2006-1544: VECTOR: A HANDS-ON APPROACH THAT MAKES ELECTROMAGNETICS RELEVANT TO STUDENTS

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VECTOR[1] A Hands-On Approach That Makes Electromagnetics Relevant To Students

Overview

The School of Electrical and Computer Engineering (ECEN) at Oklahoma State University (OSU) is developing a two course sequence in electromagnetics (EM) based upon proven pedagogical methods. The two course sequence is named **VECTOR** (**V**italizing **E**lectromagnetic **C**oncepts **T**o **O**btain **R**elevancy) and adapts existing teaching techniques and laboratories to address three inter-related objectives:

A) Create an undergraduate curriculum in electromagnetics which is *relevant* to students and shows the impact of this field on emerging knowledge and technologies.
B) Employ modern tools, skills, and techniques to emphasize fundamental concepts rather than teach legacy materials emphasizing rote, analytical solutions.
C) Create an effective introductory EM course which will pipeline students into the electromagnetics-photonics curriculum at OSU, including graduate programs.

These goals, described in further detail below, address problems at both a local and national level that are being addressed jointly by experts in engineering education, assessment, and EM.

There is a national need for reform of undergraduate engineering education; from a peak in 1987, B.S. degrees in electrical engineering dropped nearly 40% by 1998 [1] with larger declines for underrepresented minorities and women. This decline is, to a large, part due to students' experiences with poor teaching- dry lecture and a lack of connection between laboratory and class work [2]. Since engineering students often employ active [3] and sensory [4] learning styles, a lecture-based curriculum focusing on legacy materials is not an effective method of learning. By teaching electromagnetics in a format which focuses on analytical problem solving, it becomes impossible to make the material relevant to students and address cross-disciplinary problems and emerging knowledge. A two course sequence in EM, VECTOR, is being developed with the primary goal of making EM relevant to students. The courses are built on modern, proven pedagogical techniques.

As devices work at higher speeds the need for all engineers to have a solid background in EM becomes more critical. Cross-disciplinary fields such as electromagnetic compatibility, photonics, and wireless communication all require a *working knowledge* of EM based upon a sound understanding of fundamental concepts. "Working knowledge" includes use of software and hardware tools and skills such as teamwork and communication, and is not effectively taught by lecture, cookbook labs, or emphasizing analytical solution techniques. To communicate concepts and skills requires students to both *develop* an understanding of concepts and to *test* that understanding by applying the concepts and skills. Application serves as formative

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evaluation. VECTOR is a project-based approach to EM in which student teams develop and evaluate their grasp of concepts through application in a complete project design-build-test cycle.

The introductory EM course at OSU serves two student groups. One group takes a single fields course then pursues some other area of electrical engineering. The second, smaller group takes additional EM and photonics courses, gaining depth in this area. The current, traditional EM course focuses on analytic skills needed by students who will pursue depth in this area, ironically maximizing the first group of students and minimizing the second. VECTOR educates students about the applications and impact of EM in electrical engineering and related disciplines *before* focusing on analytic solution techniques. Students are given relevant design projects in the first course to motivate discovery of the theoretical foundations of the projects in the second course. We are increasing the number of students gaining depth in electromagnetics and photonics by emphasizing relevance and application in the proposed EM courses.

Background

The former electromagnetic fields course, ECEN3613, is a required junior level course with a large enrollment (50–80 students) in which both students and faculty were dissatisfied with outcomes. Faculty dissatisfaction arose from poor student performance, while students did not see the relevance of mathematically rigorous, canonical problems that are perceived as disconnected from experience. To address the large number of students, traditional lecture with summative evaluation is employed. This traditional course focused on individual assignments.

Recently a consensus on successful model programs in engineering education has emerged [5] which we have adapted for EM. We have chosen to replace lecture with active learning, by organizing the course into modular units which focus on a real world scenario or problem. Relevance is emphasized since learning is focused on a real situation. Several studies [6-8] have demonstrated significant student gains by using active learning. VECTOR also utilizes computational resources, modeling software and web-based visualization tools, to visually and interactively illustrate concepts in a relevant fashion. VECTOR also draws from aspects of Project Based Learning (PBL). Three in-depth projects mimic the environment of practicing engineers, integrate communication and teamwork skills, and permit coverage of social, economic, and ethical issues [9].

