121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #8929

Teaching Vectors To Engineering Students Through an Interactive Vector Based Game

Dr. James G. O'Brien, Wentworth Institute of Technology

James G. O'Brien is an assistant professor of Physics and Mathematics at WIT. His field of expertise is gravitation and cosmology, and has published numerous papers on alternative formulations of gravity. He is a strong advocate of project based learning in physics and mathematics, and is always trying to engage students in new and exciting ways to bring physics alive in the classroom and laboratory.

Dr. Gergely Sirokman, Wentworth Institute of Technology

Teaching Vectors to Engineering Students through an Interactive Vector Based Game

Abstract

In recent years, science and particularly physics education has been furthered by the use of project based interactive learning.[1] There is a tremendous amount of evidence[2] that use of these techniques in a college learning environment leads to a deeper appreciation and understanding of fundamental concepts. Since vectors are the basis for any advancement in physics and engineering courses the cornerstone of any physics regimen is a concrete and comprehensive introduction to vectors. Here, we introduce a new turn based vector game that we have developed to help supplement traditional vector learning practices, which allows students to be creative, work together as a team, and accomplish a goal through the understanding of basic vector concepts.

Keywords

First-Year Undergraduate, Vectors, Physics Education, Laboratory Instruction, Interactive Learning, Physics Pedagogy

Introduction

At the heart of any physics education is the study of vectors. Typically in a given STEM curriculum, it is an objective of the first year physics courses to provide a sound understanding of vectors that will carry the student through future science, engineering and computer science courses. In recent years, studies have shown the positive effects of using project based interactive learning to allow students the ability to use not only their learned knowledge, but also infuse creativity and exploration into the topic at hand.[3] As an educator, one must also consider the current state of mind of the modern student. Students today are extremely tech savvy, and a majority of students enjoy game based activities in their spare time. With all of this in mind, it was the goal of the authors to create a new type of experience to allow students to master the basics of vector manipulation in a fun, creative and competitive gaming environment.

In most entry level physics courses, students are first introduced to basic vector manipulation, and then are lead through a series of problems to help deepen and broaden the knowledge presented in class. In some cases, simple laboratory exercises are then used to further reinforce the concepts. A common exercise would be a map, where vectors can be drawn, combined and manipulated using meter sticks and protractors. Some institutions have branched out and made use of vector type scavenger hunts to further engage the student.[4] At WIT, we have the advantage that laboratory sections are restricted to 16 students maximum, so small groups and group activities are easily implemented. Also, with the authors being avid gamers themselves, the opportunity to teach vectors on a virtual space battlefield was seized.

The students who were enrolled in the courses which offered this exercise, were various engineering majors, applied math majors as well as computer science majors. Given the audience, the main learning outcomes of the vector game/lab were to:

1. Demonstrate the ability to add and subtract vectors
2. Decompose vectors into component notation
3. Write vectors in magnitude and direction notation.
4. Increase student engagement about learning vectors.

It should also be noted that it was also the intent of this exercise to overlap with other concepts encountered early in a physics course, such as estimation and user defined coordinate systems. The rules of the game and gameplay are all included in the supplementary documentation. Below we provide a brief overview of the vector game setup, assessment of students, data collected from our first implementation of the lab and future work to be done on the game. It is the hope of the authors that other instructors will see the potential in such a learning tool, as well as provide feedback to improve the student experience.

Experimental Overview

This exercise was run in a two-hour lab session. The laboratory exercise was preceded by a brief introduction of the game mechanics in a lecture session. Students were given the rules of the game before hand, as included in the supplementary documentation, and were expected to come to lab sufficiently prepared such that they would be able to play two fifty minute games in the allotted time. Students were broken off into groups of three, and team members then each chose positions for their crew. The positions included a helmsman to record and plan movement, a tactical officer to record and track enemy movements as well as missile fire, and a captain who was responsible for declaring actions as well as keeping the team on a time schedule.

