Teaching of Math and Physics Using a Flight Simulator

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Abstract- The challenges associated with the learning of Math and Science by K-12 students are well documented in literature. A multi-modal learning environment that includes active learning can be an effective approach to addressing challenges such as interest and proficiency. This paper presents an active-learning approach to the teaching and learning of Mathematics and Science concepts for 9-12 grades using commercial off-the-shelf (COTS) flight simulation software and hardware. Several modules have been developed which include detailed lesson plans and student activities supported by specially designed scenario-based flights. Students use the flight parameter data to determine answers to scenario-based questions, thus providing a link between Math and Science concepts taught in the class and a 'real-life' situation. The lesson plans were developed with input from the local school district teachers where the approach is planned for implementation during the 2012-2013 academic year. Eight undergraduate students from Aerospace Engineering, Mathematics, and Psychology at Tuskegee University assisted in preparing these modules. The preparation of these modules provided experience to the undergraduate students in working in interdisciplinary teams. These students also assisted the project team during the workshops and mentored the high school students. Teachers' responses to the approach have been positive as assessed through surveys during summer workshops in which the approach was introduced. A statistically significant positive attitude to the approach was registered in the pre-post surveys administered to the high school students who participated in a summer experience. The work is funded by the NSF ITEST grant.

Keywords: K-12, Math and Science, Flight Simulator, Lesson Plans

INTRODUCTION

The challenges associated with the learning of Math and Science by K-12 students are well documented in literature, see for example [1-3]. The performance of K-12 students in Math and Science in the United States continues to lag behind other industrialized nations. In fact, according to the 2009 report by the Program for International Student Assessment, out of the 34 countries of the Organization for Economic and Cultural Development OECD), the US has fallen to 18th position in Math and 13th position in Science achievement of 15-year olds [4]. According to the 2010 National Academies report *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5*:

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"So where does America stand relative to its position of five years ago when the Gathering Storm report was prepared? The unanimous view of the committee members participating in the preparation of this report is that our nation's outlook has worsened [5]".

The 2010 report by the Council of Advisors on Science and Technology [6] to President Obama identified another alarming characteristic of the K-12 students. It noted that the challenge to math and science achievement was not only proficiency but also lack of interest. In order to address these challenges, extensive research has been conducted on enhancing proficiency and interest of students in Science, Technology, Engineering, and Mathematics (STEM). Studies have shown consistently that an environment in which students are passive participants is less conducive to learning than an environment in which students are actively engaged. Techniques such as cooperative learning, collaborative learning, experiential learning, problem-based learning and active learning have been extensively researched. While the results of these various pedagogies vary, in general, their effect on student learning has been demonstrated to be positive in comparison to traditional lecturing, see for example [7-11].

The National Science Foundation has developed several programs including the Innovative Technology Experiences for Students and Teachers (ITEST) program under which this work is funded (NSF Grant # DRL 0929609) to support innovative approaches to enhance the STEM learning of K-12 students. This paper explains an approach to active learning that can be implemented with relative ease in the classroom to teach certain math and science concepts. The approach incorporates active, experiential learning, teaching of math and science concepts, and learning with innovative technologies.

Currently available PC-based low cost flight simulation software that incorporates accurate physics-based modeling is an attractive medium to teach and learn math and science concepts. The use of this medium in the classroom was chosen due to several reasons. First, the excitement that is generated by flying an airplane can overcome the challenge of lack of interest in course material. Second, the low cost of fielding the pedagogy makes it an economical approach. Third, unlike being just another hands-on activity, the flight simulation environment puts into perspective the real life usage of math and science students. And finally, as pointed out at the outset, the simulation models are fairly accurate physics-based models. Thus learning modules leveraging these attributes of a flight simulation environment are expected to address both proficiency and interest.

OBJECTIVES

The objectives of this project are to:
(a) Enhance the proficiency of high school students in Math and Science
(b) Explain the connection between Math/Science with real life
(c) Increase the interest of high school students in Science, Technology, Engineering and Mathematics (STEM)
(d) Expose high school students to productivity software such as Microsoft Excel

The project also has the objectives of providing experience to undergraduate students in working in a multi-disciplinary environment and service learning through working with high school students.

This paper provides details on the development of the pedagogical approach. Response of high school teachers and students of the local school district to this approach after experiencing it during workshops is also reported.

APPROACH

The approach primarily is to develop scenario-based flight-integrated lessons such that the students fly a specific mission, collect data, analyze the data and compare these results with their answers from similar paper and pencil exercises. Once developed, these lessons should be easily implementable in the class room.