We are in the third year of reforming ECEN's standard, one semester course in EM into a two course sequence, VECTOR. The first, required course will be designed for all ECEN students and focus on *concepts* and *applications* of E&M to ensure relevance. The second elective course, designed for students pursuing further study in this area, will link concepts to analytical and numerical solution techniques.

The first course, ECEN3613, is built around three case study modules in which students play the role of design engineers researching technologies to be used in the design of a wireless robot controller. The three case studies focus on design of three subsystems of the controller which reflect three basic conceptual areas of EM. A position sensitive input-output device is used to teach vector fields and forces (electrostatics). Design of a high frequency interconnect circuit is used to teach principles of circuit design outside the quasi-static limit (transmission lines and radiation basics). The third case involves design and characterization of a wireless communication patch antenna for the controller to teach propagation of energy and signals (antennas and Maxwell's equations).

To communicate the engineering design process, each module incorporates three teaching strategies in a coordinated fashion. A module begins with a **case study** [13] to place the project is a context relevant to students and introduce emerging knowledge into the curriculum. Since students have no knowledge of the focus area being covered, the case study includes simple, introductory concepts. Case studies are effective; class attendance figures typically increase from the 60% range to over 90% when this method is adapted to lecture courses [15].

Following the case study, required concepts are taught using a modified form of **team learning** [14]. In the adaptation of team learning used in VECTOR, reading/interactive assignments on a specific concept are assigned for each class period from text, web, or other resources. Students submit a web based quiz [16] before class which serves as formative evaluation. A team assignment during class serves to integrate the concepts and illustrate concepts' connection to the current design project. Three different teaching modalities are used in place of lecture to address different student learning styles [3, 4]:

- In class the Instructor reviews the previous assignments to place concepts in the context of the project.
- A team assignment given in class integrates concepts from the individual, on-line quizzes and relates them to the project.
- The class meets in a computer lab to allow the instructor and TA's time to consult with teams, answer questions, and give help needed to enable completion of the project.

Teams consist of four students; teams are constituted by the instructor to ensure heterogeneity and remain constant for all three projects. The four students who make up a team take one of four roles:

1. The Project Manager (PM) is in charge of scheduling meetings for the group and making sure that the project is on course to be completed. The PM guides the team through decision making and problem solving processes.
2. The project scientist is responsible for theoretical analysis, interpretation, and overall technical guidance of simulations and measurements.
3. The project engineer (PE) is responsible for coordinating measurements and simulations for the duration of the project. The PE's responsibility includes documentation, interpretation, and impact assessment of the measurements and simulation.
4. The Logistics/Quality Assurance Officer is responsible for project documentation, coordination of resources, and providing a cross check of project accountability to the rubric.

To ensure that students gain knowledge of all parts of the engineering design process, students must take a different role in each of the three projects.

Project based learning is broken into two related parts: a preliminary design and project construction. Midway through each module teams submit a preliminary design report of the project to be constructed. Following acceptance of the report, teams undertake construction of the project. In this phase, teams build the device they designed and test performance, comparing measurements to numerical modeling. Project construction is key to developing effective teamwork skills. A module ends with a written final report which is used for assessment; to ensure consistency in project evaluation a rubric is given to students. Written, rather than oral, reports are used since research indicates group work by students is a more positive experience when oral presentations are not required [17]. The final report includes peer **evaluation**, a vital part of team learning [14].

