Computer-based Advanced Placement Physics for Gifted Students[1]

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Abstract

Over the last two years the Education Program for Gifted Youth at Stanford University has developed and tested computer-based courses in Advanced Placement Mechanics and Advanced Placement Electricity and Magnetism. In these courses the computer has been used as the primary vehicle of instruction and almost all contact with human instructors has been through electronic means. In this paper we describe the course software in detail and discuss our experiences to date.

1 Introduction

What we describe in this paper are two college level introductory courses in physics with a calculus pre-requisite that are entirely computer-based. These courses have been developed by the Education Program for Gifted Youth (EPGY) at Stanford, a research project which provides year-round, accelerated instruction in mathematics and physics to gifted or advanced middle school and high school students via computer-based courseware. (For a detailed description of EPGY, see [7].

Students in EPGY run multi-media courseware at home or in school on personal computers using the MS-Windows operating system. Our software, unlike traditional applications of computers in education, is intended to be the primary means of instruction, and not merely to supplement a regular class. In fact, it is precisely those settings where a regular class cannot be offered, either because of an insufficient number of students or the absence of a qualified instructor, that our software is intended to be used. Since we are concerned with college level physics courses, which presuppose calculus, the issue of teacher qualification is a significant one.

We have used our course model over the last four years to teach Advanced Placement Calculus and Physics courses to gifted middle school and advanced high school students. The remainder of this article focuses the EPGY course software in the context of the Advanced Placement Physics Courses.

1.1 Background to EPGY

The EPGY program started in 1985 as a proof of concept project funded by the National Science Foundation to create a first year course in calculus which would be entirely computer-based. (For a more extensive history see again [7].) The motivation for this was the fact that fewer than 25% of the high schools in this country offer advanced placement calculus. If one had a computer program that could be the primary means of instruction, one could make calculus available to qualified students in schools that were unable to offer it.

Because our purpose was to provide qualified students with access to advanced courses in situations where no one was available to teach them, we have had to concentrate on developing software which can play the role of both instructor and demonstrator. We have assumed that our software will be used by students, and not by instructors, and have therefore endeavored to make it as instructionally self-contained as possible.

The calculus course was complete in 1990 and was used to teach the AB Advanced Placement Calculus (the first 2 quarters of college calculus) to 13 students in the 1991 year. Of these thirteen students, 6 scored 5, 6 scored 4, and 1 scored 3, where 5 is the top score and 3 is passing. Because of this success, we expanded the course during 1991 to cover the BC Curriculum (the 3rd quarter of college calculus). We offered the course to 4 students in 1991-92 all of whom scored 5.

Following these results we decided to tackle the problem of using the same technology to teach college physics. Since our students had already had calculus, we decided to develop courses to cover the AP Physics C Curriculum in Mechanics and Electricity and Magnetism, courses corresponding to the first two quarters of college physics with a calculus pre-requisite. The problem of availability is even more extreme in the case of these courses, with substantially fewer than 10% of the secondary schools in this country offering courses in these subjects.

1.2 Courses Offered

Since December of 1992, we have offered 3 sections of our AP Mechanics course and 1 section of our AP Electricity and Magnetism course. We will classify the groups of students who have taken these courses into three groups, based on which exam they took and when they took it.

The first group consists of those who took Physics C: Mechanics in the 1992-93 school year. This course was offered to all students who had taken calculus with us in 1991 or 1992. All of those from the 1992 class chose to participate, and six (3 boys and 3 girls) of the 13 from the 1991 class accepted the invitation. We will refer to this group of 10 students who took the AP Exam in 1993 as Mech93.

During the 1993-94 academic year we essentially offered two sections of Mechanics. The first section consisted of students who began the course in September of 1993 hoping to complete both the Mechanics and the Electricity and Magnetism during the year. The second section began in January 1994 and consisted of students who only planned to take the Mechanics AP Exam. These students were all required to have either completed a calculus course during the previous year or to be enrolled in a calculus course concurrently with the physics. Since these 8 students all took the advanced placement exam together, for the purposes of this paper we treat these two sections as one group, which we shall call Mech94.