The project team presented this concept to the teachers of the local high schools. This was followed by discussion with the teachers and review of the Math and Science components of the Alabama Course of Study to identify concepts that could be taught using the approach. This involvement of the teachers from the very beginning of the development process ensured an element of ownership of the product being developed, and heightened their interest in taking the teacher summer workshops. The project team was assisted by a group of undergraduate students from the Aerospace Science Engineering, Mathematics and Psychology Departments.

The project plans included development of the lesson plans and software modules for installation on stand-alone single PCs. Development of a large out-of-the-window (otw) visual environment for deployment at the two local high schools is also included in the plan. Such a visual experience increases the realism of the simulation. The 'large otw' visual setup consists of three PCs driving three LCD projectors for the out-of-the window views, while a fourth PC is the master and drives the instrument panel. Figure 1 shows the three out–of-window views, with the instrument panel displayed on the fourth PC screen.

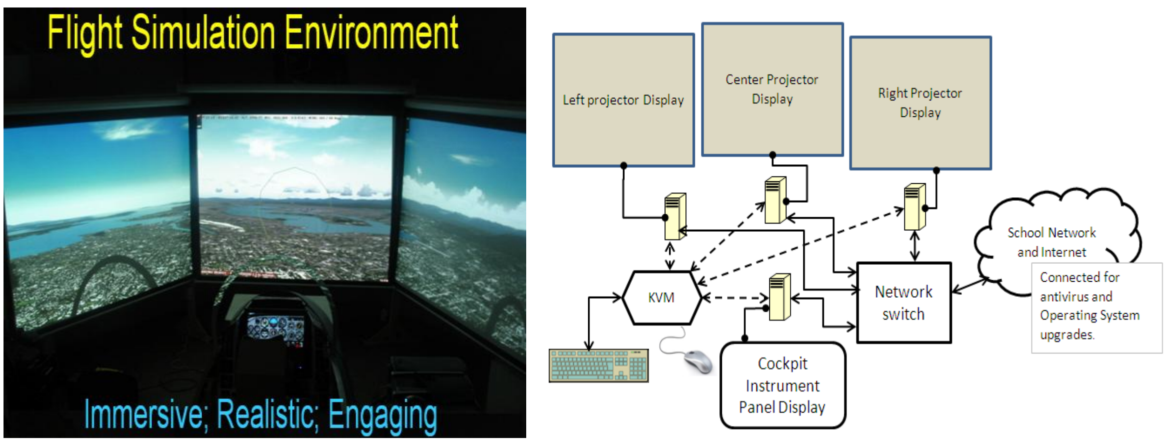

Figure 1: Flight Simulation Environment

The four PCs are connected through a high speed Ethernet switch. The large simulator is equipped with a yoke, throttle quadrant and rudder pedals. A keyboard-video-mouse (KVM) switch is used to transfer control between the four PCS to a single keyboard and mouse. The stand-alone PC-based system is equipped with a joystick having an integrated throttle. Microsoft FSX flight simulation software was chosen for developing the lessons. A shareware software was used to record flight data. Flight data collected included flight parameters such as altitude, heading, and bank angle which were recorded every second of flight.

The hardware setup was also carried out by the undergraduate students under the direction of project faculty. This included the design and fabrication of the large screens and projectors setup and hardware/software configuration of the PCs. The students and faculty developed a conceptual design of the setup, determined dimensions for projector placement based on the available rear-projection screen and determined a fabrication mechanism that facilitated a quick assembly/disassembly of the setup.

To collect data suitable for performing mathematical calculations addressed in the lessons, the missions need to be flown with considerable accuracy. This requires a certain level of expertise in flying a simulator. Because such proficiency is beyond the scope of a mathematics or physics class, it cannot be developed as part of the learning objectives. The 'mission' supporting the learning objectives therefore needed to be such that students with little experience could fly it and collect useful data. This required placement of appropriate constraints on the flight model. The various canned lesson in MSFSX e.g. straight and level flight, turning flight, landing flight were appropriately modified by undergraduate students of the Aerospace Science Engineering Department under the direction of the project faculty to conform to the planned missions. For instance, a level turn flight was modified by activating the autopilot to maintain wings level attitude, altitude and heading and allow only throttle manipulations. Five modules with the learning objectives of slopes/rates, circle, vectors, potential/kinetic energy, similar triangles have been developed.

The flight data is recorded during the simulator flight by the flight data recorder and is saved to a text file. This format does not lend itself to easy manipulation in context of the learning objectives of the lessons. The data is therefore imported into an Excel sheet and the students can export the needed parameters, e.g., altitude and speed, to an Excel workbook by a single button macro and typing in the parameters.