In contrast to the first introductory course, the second course of VECTOR, ECEN3623, is designed for students who will take additional EM courses. This course focuses on how to mathematically define and solve problems using computational and analytical methods. Students will revisit elements of the design problems from the first course in more mathematical detail, both deriving approximate analytical solutions and adapting these to fundamental computational methods. In ECEN3613 students learn concepts using existing, high-level visualization software. In ECEN3623 students are taught to analyze and model problems in EM by writing their own algorithms using Matlab®. Since students have already been introduced to the concepts and relevance of the assignments, ECEN3623 focuses on *application* of higher level mathematics to EM problems.

To measure how relevant the projects are to students we have used a *Student Assessment of Learning Gains* (SALG) [21]. A scoring rubric [23] ensures scores collected from different years can be compared. In-class exams incorporate both quantitative and conceptual problems. We are in the process of developing *concept maps* [24] and *conceptual diagnostic tests* [25] for each module. *Web-based portfolios* are the primary grading mechanism in both courses

Results

The student assessment of learning gains contains interesting results. Forty students were surveyed for the offering during the Fall of 2003. As a form of pretest, the class was taught in the Spring of 2003 with the author serving as the lecturer in a regular class format. Subsequent Fall semesters provided additional data (VECTOR 2004 and VECTOR 2005) that will be presented in the following figures.

As seen in Figure 1, the efficacy of lecture is presented with students asked "How much did lecture help your learning?" During the lecture-based course in Spring 2003, 53 % of respondents indicated that lecture provided "much help" and 28 % respondents that lecture provided "very much help". This is contrasted with the following semester in which lecture was purposely avoided in the full implementation of VECTOR in Fall 2003. During the fall of 2003 28 % of respondents indicated that lecture provided "much help" and 4 % respondents that lecture provided "very much help". These declines are expected and are to be viewed as an expected consequence of the VECTOR implementation - we have changed the method of delivery. We intend for the students to be developing into independent learners which is precisely what we observe as will be demonstrated in the next two sets of findings.

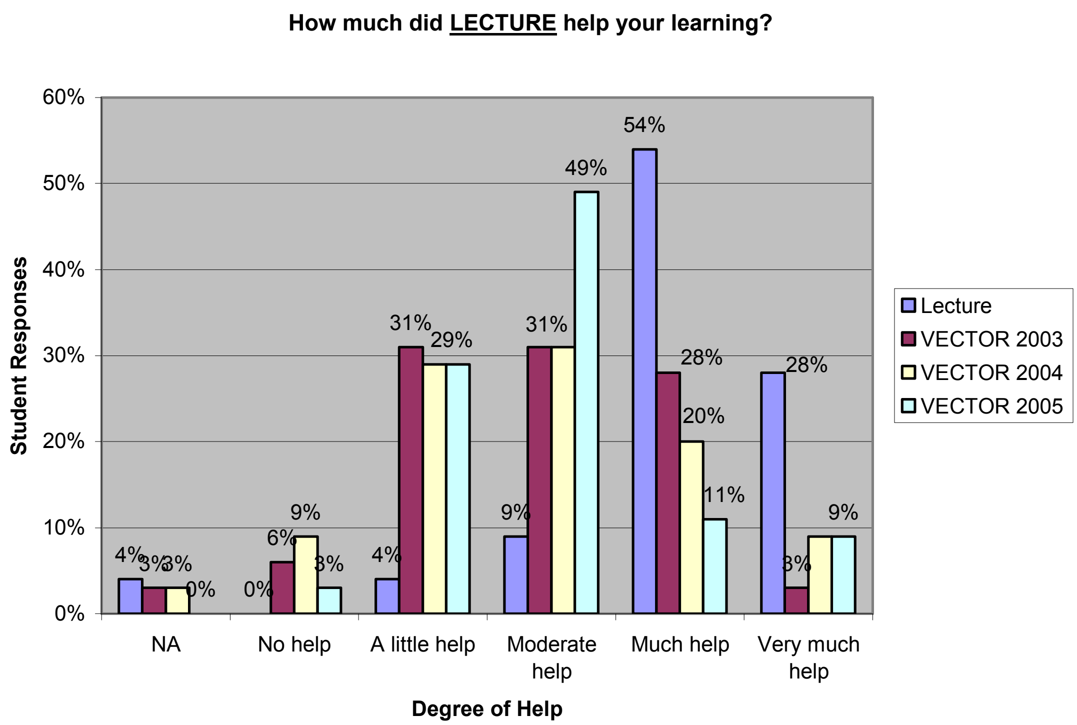

Figure 1. A comparison of the impact of lecture before and after VECTOR.