Experimental Procedures

Lab tables were arranged so that a game board consisting of two tables would be flanked by two work areas of one table each, prior to students arriving in lab. Once present, students assembled their teams and took position on opposite ends of the game board in the work areas, and obtained a small plastic ship attached to a small circular (360°) protractor. Students then agreed on a coordinate system which was then drawn onto the table with dry erase markers. All measurements in the exercise were made with respect to this agreed upon coordinate system. Ships were then placed on the table no less than 50 cm apart from one another, at rest, and the games commenced. The teams proceed simultaneously plotting and executing actions. In each turn teams had 4 minutes to perform their actions, which were broken into two phases, movement and attack. Each team could assign their ship a thrust, which had to be declared as the magnitude and direction of a thrust vector. After each team had written down their thrust, the thrusts were revealed, and each team moved their respective ship according to the total resultant movement vector. It was the duty of each team to check the other team's move to be sure that all movements made were legitimate and correct, though instructors were checking as well. After the teams completed their simultaneous movement, missiles could be fired according to the rules (see supporting documents)[6] and were fired independently of the motion of the ship. After firing missiles, the turn was over, and in the next turn the phases repeated. The game concluded when either one ship was destroyed by enemy firepower, or moved off the game board. A game could end in a draw if the time limit expired and no clear victor had been determined.

General Discussion

The physics lesson of vector manipulation kicked in by turn two of the game/lab. Since the ships moved on thrust per turn alone, when the ships moved in the second turn (and later), students had to account for the fact that the ship was drifting from its previous turns' thrust. Thus, the resulting motion in the second turn was the addition of the new thrust vector plus the pervious thrust vector. In later turns the movement was the sum of the current and all previous thrust vectors. Often this came as both a surprise and an 'Aha!' moment for the students. It should be noted that there are advanced rules in the game (see supporting documents)[6] that allow for more vectors to be tallied by each team.

Initial Reaction from students to a game atmosphere in a graded laboratory was mixed. In general students had a rough idea of how to do basic vector manipulation before coming to class, but even if they had read the rules beforehand, the games always started out slowly. Students took more time than needed to discuss initial moves. Similarly, after the first set of moves there was hesitation because the students had to face the fact that every subsequent thrust generates a resultant movement vector composed of all previous thrusts for the following move. Usually by turn three or four students had developed confidence, and turns began to move more quickly. Usually by the completion of four turns, teams were working together efficiently, and more competent team members had coached the confused members to a point where they were caught up with the concepts. Games in general lasted about eight to ten turns, and by the end of the first game, a majority of the students had a solid handle of the rules of the game, and were in the competitive spirit. The second round of games tended to move more smoothly, and students could be seen testing strategies rather than just learning the vector math. Some groups stayed late just to observe other games being played, or to play third games with other teams.

In general we try to run laboratory sections at WIT as a group based and engaging exercise. For this game/laboratory, we noticed an extremely high level of interaction between students, not only within their own groups, but between groups as well. The game atmosphere seemed to disguise the lesson from the point of view of the student. The competitive component placed a personal responsibility and personal sense of accountability on each team member, which helped internalize the lesson. It was evident that instead of the usual attitude of students during a laboratory exercise: "Let's take our data and we can figure it out later at home," students were more open to "on the fly learning" driven by the desire for a team win. In the authors' experience, this laboratory exercise was one of the few where students who were clearly the passive member of the group at the start of the lab, observe, learn and implement the lessons, by later completely taking over the coordination of the group's efforts in a second or third game.

Data on Learning Outcomes

In order to try and measure the effectiveness of this lab at meeting the desired learning outcomes listed above, data was collected across a sample of about 200 students. About 100 of them played the vector game/lab. A similar sized control group of students did not play the vector game, but instead performed a laboratory exercise of drawing multiple vectors on a map. We assessed the absorption of the material using a quiz, given online, on vector manipulation before and after each of the laboratory exercises.[5] The results of these tests were not surprising. For the control group, the overall scores of the quiz on vector manipulation remained relatively constant both before and after the map exercise. Scores showed a slight increase, but for the majority remained steady. However, students in the groups that played the vector game showed a significant improvement in scores after their lab experience. As a whole, over the sample of the group playing the vector game/lab the student average increased by about twelve percentage points when normalized to a Gaussian as compared to a four percentage point increase for the control group. The standard deviation also decreased for the game/lab group by a small margin, which showed us that the information was not only being better retained, but also was being delivered to a greater number of students.

In order to assess the level of engagement of the students, we monitored the time spent on the actual exercise as well as participation from group members. In the control group of the map exercise, groups tended to rush through the work, and usually one group member dominated the actual computation portion of the work while others passively waited for completion. On the average, groups in the map laboratory were done in less than one hour. For the game laboratory, several interesting observations were made. First, groups that did not finish a game on time asked for more time, showing that there was interest in completion. Also, every group and group member remained for the entire two-hour lab session, and many stayed after class to play a third game against other victors using some advanced rules. On the average, we saw a rise in active participation time more than double, to an average of 125 minutes (with students staying after lab) of lab time in the game/lab versus an average completion time of 56 minutes in the standard vector map assignment.