The undergraduate Aerospace Science Engineering students assisted in the development of the Excel macros. The Math students assisted in the development of practice problems supporting the concepts to be taught under the Alabama Course of Study objectives, while the Psychology students supported the development of assessment instruments such as attitude questionnaires and workshop evaluations. The Psychology students also assisted with data entry for subsequent analysis. Members of all three disciplines attended lab meetings to discuss the project to facilitate interdisciplinary exposure and learning.

Summer Workshops

The developed lesson plans were pilot tested in a 3-day summer workshop in 2010 with local high school Math (4) and Science (5) teachers (9 females, 1 male) as participants. This workshop provided valuable input into the effectiveness of the modules as well as the training needed for the teachers to successfully implement the approach in the classroom. The approach was also pilot-tested in 2010 with a group of African-American high school seniors (N = 16) who were on campus for another summer program. The refined lesson plans and additional modules were the subject of a 4-day summer workshop for teachers (8 females, 1 male) in 2011. Most of the teachers were the same as the previous summer who had requested additional practice in developing their own lesson plans and to increase their expertise with the flight simulation software. A group of African-American students (11 females, 9 males) from the local high schools were also provided a 3-day experience utilizing the approach in 2011. This group of high school students was different from the previous year. The undergraduate students assisted in the conduct of the workshops by providing hands-on help to the participants to become proficient in flying basic maneuvers on the flight simulator, in collecting data from the flights, etc.

The objectives of the summer workshops for teachers were to determine the teachers' responses to the approach, relevance of the flight simulator based hands-on activity, and ease of implementing the lessons in their classrooms. The workshops consisted of the following topics:

(a) Physics of Flight or How Aircraft Fly
(b) Introduction to Flight instruments and Controls (yoke/joystick and throttle)
(c) Hands-on Practice on Flying the Simulator
(d) Primer on Excel
(e) Demonstration of Teaching of Specific Math/Physics Concepts Supported by Flight Missions on the Simulator

At the end of the workshop the teachers had the opportunity to work in groups to develop appropriate lesson plans based on a given flight scenario. Teachers' attitudes towards the teaching of Math and Science were surveyed through slightly modified versions of the Science Teaching Efficacy Belief Instrument [12] and Mathematics Teaching Efficacy Belief Instruments [13]. These instruments assess self efficacy and outcome expectancy based on responses on a 5-point Likert scale (5-Stongly, 4-Agree, 3-Neutral, 2-Disagree, 1-Strongly Disagree). The modified survey instruments included ten questions to determine teachers' attitudes towards the implementation and effectiveness of technology in supporting learning in the class room. The pre-workshop responses of the participating teachers in the 2010 workshop are shown in Fig. 2. The positive responses of the participants indicated their support for technology-based pedagogies in general.