The Electricity and Magnetism course was offered for the first time in December of 1993. The group of students which took this course, which we will refer to as EM94, was comprised of nine of the ten students who had been in Mech93, the tenth having finished high school last year, together with 4 students from Mech94. All 13 of these students took the Physics C: Electricity and Magnetism Exam in May of 1994.

As mentioned above, the main prerequisite for taking the Physics courses with EPGY was having the appropriate mathematical background for the course taken. We did not require that students first complete a conceptual physics course, e.g. Advanced Placement Physics B, and in fact only two from Mech93, and five from Mech94, had taken any physics before.

All of these students ran the physics course at home on personal computers under the MS-Windows operating system. They were in contact with Stanford instructors primarily by phone and electronic mail, though monthly review sessions at Stanford were open to them as well.

1.3 System Requirements

The EPGY courseware consists of a course driver common to all courses, together with course specific files containing lesson and lecture material. The course driver is necessarily dependent on a particular architecture and operating system. However, the lessons and lectures are machine independent, and in principle can be used on any machine to which the course driving system has been ported.

The EPGY course driving system was initially developed on IBM RS6000s, using the ACPA sound card, and the X-Windows display system. During 1991 such a system cost well over $10,000. The course driver was first ported to personal computers using MS-Windows in the summer of 1992. At that point personal multimedia computers were available for less than $3000. While we were running on RS6000s we were limited in our number of students to the number of computers we could put in schools. After we ported the program to personal computers it became feasible to require students to supply their own machines to run the course. The exception to this has been in the case of students participating in EPGY who qualify for financial aid, in which case we supply them with a computer belonging to EGPY.

Under the MS-Windows operating system, the following is the minimal configuration necessary to successfully run the course software:

- 386 compatible computer with 4 MB RAM and MS-Windows 3.1.
- Hard-drive with 20 MB of free space and a 1.44 floppy drive.
- VGA monitor.
- 2400 baud modem.
- 8-bit sound card with a compatible CD-ROM drive.

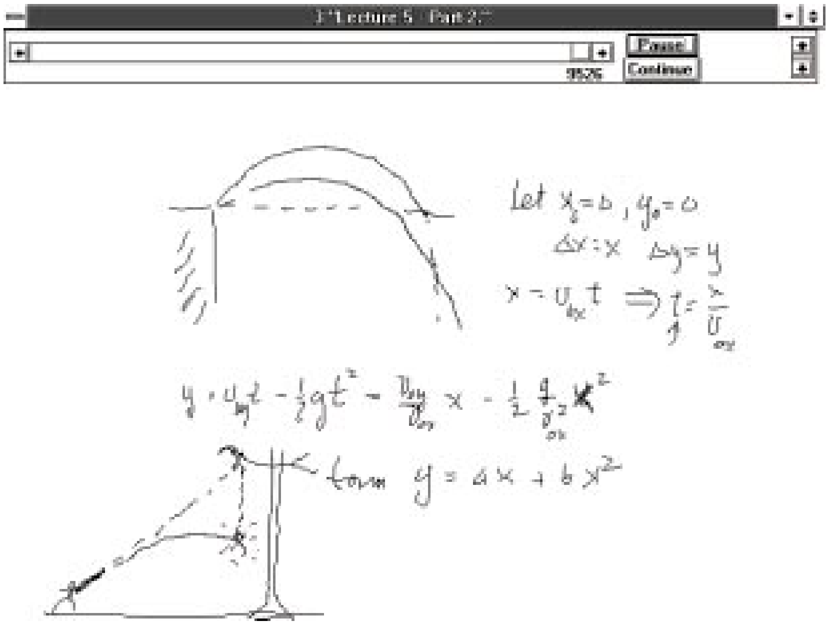
Because we make extensive use of symbolic algebra in processing student input, a computer faster than a 386 is desirable. In fact, for some of the problems in the physics course even a fast 386 can take over a minute to process a student answer. Certain optional features built into our lecture delivery system require a fair amount of digital signal processing, and do not operate correctly on slower machines. For these reasons we recommend that our students who do not have a computer buy at least a 486DX33.

