OPEN SOURCE SOFTWARE IN TEACHING PHYSICS: A CASE STUDY ON VECTOR ALGEBRA AND VISUAL REPRESENTATIONS

Erdat CATALOGLU, Ph.D.
Physics Education, Faculty of Education
Abant Izzet Baysal University
erdat@ibu.edu.tr

ABSTRACT

This study aims to report the effort on teaching vector algebra using free open source software (FOSS). Recent studies showed that students have difficulties in learning basic physics concepts. Constructivist learning theories suggest the use of visual and hands-on activities in learning. We will report on the software used for this purpose. The effect of FOSS on students understanding of vector algebra was determined by a non-equivalent control group design. A total number of 113 freshman students from two classes of introductory level physics courses were involved. The experimental group's students learning processes were supplemented by instruction utilizing FOSS while the control group was taught in traditional manner. A significant difference in students' performance was found that could be attributed to the treatment. Consequently, visualization of vector and related concepts by FOSS simulations helped students to understand them well and contributed to shorten the time needed to learn these concepts.

1. INTRODUCTION

Teaching and learning is a complex process which is being studied intensively. Important studies regarding human learning effects learning theories especially those related to school learning. Learning models based on are now being scrutinized. Many problems have been identified with traditional teaching approaches which was based behaviorism. In traditional teaching, the teacher is the authority and the students are passive learners. This type of structure favors the world view of "one type correct" answers even to complex problems (e.g. Environment & pollution), and has an elitist approach towards students. While some students are able to perform and solve complex problems in physics they fail to apply basic knowledge in novel situations (Driver et al., 1994).

Recent theories focusing on the nature of learning promote the constructivist theory. This theory arose out of Piaget's works in developmental psychology. Briefly constructivism regards the learning processes as a continuous construction and reconstructions of concepts. Throughout these procedures the students are actively involved in their own learning processes. Students are put into a situation where an engaging environment is being created by stimulating, challenging, and provoking the interest of the students. Teaching strategies should be structured in such a way that the students are active participants and the teachers act more as a guide rather then the all knower. Constructivist teaching and learning theories emphasize that teaching should be build around open ended problems where students are allowed to explore different paths to reach desired conclusions. Another important factor to consider is that learning takes place in social environments. Therefore, peer interaction is viewed as an essential component in cognitive development (i.e., learning) Feltovich et al. (1996).

Accordingly, contemporary learning theories in education, emphasize the need to provide the learners with a variety of learning opportunities. These environments should also include the possibility of peer interaction and collaboration opportunities.

2. RATIONALE

Reaching a meaningful understanding of Vectors is essential to be able to learn the concepts presented in physics, algebra and geometry. In physics, vectors are defined as physical quantities that have both magnitude and associated direction to it. Displacement, velocity, acceleration, force, momentum, and impulse are all examples of vectorial quantities. Unlike scalar quantities such as temperature, mass, time, energy, power, and work, the mathematical manipulation of vectors is somewhat more complicated. For a typical introductory mechanics course the topics to be studied include areas such as kinematics, dynamics and Newton's Law of motion, work and energy, impulse and momentum, and rotational motion. In order to reach a sound understanding of the concepts presented in these topics a basic understanding of vector algebra is also needed.

Online tutorials and aids can help the students foster their understanding of vector mathematics by providing immediate feedback in a structured environment. Rothney, Roselli and Howard (2003) developed "Courseware Authoring and Packaging Environment" software (CAPE) that supplied diagnostic correction mechanisms that identified common student errors. This tool also provided specific feedbacks based on the type of mistake encountered for a biomechanics course. This study aims to develop a teaching model that extends traditional teaching by making use of a series of additional tools to help the students understand the concepts of vector algebra for introductory mechanics. Visualization was a key factor while deciding on theses tools. Interactivity was another important factor. Finally we also opt for tools that would be available to the students in class hours as well as out of class. This way we also opted to provide the opportunity for the students to work outside of class with their peers. However, we did not mandate the collaboration outside of class.

For this study we utilized non-commercial software for obvious reasons. We wanted to build an additional learning tool for our students besides what they have been already using. As it is in many introductory physics classes, students use books and to some extend calculators depending on the level of physics being taught. Besides these tools, the students have nothing else, especially outside of class hours, to help them aid their learning process of vector mathematics. Students' misconceptions in vectors can hinder their ability to advance in successive topics in mechanics because the concepts presented in kinematics, dynamics, momentum & impulse, and rotational motion all depend on a sound understanding of vector algebra. The software used were Octave & goOctave.cgi, Java applets, GNU plot, putty, ssh & bash and apache web server all running on a Linux operating system. A somewhat extended explanation will follow on Octave, GNU plot and the java applets whereas a discussion on the later software (i.e., apache, ssh, bash etc) will be omitted since we believe they are all well know. More information about Octave follows as it relates to vector algebra.