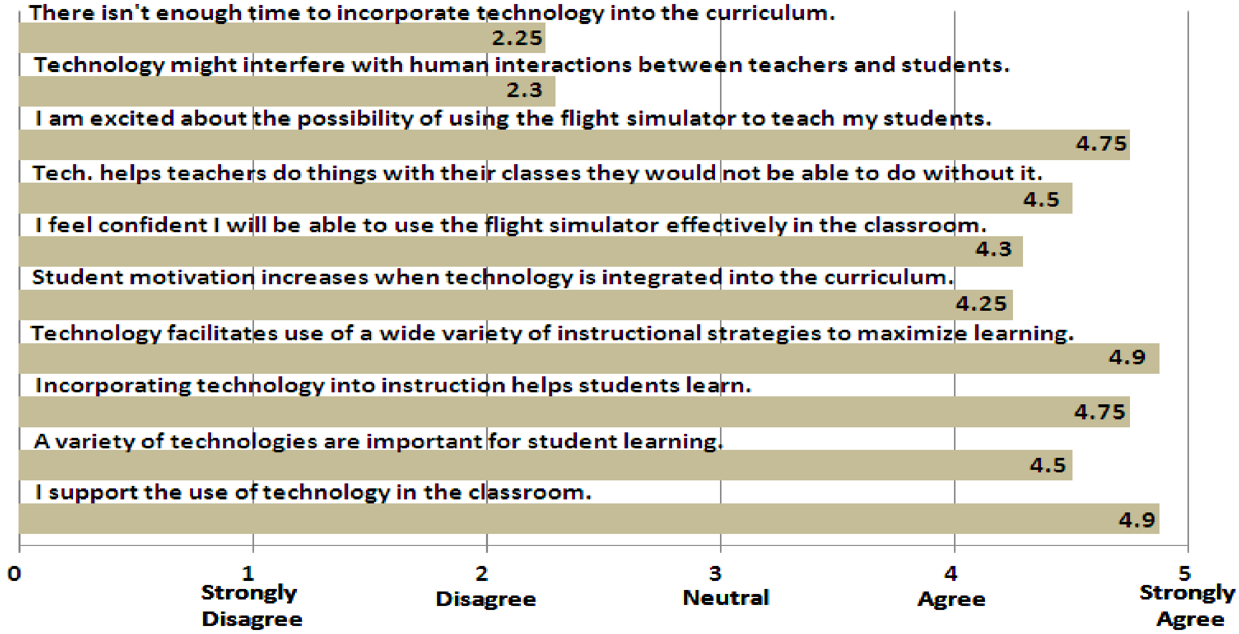

Figure 2: Teachers' Responses to Implementation and Effectiveness of Technology

A 5-point Likert scale post-workshop survey of the teachers indicated that contents of the lessons plans developed as part of the project were aligned with the Alabama Course of Study (4.67) and that the lesson modules are organized for implementation (4.33) in the classroom. They were also of the opinion that the flight simulation environment is useful for teaching the connection between science and mathematics and will excite the students (both 4.67).

Attitudes towards science and math of the students participating in the summer 2011 activity were surveyed using the instrument of Ref. 14. However no statistically significant change was observed in the pre-post responses of the participants. Given that many of the students were excited to participate prior to the program, and their attitude after the workshop remained high, the lack of an attitudinal change in a positive direction is not indicative of the program's limitations, but rather, its potential. The students were also asked their opinion on the use of the flight simulator based Math and Science lessons/activity. A statistically significant positive change (on a 5-point Likert scale, 5-being strongly agree and 1-being strongly disagree) was observed (pre-test mean = 3.88, post-test mean = 4.48, $p < 0.05$) indicating the usefulness of the approach.

CONCLUSION

The use of a flight simulation environment is being explored as a pedagogical technique to increase the interest of high school students and enhance their learning of Math and Science. For this purpose, commercial off-the-shelf hardware and software has been used to develop the environment and lesson plans. An interdisciplinary team of faculty and undergraduate students worked on the project; as a result, the undergraduate students experienced an interdisciplinary research project and were exposed to developing and validation of lesson plans. The students also were exposed to practical applications of Math and Science concepts while working on the project. The workshop data suggest that the Math and Science teachers consider this approach as a viable and effective pedagogy to improve student learning. The teachers also validated that the lesson plans were aligned with the State standards.

According to the teachers, the developed lesson plans would be effective in teaching the concepts. Students participating in the summer experience indicated the approach to be enjoyable and effective.

The flight simulator (hardware and software) and the lesson plans will be deployed in the local high schools during the 2012-2013 academic year. The objective is that the teachers who have been trained during the summer workshops will implement the pedagogical approach in their class room. The performance of the students will be tracked to assess the effectiveness of this approach in improving their Math and Science skills.

The lessons plans and details of the approach will be made available on a website dedicated for this purpose. The ITEST Learning Resource Center (www.itestlrc.edc.org) will have appropriate project information and link to the dedicated project website.

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EXAMPLE LESSON PLAN

Radius, Diameter and Circumference of a Circle
(Used with Level Turn Flight)

Lesson Plan
Subject: Math
Title: Radius, Diameter and Circumference of a Circle
Grade: Grade 10-12
Goal: Students apply and enhance their understanding of mathematics concepts related to a circle by participating in this active learning using a flight simulator.
Objectives: Students will be able to solve problems of radius, diameter, circumference and area of a circle.
Alabama Course of Study Objectives
Students will learn how to:

- Change a verbal description to an algebraic expression and solve the equation.
- Identify the given and required quantities, and what is the unknown in the word problem.
- Use the circumference and/or the area of a circle to solve the given problem.

Additional STEM Learning Objectives

- Understand and use the connection between mathematics and other disciplines.
- Understand and use the concepts of latitude and longitude.
- Use graphs in excel to interpret and understand the results obtained.
- Understand any differences between the results obtained from their calculations and the output from the flight simulator.
- Understand how engineers and other scientists may resolve such differences.