In Figure 2, a comparison of the impact of the increased use of computer modeling is presented. During the spring of 2003 (Lecture) 30% of students indicated that computer modeling provided either "much help" or "moderate help". No students indicated that modeling provided "very much help". This is actually a little surprising because there were no specific computer assignments given even though the internet was used extensively along with demonstrations of electromagnetic principles. A dramatic shift occurred in the fall of 2003 (VECTOR 2003) with the significant and overt use of computer modeling of electric fields, optical filtering, and microstrip filter simulation. 70% of students responded that computer modeling provided either "much help" or "moderate help" in helping their learning experience. 8% of respondents indicated that their learning was "very much helped" by modeling. This trend has increased over the 2004 and 2005 offerings of VECTOR, with a doubling of students indicating that learning was helped "Very much" by computer modeling.

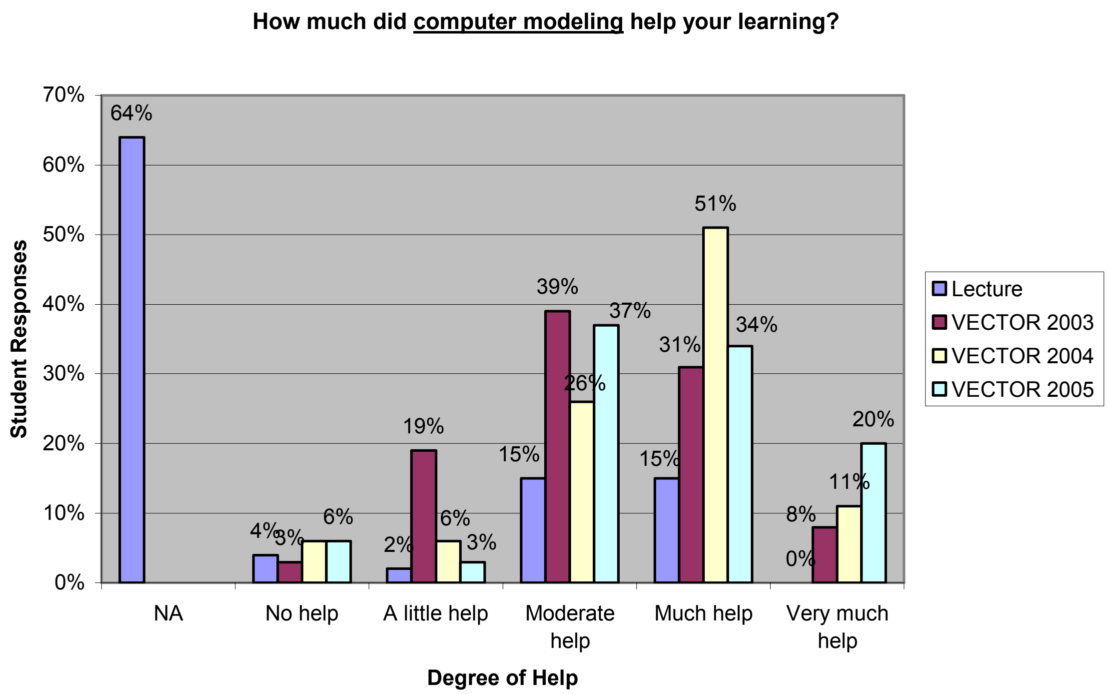

Figure 2. A comparison of the impact of the role of computer modeling before and after VECTOR.