2.1. Octave

Octave is a powerful mathematics tool, in some references it also defined and known as a high-level language. It uses the command line interface (CLI) as its main source of interaction. It is a tool especially designed to manipulate matrices. The tool can be used to accomplish numerical computations as well. MatLab, for example, would be a commercial equivalent of Octave, in fact, the description in its LSM entry reads ``GNU Matlab--A numerical matrix mathematics program.''

Initially Octave was designed in educational settings. The goal was to construct Octave as a pedagogical instrument to help to teach better chemical reactor and problems related to this subject. The first version was released in 1994 and since then has been undergone numerous revisions. The authors "wanted to create something that would enable students to solve realistic problems, and that they could use for many things other than chemical reactor design problems". Octave is now included with Debian GNU/Linux and SuSE Linux distributions, Redhat Package Management (RPM) binaries for RedHat and Fedora distribution are also available. Hence octave seems to have accomplished a major success. "Today, thousands of people worldwide are using Octave in teaching, research, and commercial applications" (http://www.octave.org/history.html)

Information regarding how to use Octave can be easily located at their website. They do provide an exhaustive manual on how to use this tool. A WIKI website provides additional help topics ranging from how to do simple compiling and installation issues to complex scripting and advanced batch programming. Finally, as mentioned previously, Octave is similar to Matlab. Because of this similarity, tutorial's regarding Matlab are also to a great extend valid for Octave. Especially those that use the CLI as the main input and manipulation interface.

2.2. goOctave.cgi

The goOctave.cgi script is a code written by Mai Zhou (http://www.ms.uky.edu/~statweb/testOctave.html). The script lets the students interface with Octave over the web through a simple html form. By means of such an interface, the students have direct access to Octave any time out of class. Students can run examples and experiment with the examples from anywhere provided they have web access. Another major advantage of employing this script is to have the tool ready for teaching without the need for complex and tedious setups. Finally, having the tool up on the web provides students who do not own a computer with octave

The goOctave.cgi script provides the students with a form where they are allowed to type in the equations. The result is being rendered on the same webpage. Moreover, goOctave.cgi can render also graphs if desired. The graphs are produced in png format and rendered as such on the webpage. The students can save these rendered graphs on their local hard drives and if needed import them to their favorite word processor. goOctave.cgi script had some limitations which were easily overcome. The authors made some coding modifications to meet our needs. For example, the script could not run in multiple-user mode. The code was modify so that it could render graphs while simultaneous other users were working on the webpage. Additionally all descriptions were translated into native language, i.e., Turkish. The webpage can be accessed through the following URL: http://per.ibu.edu.tr/cgi-bin/goOctave.cgi.