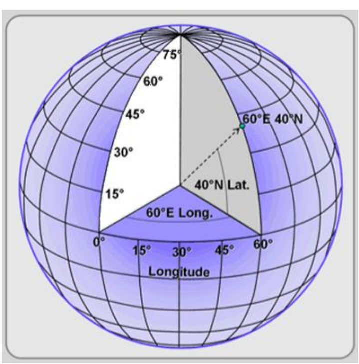
Materials
PC, joystick, MSFSX, Eszett Flight Data Recorder, Excel
Flight Simulator software/hardware
Microsoft Excel
Time: 80 minutes
Lesson Plan
Mathematical Concepts for a Circle

Engage
Discuss various examples where it is needed to determine circumference, radius and areas of a circle. An example is the athletic race track where athletes are positioned at different starting locations depending on their track for races of say 400m, 800m etc.
Explain
Explain a circle, radius, diameter, area and circumference of a circle.
Explain the relationships between these characteristics of a circle.
Provide solved examples of determining the unknown when the other is given.
Evaluate
Reinforce the concepts by asking the students to solve several problems using these concepts.
Extend
Use the flight simulator activity to reinforce these concepts and form connections between theory and real life use.
Hands-on Activity with the Flight Simulator
Tell the students that they will fly a level 360^o turn on the flight simulator. But first they need to calculate the radius of turn and then compare their calculation with what they get from flying the plane.
The parameters the students will need are bank angle $\Phi = 20^o$, speed V = 100 knots (where 1 knot = 1.69 feet/sec), the acceleration due to gravity $g = 32.2$ ft/sec^2, and the relationship between radius of turn and these parameters:

$$R = \frac{V^2}{g\sqrt{n^2 - 1}}$$ where n = 1/Cos Φ

Ask the students to explain the effect of increasing the bank angle on the radius of turn.

The students will then fly the level turn, record the data, extract the data to an Excel sheet, plot the data and determine the radius of turn. Since the position data recorded is in latitude and longitude, explain the concept of latitude and longitude to the students.



Latitude and Longitude of a Point on Earth
Once the students' flight simulator activity is completed, explain the use of Excel in transforming lat/long data into feet.

Distance in feet =ACOS(COS(RADIANS(90- current latitude)) *COS(RADIANS(90-latitude of touchdown)) +SIN(RADIANS(90- current latitude)) *SIN(RADIANS(90- latitude of touchdown)) *COS(RADIANS(longitude-longitude of touchdown))) *3959*1760*3

In this conversion the radius of Earth is 3959 miles.

The practically obtained radius will be compared with the theoretically calculated value. Ask the students to determine the error and elicit the possible reasons for the error.
Level Turn on the Flight Simulator:

You are flying a Cessna 172 and coming in for landing at Montgomery Regional Airport. As you get close to the airport you are informed by the Air Traffic Control (ATC) that you are not cleared for landing. You are instructed to wait by flying a holding pattern that consists of a level 360 degree turn. This means that that you will be flying a circular path without losing altitude.

Your aircraft is flying at a speed of 100 knots and at an altitude of 3000 feet. You execute the 360^o turn with a 20^o bank angle.

Using the relation:

$R = \dfrac{V^2}{g\sqrt{n^2 - 1}}$ where R = radius of the turn; V = speed (in feet/sec), g = 32.2 ft/sec^2, n = 1/cosΦ, Φ = bank angle

Determine the radius of turn, the circular distance the aircraft will travel during the 360^0 turn and the area of the circular turn.

Now you will fly this scenario in the flight simulator. Your aircraft is flying at a speed of 100 knots and at an altitude of 3000 feet. The first part of this flight is a short tutorial on how to fly a level turn. Please listen and watch carefully. When the message appears that you are now flying, press the 'record' button of the flight data recorder and execute a 20^0 turn to the 'right'. Note that when you started the turn you were flying 'E' (the east direction) as shown on the heading indicator. You will complete the turn when your airplane points to the east again. Bring the wings level a few degrees before you reach 'E" so that you don't overshoot.

Press 'stop recording' button on the flight data recorder. Press 'Esc' and 'End flight'.
Save the data to a txt file e.g. LevelTurn-1
Export the data to Excel using Data Extract.xls. You will be extract 3-columns. Extract the timestamp, latitude and longitude columns to an Excel sheet say LevelTurn-1.xls.
Open LevelTurn-1.xls
Change latitude & longitude to feet using the relation:
Distance in feet =ACOS(COS(RADIANS(90- current latitude)) *COS(RADIANS(90-latitude of touchdown)) +SIN(RADIANS(90- current latitude)) *SIN(RADIANS(90- latitude of touchdown)) *COS(RADIANS(longitude-longitude of touchdown))) *3959*1760*3

Plot the data.

Determine the radius from the flight data. How well does this radius compare to the theoretical radius that you calculated using the formula? Determine the error between the two values.

Can you give possible reasons as to why the two answers are different?

Will the radius of turn increase or decrease if the bank angle is increased to 30^o?

Why don't you fly a 360^o level turn with a bank of 30^o to practically see what happens when the bank angle is increased from 20^o to 30^o?

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