We are aware of the fact that in requiring such an elaborate minimal system, our program cannot be used on the widely installed base of 8088 and 286 machines. Our goal, however, has been to not compromise our pedagogical model, knowing that by the time we were ready for wide distribution, the technology would have caught up with us. And it has, since a minimally configured multimedia 386 can be now purchased for approximately $1000. We feel that within 3 years, most schools will have computers capable of running our program. While this price is not cheap, it is not prohibitive to the majority of students.

1.4 Course Design

1.4.1 Lessons and Lectures

The EPGY courses are completely computer-based, with the computer delivering the vast majority of the instructional material. The on-line course components include a complete, interactive, multi-media exposition of the



Let $x_0 = 0$, $y_0 = 0$

$\Delta x = x \quad \Delta y = y$

$x = v_{0x} t \Rightarrow t = \frac{x}{v_{0x}}$

$y = v_{0y} t - \frac{1}{2} g t^2 = \frac{v_{0y}}{v_{0x}} x - \frac{1}{2} \frac{g}{v_{0x}^2} x^2$

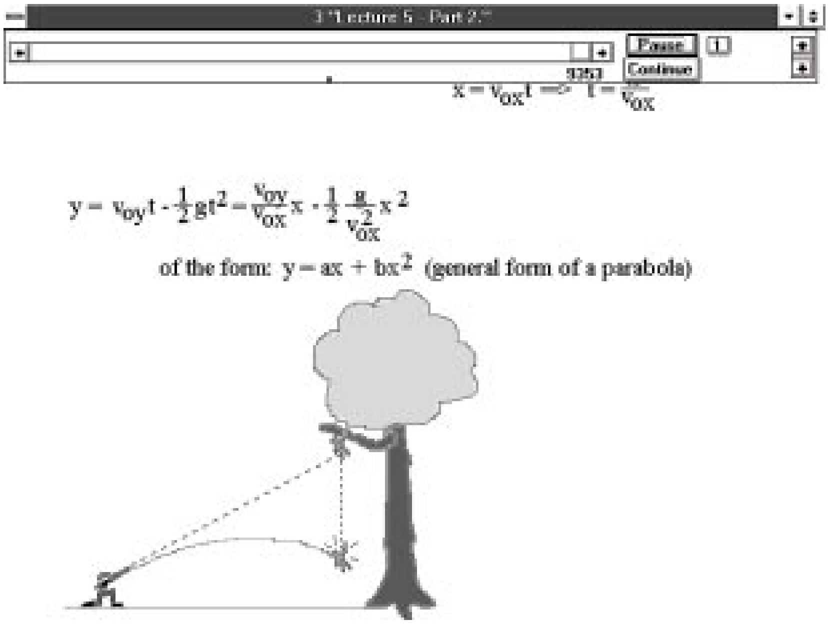
form $y = ax + bx^2$

Figure 1: Handwritten Blackboard from Mechanics Lesson 9050.

curriculum material involving digitized sound and graphics, an interactive problem-solving environment, mastery quizzes, problem sets, and databases of off-line problems. Additionally, a derivation system using the Maple symbolic computation system is available to students for use in doing computations. The fundamentals of this derivation system are also used in processing student answers so that a wide variety of equivalent mathematical expressions can all be counted as correct.

Similar to their classroom counterparts, our courses are divided into several lessons, each of which corresponds to a topic in the course being taught. These lessons have been designed to mirror the form of the standard university presentation of the material. (A complete list of the lessons for the Mechanics and Electricity and Magnetism courses is presented in Appendices A and B, respectively.)