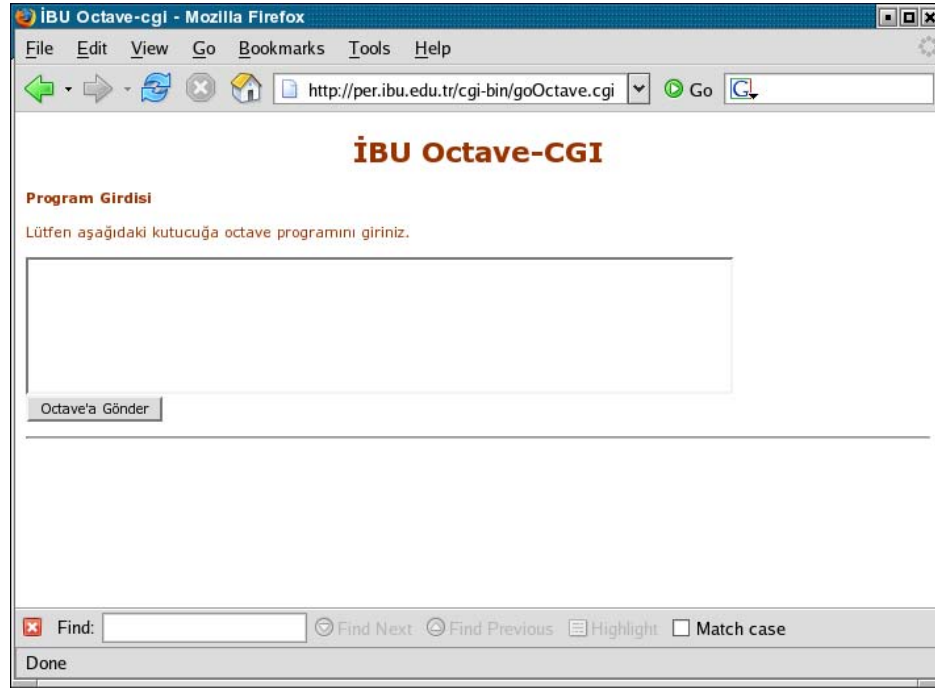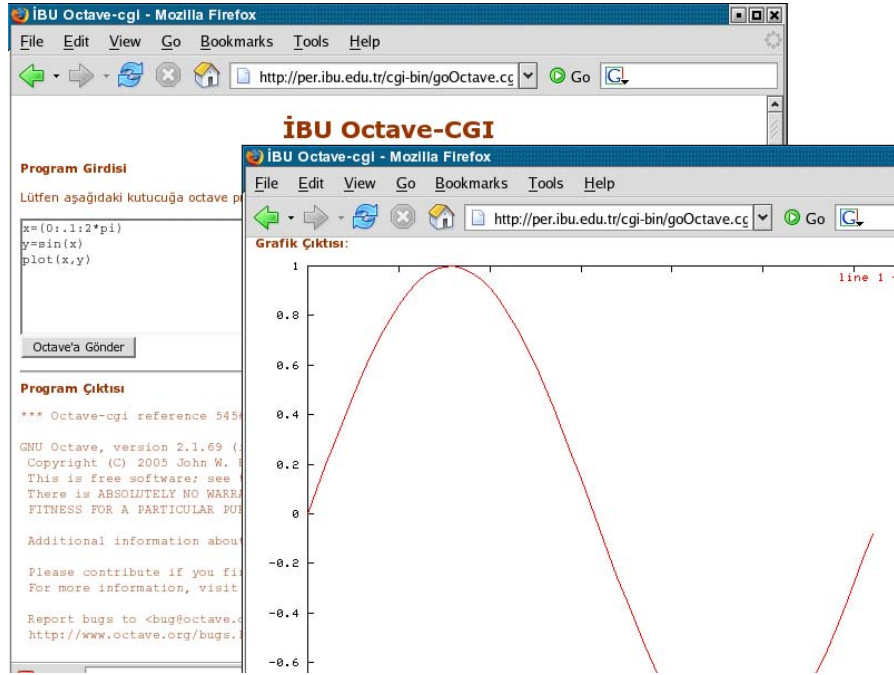**Figure 1. Modified Web Interface of goOctave.cgi**

Figure 2. Web Interface: Sample Output

2.3. Example on Basic Vector Algebra and Octave

Since vectors can be expressed as column matrix Octave is an ideal candidate for basic vector algebra.
Vectors are simple to enter into Octave. To input a one dimensional vector one needs to type in the following text

    a = [0,3;0,0]

for the above example **a** is a vector parallel to the x-axis that is 3 units in length

    b = [0,0;4,0]

here, b is a vector parallel to the y-axis that is 4 units in length
Now adding these two vectors is a simple task. One only needs to type in the following expression:

    c= a + b

In order to compute the magnitude of the new vector c, one has to type the following expression:

    d= mag(c)

here, "mag" stands for magnitude which is a slightly modified function of trace; a build in function of Octave.
For the above example, Octave returns the magnitude of the vector addition i.e., the resultant vector as:

      d = 5

2.4. Java Applets

Java applets provide powerful visualization aids especially in physics education. Since the Java technology has emerged, many applets have been created for physics instruction. These applets range from simple cases to complex modeling of physical phenomena. For example a very complex modeling example real time 3D physics simulator applet can be located at http://www.ambromley.co.uk/fizz.html.

    Regarding the numerous benefits Java Applets can bring into a physics classroom and its relative easiness to employ lead to many applets available for physics instruction. Physlets resource pages (http://webphysics.davidson.edu/Applets/Applets.html) is one such example. Many interactive examples ranging from introductory level physics to quantum mechanics can be found at this resource.