Another significant improvement has been in the area of technical writing. Figure 3 presents the gains reported by students in the application of writing skills to their experience in learning. In Figure 3 we are specifically exploring the outcome of an increased skill in technical writing. During the spring of 2003 only 5 % of students indicated that their technical wring skills were improved either "a lot" of "a great deal". There were no writing assignments other than typical homework and tests. During the fall of 2003, VECTOR was implemented and a dramatic shift occurred with fully 50% of the students indicating that their technical writing skills have improved either "a lot" of "a great deal". Note that this has been done without significant loss of content.

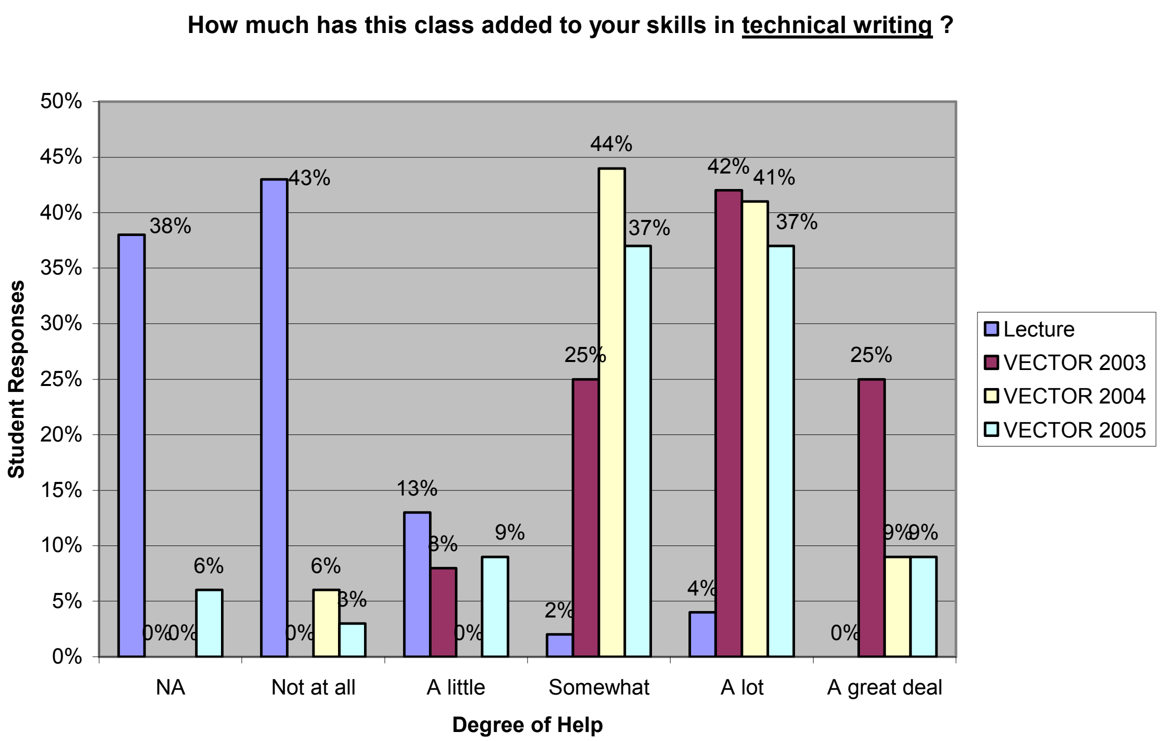

Figure 3. A comparison of the impact of the role of technical writing before and after 3 years of VECTOR.

In some respects these results are not surprising in that we have focused our attention thus far on aspects that of instruction most directly impacted within the VECTOR implementation. These results do provide a baseline for the application of the student assessment of learning gains (SALG) as a means of assessing the ongoing impact of VECTOR on the electromagnetics course at Oklahoma State University. The presence of additional courses using similar teaching methods tends to modify the results after 2003.

The trade-offs associated with using the PBL approach to team learning is presented in Figure 4. It should be noted that the italicized items in Figure 4 represent independent learner characteristics – items in which we hope to see significant gains. The non-italicized items are considered dependent learner characteristics and it is hoped that the losses in these items will be offset by gains in independent learner traits. This figure illustrates rather dramatically the significant increases in teamwork, communication, and the use of computer tools. It should also be observed that there was a significant loss in the students' perception of the assistance provided by lectures, homework, and professor assistance. There were only slight gains and losses in the impacts of enthusiasm and relevance in the first offering of the course.