A computer lesson usually begins with a lecture, in which a student listens to digitized sound recordings and watches graphics tablet writing (or formatted text and graphics) appear on the computer screen in real time, synchronized to the voice, so that the net effect closely resembles that of a teacher



$x = v_{ox}t \Rightarrow t = \frac{x}{v_{ox}}$

$y = v_{oy}t - \frac{1}{2}gt^2 = \frac{v_{oy}}{v_{ox}}x - \frac{1}{2}\frac{g}{v_{ox}^2}x^2$

of the form: $y = ax + bx^2$ (general form of a parabola)

Figure 2: Formatted Blackboard from Mechanics Lesson 9050.

writing on a chalkboard while lecturing. The lectures in our courses have been given by Professor Mason Yearian of the Stanford University Physics Department and director of the Hanson Experimental Physics Laboratory. Screen dumps of the two types of lecture are shown in Figures 1 and 2.

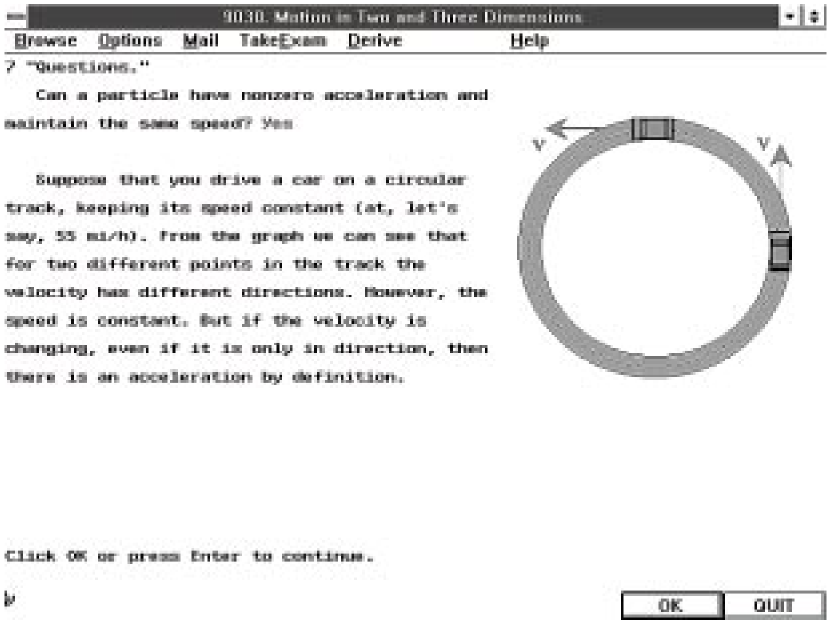
It is worth noting that these lectures have been designed so as to preserve the informal nature of spoken physics as contrasted with the more formal prose style of text books. This is important since it has been observed by many people, but not studied as thoroughly as it should have been from a research standpoint, that oral lectures are an important part of learning the mathematical and physical sciences. There is a natural difference in style between the way physics is written and the way it is talked about. The written style tends to be formal, detailed and rigorous, while the informal spoken style is more intuitive and also more flexible. Whereas in a text book, one finds a homogeneity of style, lectures can waver in their degree of rigor to suit the point being made.

We believe that there are many matters of style that are important for students to absorb in such informal lectures. It is a matter of learning both how to talk and informally how to draw diagrams and write physical equations. We also do not hold to the regime of long lectures. The lectures in the courses described here are broken into segments of not more than ten minutes each, after which students are required to do some exercises or to investigate a computer simulation. The advantage of such short lectures has been remarked upon by Hestenes and Wells [2] regarding Eric Mazur's Introductory Physics Course at Harvard in 1991.

It is also worth mentioning briefly that the reasons we have chosen to use lectures based on graphics tablet and digitized sound, rather than trying to use full motion video. First, an order of magnitude less digital storage space is required. Second, and probably even more important, the expense of video production is significantly more than the expense of producing the mini-lectures in audiovisual form using digitized voice and digitized graphic display. Finally, there is the fact that the graphic images of handwritten equations and the like, are much sharper visually than what can be obtained by ordinary video procedures which include shots of the lecturer and the chalkboard. By focusing entirely on what corresponds traditionally to the chalkboard we are able to get a very fine, detailed image from the graphic tablet.