Figure 3. Vector Applet
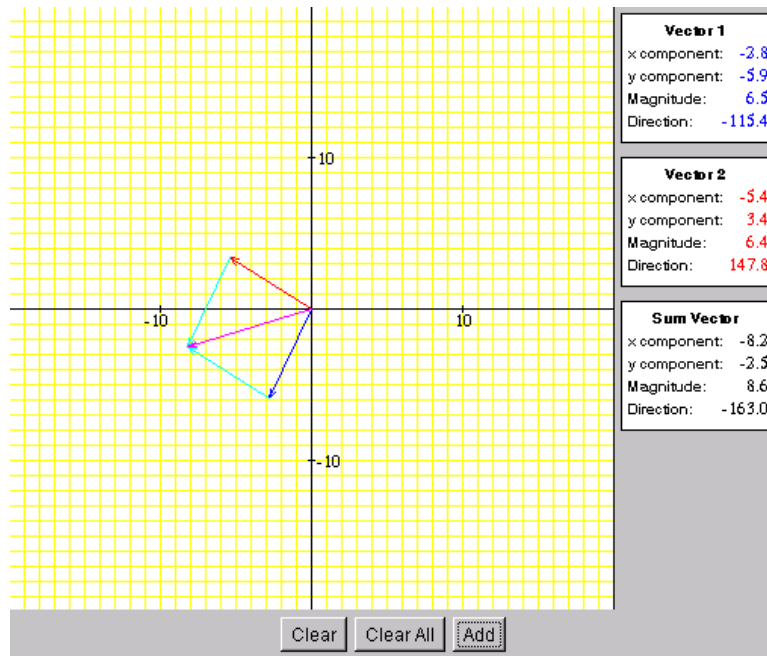
3. METHOD
The study took place during the Summer School of 2005 at Abant Izzet Baysal University. A total of 113 students were divided into two groups (experimental & control group) participated in the study. (# of students in experimental group 55; # of students in control group 58) General Physics 1 is a one semester long mandatory freshmen-level introductory mechanics course with three 50 minutes lectures per week and no laboratory work. Most of the students took the course for the first time (68%) while some of the students took the course for the second or more times. The number of female students (female=62) was slightly more then the number of male students (male=51).

3.a INSTRUMENTS
Two instruments were utilized in study to collect data. The first one was a vectors test that consisted of five open-ended question. This test was administered at the beginning of the unit of vectors as a pre-test. The same test was administered as a posttest at the end of the kinematics unit. The questions asked the students to do basic vector calculation which they are expected to encounter on a regular basis in the forthcoming topics. The first question asked the students to add two given vectors **A** and **B**. The second question asked the students to find the components (i.ei, R_x and R_y) of a given vector **R**. The third question asked the students to compute the magnitude of a two dimensional vector. The fourth and fifth questions asked the students to perform a dot product and cross product respectively of two vectors $A_x+A_y+A_z$ and $B_x+B_y+B_z$. To ensure the reliability of the test, they were graded by two instructors independently. The reliability of test-retest coefficient for the vector test was found to be 0.85, indicating a relatively high internal consistence of the scores. In addition, to the vector algebra test, an open ended 5 items questionnaire was administered to the experimental group after the instruction regarding their experience and perceived benefits in using FOSS.

The experimental group received a handout detailing on how to use the web interface, java applet, and how to use CLI by login into to server where octave was installed (ssh through putty were used to login to the server). Additionally, office hours were provided for students who needed further assistance.

4. DATA ANALYSIS AND RESULTS
The data for this study were the pre-and posttest scores of the 113 freshmen students including gender. The data were analyzed by using SPSS statistical package. Data analysis and results for this study were reported in two

subsections. The first subsection provided an initial descriptive analysis reporting on the overall mean scores, mean score distributions with respect to treatment, and female male score distributions. The second part reports on a univariate analysis by comparing the posttest mean score as the dependent variable, posttest scores as covariate, and treatment as the fixed factor.

Table 1. Summary of Pre-and Posttest Data results with respect to gender

Group	Gender		Pretest	Posttest
Experimental	Female	N	31	31
		Mean	17.74	31.45
		Std. Dev.	12.17	10.89
	Male	N	24	24
		Mean	15.42	33.54
		Std. Dev.	11.41	10.78
	Total	N	55	55
		Mean	16.73	32.36
		Std. Dev.	11.79	10.79
Control	Female	N	31	31
		Mean	14.35	24.68
		Std. Dev.	11.24	10.32
	Male	N	27	27
		Mean	21.67	30.93
		Std. Dev.	10.92	11.44
	Total	N	58	58
		Mean	17.76	27.59
		Std. Dev.	11.59	11.21
Cumulative	Female	N	62	62
		Mean	16.05	28.06
		Std. Dev.	11.74	11.06
	Male	N	51	51
		Mean	18.73	32.16
		Std. Dev.	11.48	11.10
	Total	N	113	113
		Mean	17.26	29.91
		Std. Dev.	11.65	11.22

The descriptive analysis revealed that the control group pretest mean score ($x_{control}$ = 17.76) was about one point higher than the experimental group mean score ($x_{experimental}$ = 16.73). When analyzed with respect to gender the control group mean scores for both female and male students were substantially higher than the experimental group female and male mean scores. However, after treatment we observed the overall mean score difference in favor of the experimental group. The same positive trend was observed for gender as well. Another interesting point was that the female scores before treatment of the experimental group were higher than those of the male students.