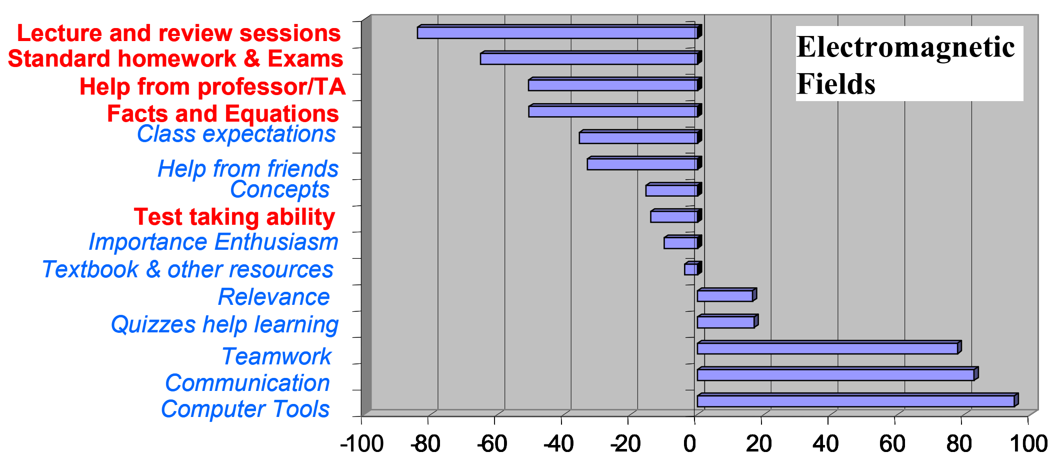

Figure 4. Gains and Losses under the VECTOR implementation during 2003.

Another series of questions were designed to gauge the students' attitudes toward the course as related to relevance, format, and effectiveness and these results are presented in figures 5-7.