In order to assess individual contribution to the group project, simple observations were made based on the materials handed in at the completion of the exercises. For the control map group, to further re-iterate the previous observation that most of the work was dominated by a single student, groups would turn in their total completed work, which for 90 percent was a singular hand in, with only one hand writing in all sections. In the lab/game exercise, 90 percent of the work handed in contained some form of work from EACH group member, with only a small fraction of groups handing in work in a singular handwriting.

A more generalized observation was that students were clearly actively engaged, getting up, walking around the "battlefield", estimating and making assessments of a dynamic situation. Similarly, many groups actively swapped roles within their team. In one extreme case, a student who before the game started was open with their group about how they "did not even know what a vector meant", by the end of the two hour lab, lead the group to a victory over an opposing team with some very strong students on it.

Based on these observations, we believe the learning outcomes were achieved with high success. We also believe based on these observations that one of the major goals of the lab/game exercise was fulfilled in creating an engaging atmosphere for students outside of traditional learning techniques. As the lab/game exercise is now in its second generation and proper research policy regarding human subjects has begun to be observed, a more student-by-student statistical analysis will be done in order to address individual learning assessments.

Future Work and Follow Up

Our work on this vector game is still in its early stages. Several avenues for growth of this game/lab as an interdisciplinary project exist. A computerized version of the game would allow for rapid testing of modification to the rules, and could potentially be used for instructors to rapidly check student calculations during games. In designing this project, the authors have had to constantly create a balance of playability of the game versus deliverability of the lab objectives. To this end, students from the Computer Science department at WIT have been recruited to code a virtual version of the game.

Perhaps a more interesting and unique collaboration has recently manifested, involving senior industrial design (ID) students on the project. WIT has a long-standing tradition of being a leader in innovation in the field of industrial design. In an exciting collaboration between the Science and ID departments, fifteen students in a senior studio class will observe and analyze the design elements of the game-lab, and spend numerous hours re-thinking and re-shaping the tactile layout of the game in order to make the game more engaging. These students will not only be learning themselves, but will be enhancing the education of future Wentworth students. At the current stage of the project, the senior ID students have participated in a live observation of engineering students playing the game, and a voluntary debriefing occurred with both winners and losers of the lab/game exercise. This debriefing was to collect feedback from actual student users to further the senior design students' efforts into game layout and design. In addition, the collected feedback can be used by the instructors to tweak the rules so that the learning objectives can be completed to the highest degree of efficiency in the constraints of a fun and playable game. It is the authors' hope that a follow up to this work will include a workshop on the lab/game itself, presenting a complete package refined by data gathered over the course of recent and upcoming instruction.

Conclusion

As the world around all of us changes, so too does the college learning environment. A key element of an evolving higher education program is for the faculty to grow and adapt by discovering new and exciting ways to engage and hence better educate the student. We believe that the use of this game-lab exercise makes students become more engaged in an otherwise cut and dry topic in physics. To promote maximum potential for learning, future work on fine-tuning the game parameters, as well as design elements for better aesthetics are already in the works.

References

[1] David R. Sokoloff, Ronald K. Thornton and Priscilla W. Laws, "RealTime Physics: Active Learning Labs Transforming the Introductory Laboratory," *Eur. J. of Phys.*, **28** (2007), S83-S94

[2] Ronald K. Thornton and David R. Sokoloff, "Assessing Student Learning of Newton's Laws: The *Force and Motion Conceptual Evaluation* and the Evaluation of Active Learning Laboratory and Lecture Curricula," *American Journal of Physics* **66**, 338-352 (1998).

[3] David R. Sokoloff and Ronald K. Thornton, "Using Interactive Lecture Demonstrations to Create an Active Learning Environment, "*The Physics Teacher* **35:** 6, 340 (1997).

[4] See for example, UCONN Physics Olympiad, 2008 Physics Competition

[5] Due to IRB guidelines at WIT, we cannot publish individual statistical results of the data collection until completion of this game lab sequence in the spring and summer semester of 2014.

[6] Supporting documents for this paper can be found at: myweb.wit.edu/sirokmang/vector.html