Table 2. ANOVA source table of posttest scores by treatment

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	11171.027	2	5585.513	209.832	.000
Intercept	8564.394	1	8564.394	321.740	.000
Pretest	10526.708	1	10526.708	395.459	.000

Treatment	895.125	1	895.125	33.627	.000
Error	2928.088	110	26.619		
Total	115200.000	113			
Corrected Total	14099.115	112			

a R Squared = .792 (Adjusted R Squared = .789)

Table 2 shows the results of the analyses of covariance (ANCOVA) on the dependent variable which was the posttest scores and the covariate which were the prettest scores, in this analyses the independent variable is treatment. This result showed that there was a statistically significant difference between posttest scores of students in experimental group and control group i.e., treatment. For our case, it can be argued that, utilizing Octave -Free Open Source Software in teaching vector algebra is more effective than traditional teaching method. In addition, to the vector algebra test, an open ended questionnaire was administered to the experimental group after the instruction. The questionnaire questions and common answer given by students is provided in Table 3.

Table 3. Questionnaire and Answers

Question	*Common Answers*
Did you like or dislike the software used in this course. If your answer is No, please specify why.	58% of the students liked the software. Some of the students thought that is was somewhat difficult to use and.
Do you think the software used in this course is easy to use? Please explain your ideas.	47.3% of the students stated that the use of software was not easy.
Would you recommend this instruction for the next semester's students in freshmen physics course. If your answer in No, please explain why?	40.0% of the students recommended for the new students. 34% of the students stated that, software used in this course should be modified to make it more user friendly.
Do you think the software used in this course increased your understanding in vector algebra? If your answer in No, please explain why?	56.4% of the students answered YES to these questions. 16.4% of the students didn't perceive any value using this tool; moreover they felt that it did not make any substantial contribution to their understanding of vector algebra.

Although, some students had negative attitudes toward the utilization of the software, still an important number of the students' answers were relatively positive (see Table 3).

5. CONCLUSION AND FINAL REMARKS
Ann Thompson points out the importance of FOSS "open source software will provide new and exciting possibilities for educators. Obviously, the free or low-cost availability of open source software has great appeal for educators at all levels, and the Linux [operating] system is already gaining popularity in schools and districts around the country [USA]. Equally important to the coast issue, however, is the opportunity provided by open source software for education to adapt software to the needs of their students. In the same way a teacher might adapt a lesson plan to his or her needs, open source software may provide the opportunity to adapt a software program" Thompson (2002).

In this study we attempted to provide our students the ability to use advanced FOSS through octave and Java applet in order to help them to construct a better understanding of the concept of vectors. Needless to say, a sound understanding of vector algebra in introductory mechanics is crucial and will help the students further towards a better construction of the concepts presented in topics such as kinematics and dynamics physics units. It is our belief as science educators, that we are responsible to provide our students with as many learning tools as possible. Octave and goOctave.cgi are examples of such learning tools, they are readily available, and are relatively easy to setup. Although, not a part of this study, it was also our experience that octave through CLI

management helped the students to develop an understanding another aspect of computers, namely that computers are actually computing devices that do recursive tasks, beyond the students accustomed point and click use provided by so many GUI applications. The use of web application is also important, because it provides access to computer software beyond the school laboratory facilities. This way the educators and schools can provide the students advanced software, as it was in our case with goOctave.cgi and Java vector applet, the ability to study and work outside of class hours. Therefore, FOSS helps to foster the use of asynchronous teaching methods. Clearly, one can envision that the deployment of FOSS towards specific needs, will facilitated broadening the classical learning environment which will incorporate asynchronous teaching methods beyond traditional Learning management system (LMS) which are more generic in nature. A major limitation of LMS for physics education is that they lack mathematical learning tools.

The findings of this study suggested that by utilizing FOSS students were able to achieve higher level of understanding of vector algebra. Although one can argue on actually what main factor contributed to these high achievement with respect to the control group mean posttest scores, one point is clear; the students involved in the experimental group spent more time on the vector unit. The students had also the opportunity to work outside of class with their peers. Technologies such as octave may also have led to a positive motivation about the subject taught. Another important factor was the explicit use and need of the Cartesian coordinate system in order to do basic vector algebra.

Visualization through Java Applet technology was also beneficial. This technology provided instant visual aids as how the resultant vector with respect to the vector components changed. The students liked, especially the java applet. In overall, we feel that we added some more valuable learning tools for the students although some negative feedback was voiced by the students.

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