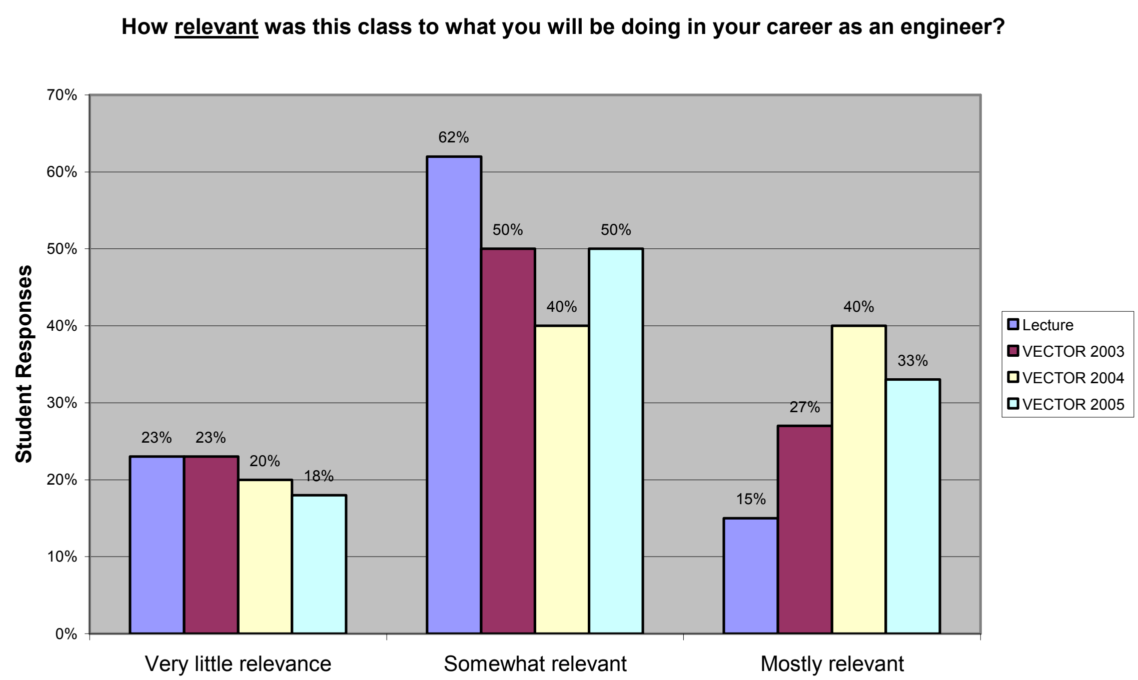

Figure 5. An examination of the students' views of the relevance of three years of VECTOR implementation.

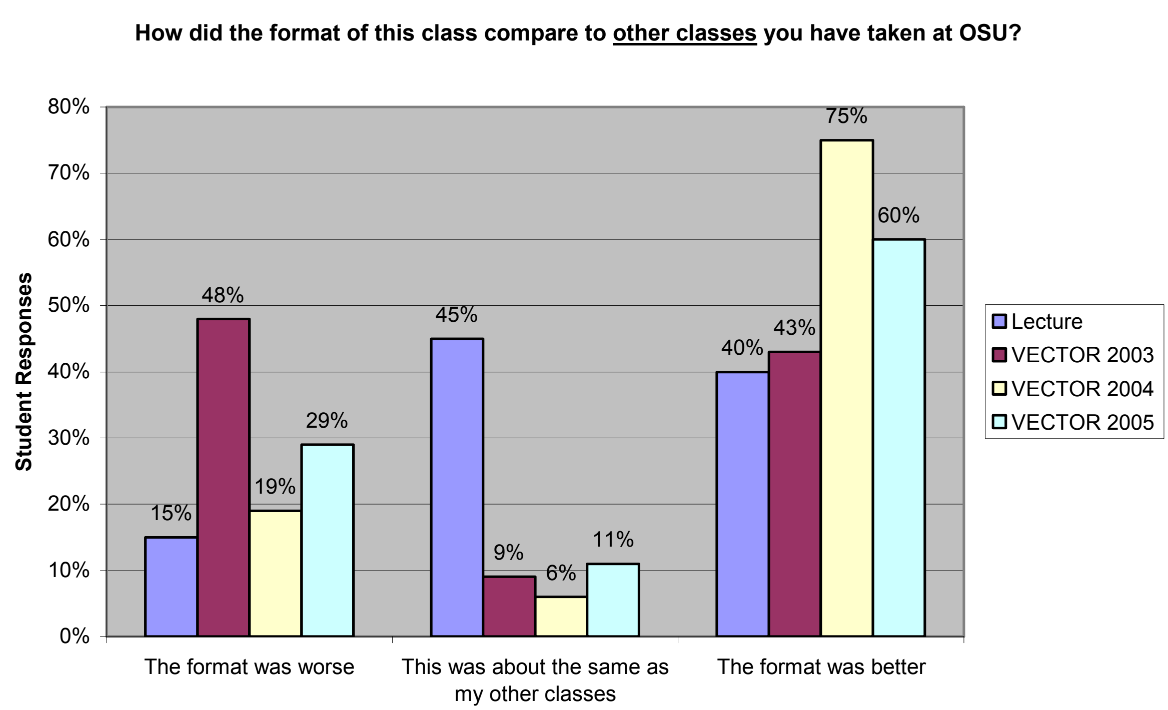

Figure 6. A comparison of VECTOR's format to other classes at OSU.