The lectures are followed by a set of simple questions which review the students understanding of the material just presented. After these review questions students are presented with a set of interactive exercises, which consist either of a quiz on the material covered in the lecture, interactive exposition in which the student is lead through a detailed argument step by step, or a derivation in which the student is asked to obtain the answer to an exercise. A sample question in one of these exercises is shown in Figure 3.

As we would expect, the difficulty level of the exercises increases as the student progresses into a lesson. Depending on its complexity the student may have to make several intermediary computations. These computations can be done either with paper and pencil or by using a calculator. We hope to eventually add to these options the use of our Derivation System, a symbolic computation system built on top of Maple. We are only just now thoroughly integrating the derivation system into our mathematics courses. After we have finished doing this, we intend to extend its use into the physics courses. The important role played by such derivation systems in computer-based courses has long been championed by our group (see e.g. [8]. A detailed discussion of the derivation system in the larger context of pedagogical ap-



7 "Questions."

Can a particle have nonzero acceleration and maintain the same speed? Yes

Suppose that you drive a car on a circular track, keeping its speed constant (at, let's say, 55 mi/h). From the graph we can see that for two different points in the track the velocity has different directions. However, the speed is constant. But if the velocity is changing, even if it is only in direction, then there is an acceleration by definition.

Click OK or press Enter to continue.

Figure 3: A Sample Question from a Mechanics Exercise.

plications of symbolic computation is given in [6].) Incorporating symbolic computation into physics instruction is becoming increasingly important as more and more physicists come to use such programs in their daily routine.

It is important to emphasize that students are not constrained to giving numerical answers. In fact any answer may be accepted that is mathematically equivalent to the one intended by the author. Inflexible processing of student answers is a standard complaint with computer taught courses. Because answer comparison is most often some variation of string matching, students are required to follow a standard form for input. The reason for this is to eliminate the wide variety of natural variations in the ways in which people express even relatively simple mathematical expressions. By processing the answers symbolicly, taking into consideration their mathematical meaning, and thinking of possible correct answers in terms of equivalence classes, the computer is able to understand natural variations of correct answers. This is important both because it minimizes the need to force students to conform to an arbitrary input standard, and of variation in student input preferences, and more importantly because different approaches to the solution of a problem can result in equivalent answers with different forms.

A simple example from algebra shows the natural variety that a student's answer can take. Suppose a student is asked to solve the equation x^2+x+1 in the complex plane. One may want to accept as correct all of the following variants: $\frac{-1+i\sqrt{3}}{2}$ and $\frac{-1-i\sqrt{3}}{2}$; $-\frac{1-i\sqrt{3}}{2}$ and $-\frac{1+i\sqrt{3}}{2}$; $\frac{-1}{2}+\frac{i\sqrt{3}}{2}$ and $\frac{-1}{2}-\frac{i\sqrt{3}}{2}$; $\frac{-1}{2}+i\frac{\sqrt{3}}{2}$ and $\frac{-1}{2}-i\frac{\sqrt{3}}{2}$ not to mention several others with essentially the same form, and this does not include variations in spacing. To code each of these pairs of answers for the purposes of simple string comparison would be a chore and would fail to exploit the semantic content of the mathematical expressions. What counts as a correct answer here is any pair mathematically equivalent to $\frac{-1+i\sqrt{3}}{2}$ and $\frac{-1-i\sqrt{3}}{2}$. Whether or not the student's answer is correct can be determined by passing the student's input and the author coded answer to a symbolic computation program for evaluation and comparison. By exploiting the fact that the answers are mathematical expressions, a great increase in flexibility for both student input and author coding is obtained.

Such flexibility in answer input is a result of processing answers using Maple to look for forms equivalent to the author coded one. Our authoring language enables the author to specify how much flexibility a student should be given in terms of form. Furthermore, aside from allowing flexibility in student input, processing the answers with Maple means that we can treat answers like $(3,4)$, where a vector is expressed with parentheses, and $3\hat{\imath}+4\hat{\jmath}$, where the vector is expressed in terms of the unit basis, as both being correct, without the author having to explicitly give both as possible answers.

