Scenarios of two learning modules for explaining trigonometric functions and quadratic functions are as follows:

Scenario 1: Measuring the height of a water tower. Climbing to the top of the tower and using a long tape measure to find the height is risky. Instead, we can use alternative approaches, either the characteristics of similar triangles or angle measurement of protractors, to accomplish this task. For example, the second approach can be depicted mathematically as a trigonometric problem (shown in Figure 2).

![Figure 2. Math equivalence of one approach for water tower measuring](image)

To measure the height of water tower (denoted as $y$), first we need to find a field that is flat and we can see the top of the water tower; it should also give us some distance to walk through (spot A and spot B); $x$ denotes the distance from B to the base of the tower spot C; and $l$ is the distance between A and B. Although $x$ is long to measure, we can measure $l$, $\theta_1$, $\theta_2$ using a normal tape measure and a protractor, respectively. Following the related math theory, we can find the $y$ by solving the two trigonometric function based equations.

$$\tan \theta_1 = \frac{y}{x}, \quad \tan \theta_2 = \frac{y}{l + x}$$

To help students understand the questions, we designed a “water tower height and trigonometric function” learning module. In our virtual world, students first see the 3D scene consisting of the tower, a park chair, some trees, and two students. First, the tutorial presents the engineering question to students; then the math theory and the approach to be used to accomplish this engineering task are addressed. After that, the system animates the procedures of solving the problem in 3D space. Finally, students will be allowed to navigate in the 3D space and solve randomly popped out questions related to the question.

By clicking different “view” buttons, the software allows student to watch the tower from different angles to simulate what they feel in real world. Meanwhile, students may adjust the parameters for different A, B spots and the height of the tower to see the changes of $\theta_1$ and $\theta_2$. The module will prompt student to follow the tutorials to calculate the height and give students instant feedback. The snapshots of the module are depicted in Figure 3 and 4.
Scenario 2: A human cannonball is launched with an initial velocity $v$ m/s at an angle $\theta$, find the distance and height the cannonball can travel. Mathematically, we can solve the problem by finding the cannonball’s vertical and horizontal initial speeds and calculating the distances based on two different equations (depicted in Figure 5).

\[ v_x = v \cdot \cos \theta \quad \text{and} \quad v_y = v \cdot \sin \theta \]

During the travel of the cannonball, at any time $t$, his height can be calculated by

\[ \text{height} = g \cdot t^2 + v \cdot t \cdot \sin(\theta) \]

And the horizontal distance he travels can be calculated with the following equation:

\[ \text{distance} = v \cdot t \cdot \cos(\theta) \]
Accordingly, we designed a “Motion of human cannonball and projectile” learning module. In our virtual world, students first see a circus scene consisting of a cannon, three elephants, and two students. First, the tutorial presents the engineering question to students; then how to use the $v$ and $\theta$ to find the horizontal and vertical velocities, and how to acceleration rate/gravity ($g$) to calculate the values are explained. After that, the system animates the procedures of solving the problem in 3D space. Finally, students will be allowed to navigate in the 3D space and solve randomly popped out questions related to the question. Similarly, by clicking different “view” buttons, the software enables student to watch from different angles. Meanwhile, students may adjust the parameters for different $v$ and $\theta$. The module will prompt student to follow the tutorials to calculate the height/distance and give students instant feedback. As the cannon ball travels, students may pause the ball at any time to verify their calculation results. Some snapshots of the module are depicted in Figure 6.

![Figure 6. Virtual lecture and exercise](image)

Compared to traditional physical and engineering labs, virtual labs and learning modules are handy and cost effective. Many limitations of conducting physical labs, such as room and equipment arrangement, scheduling, weather and safety issues can be avoided. Through the Internet, students can do labs and study by themselves at any time and at anywhere. The learning modules, once developed, can be easily adapted and reused for many semesters. The system can also be expanded to include functionalities for class stats generation. More importantly, with a virtual environment, we can simulate complicated phenomena which, unpractical to conduct in real world though, can truly broaden students’ knowledge base and attract them into STEM disciples. Therefore, we can provide students with extensive learning opportunities besides traditional teaching.

**Ongoing Project at PVAMU and Implementation**

We are following three steps to achieve the project goals and objectives:

**Phase 1**: Establish the proposed 3D game-like learning environment and develop math modules/labs for college mathematics level I - College Algebra and Trigonometry and test them in targeted courses (i.e. math and engineering lab). To fully utilize the modules and engage students in class activities, we will also revamp the course materials. More interactive exercises and quizzes will be defined in formats that can stimulate students’ interests and assist collaboration (e.g. Jeopardy Game). Pilot student surveys will be conducted.
Phase 2: Develop more courses modules for college mathematics level II- Calculus I and Calculus II, and test them in targeted courses. At the same, we will refine the math modules based on the student’ feedback and enrich the functions of existing math modules. We are currently at this stage! So far, surveys conducted showed that more than 90% of students and faculty feel excited about this learning style, and about 80% students believe the modules can enhance their math learning. Compare to the traditional labs, some learning modules even receive more positive feedback.

Phase 3: System expansion, evaluation, and outreach. At this stage, we will broadly adopt more math topics and develop related learning and training modules to reinforce STEM education. The project discovery and results will be presented to college and university levels. Outreach activities will be used to disseminate project outcomes to neighbor schools and community.

During the proceeding of the project, formative and summative evaluation will be implemented. We will collect and compare course assessment data before and after applying the educational innovation to show the differences in teaching effectiveness. These data serve as the objective evaluation of the project results. We will also administer student survey for subjective feedback on each targeted course to see the improvement in student learning and class engagement.

Conclusions

To summarize this ongoing project, we are developing new math learning modules and labs using 3D gaming and virtual reality technologies to engage students and enhance their learning effectiveness. With these learning modules, abstract and difficult mathematics concepts can be smoothly connected with engineering problems. It makes the math learning attractive and easy to understand. A phased implementation plan is followed to ensure the attainment of the project goals. Upon the completion of the project, we expect to have the following outcomes: (1) the virtual reality learning environment and modules are applied to a number of mathematics and engineering courses. The teaching/learning pedagogy is deposited into the current courses and curricula; (2) math teaching and learning effectiveness is strengthened. Students gain more experience in engineering applications and have better understanding in breadth and depth of the targeted courses; (3) Students’ motivation and passing rate in mathematics courses are increased. More students are attractive to STEM programs.

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Bibliography