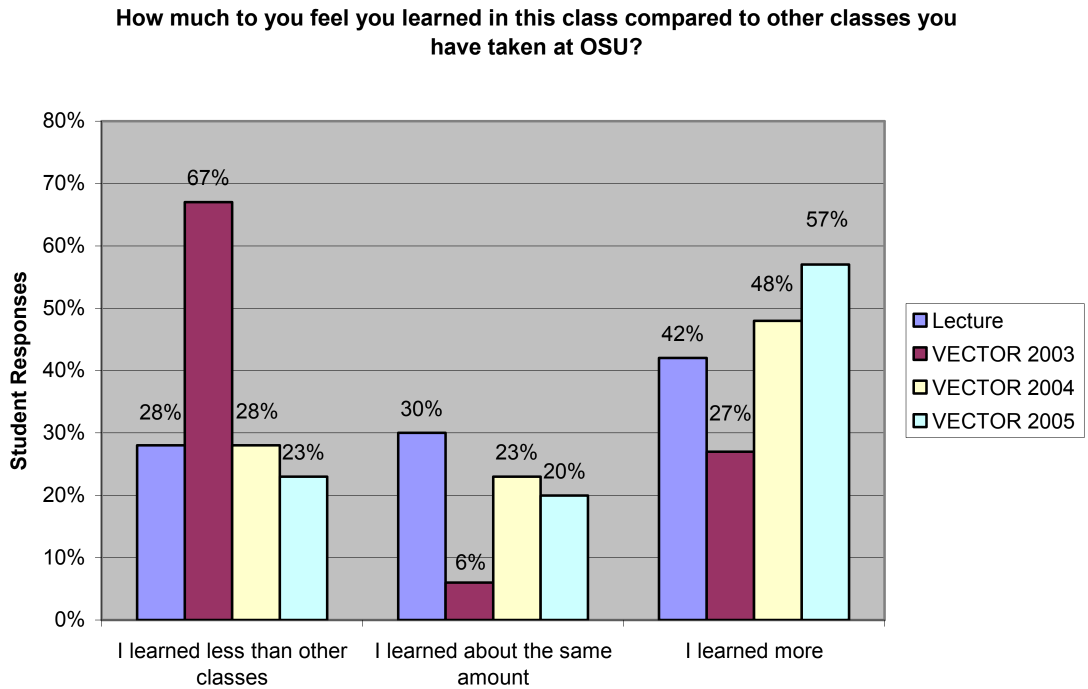

Figure 7. A comparison of VECTOR's effectiveness to other classes at OSU.

From Figure 5, we observe a small (5%), but continual decline in the number of students who view the course as not relevant to their career. There is however a significant gain from 15% to 33% of those students who perceive the course as relevant to their future career. Figures 6 and 7 depict an interesting bi-modal distribution of students' attitudes toward both the format of the course and what they felt they had learned from the course. The fewest students felt that the course format and amount of learning was the same as other courses. With the exception of the first year of implementation, there are nearly twice as many students who feel that both the format and the course effectiveness were better than other courses. During the first year of VECTOR (2003) there were significant losses for both format and effectiveness. This initial loss is not surprising and can be attributed to the newness of the method and the inexperience of the author in the method.

Conclusions

The number of students taking the second junior level EM course (ECEN 3623) has remained relatively constant (at 4% of the total headcount enrollment in ECEN). The course required a significant initial investment in instructor time for the development of on-line quizzes, in-class assignments, and project development. The case-studies that were developed provide scaffolding for the problems and help the students connect them to real-world situations that they believe to be important. The case studies are easily modified to present additional topics if needed to support particular projects. Future offerings of ECEN 3613 may include other projects including magnetic sensing and RFID technologies – the major emphasis is on that of bringing research into the classroom in order to increase the perceived relevance of EM. There is an increased interest in project-based learning at OSU with new faculty and more well-prepared students (those taking other similar courses in the ECEN department).

After suffering initial losses in student perceptions of the course format and effectiveness, the results for VECTOR are extremely encouraging with a doubling what the students felt they had learned over other courses. These numbers will be modulated somewhat by the increased presence of these courses through our department level reform grant.

The author would go further to indicate that the new mode of instruction has made teaching fun! By bringing genuine research problems and modern tools into the classroom we are able to pursue interesting issues (economic and ethical) and technologies (at which we could only hint in the traditional lecture format).

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