If in an exercise, the student gets the correct answer, another exercise or lecture is presented. If the answer is incorrect, a short explanation of how to solve the problem is given, either in the form of a lecture or as text. In some cases, rather than explain the answer to students, the course may reformulate the problem into several simpler intermediate problems and lead the student through the solution step by step.

Independent of the above, all answers given, correct or incorrect, are stored on the student's computer for further evaluation of the student's progress by the instructor at a later time.

One lesson generally comprises two to four lecture-exercise units. After students have completed a lesson, they are expected to read their text books and do standard problem sets. Students spend on average as much as 75 minutes doing additional off-line homework—reading and solving exercises in the textbook [9]—for every lesson they complete on-line. Laboratory work is also required of students. Homework and labs will be discussed in more detail below.

1.4.2 The Report Facility

An important feature of the EPGY courses in the role played by electronic communication between the students and the human instructors. We have dubbed the communications package that we have built into the courses the "reporting system." The reason for this is that every time a student is asked a question, his or her computer keeps track of how long it took him or her to answer that question, whether the answer was correct or not, if incorrect what the answer was, and similarly for subsequent askings of that question. This information is stored in a report file, which students are required to send electronically to Stanford once a week. To send such a report the student simply chooses *Report* from a pull-down menu in the MS-Windows menu bar. Depending on how the student's machine is configured, it will either dial the Stanford computer immediately and transfer this report to the Stanford computer, for later processing by the reporter facility, or it will write it to a file for the student to send at his or her convenience to the Stanford computer over the Internet as simple electronic mail. Once the report is received by the Stanford computer, the reporting facility processes the message in the same way as it does those sent directly over the phone. This processing consists of filing the student's responses into the appropriate place in the student database, and in sending any comments or questions the student had to the Stanford instructor as e-mail.

In cases in which the student's computer has dialed into the Stanford computer directly, the reporting process ends by retrieving any messages that the student has in his or her mail box, and writing these to a file on the student's computer. Students can then review their mail after the reporting session has terminated. In this way, the actual phone connect time is kept to a minimum.

The reports supply the course instructors with detailed information about individual student progress, useful both for purposes of tutorial support, and also for detecting problems in the course material.

A sample of an actual report is showed below.

```
Wed Oct 6 16:21:32 PDT 1993
```

```
---START 750008964 ---
Thu Oct  7 08:49:24 1993
!REMARKS

from    student-epgy-id     at 9010 / 1 / 1
       ------------------

last typed:
Hello, 9010 is fun.
---START 750283415 ---
Sun Oct 10 13:03:35 1993
!REMARKS

from    student-epgy-id     at 9010 / 1 / 1
       ------------------

last typed:
    Are we allowed to fax homework?

---START 750291196 ---
Sun Oct 10 15:13:16 1993

!HISTORY
 Oct 16 01:33:05, START 9070 0
 Oct 19 08:19:45, PB_TYPED
 Oct 19 08:19:46, CONNECT 4
 Oct 19 08:19:48, CONNECT 1
 Oct 19 08:25:14, CONNECT 8
Oct 19 08:25:14, END
 Oct 19 08:25:14, START 9070 2
 _r 5
 _r 3
 _r 8
 Oct 19 08:25:34, CONNECT 20
Oct 19 08:25:34, END
 Oct 19 08:37:29, START 9070 4
 _r 10
```

```
 _r 19
200
 _w 89
```

It is not difficult to understand the data we can retrieve from the above report. The structure of a report is as follows. The first line has the date that the student enrolled in the course. Following that are blocks of text which have the header “——START xxxxxxx——.” Each of these represents a complete report sent by the student. The number following the word “START” is the date that the previous report was sent. Following this are two option fields, identified by “!REMARKS” or “!HISTORY”.

Remarks are messages which are to be sent to the instructor as electronic mail by the reporting facility. For example, immediately after the third line we have an example of such a message. The body of this message has the text “Hello, 9010 is fun.” It is worth noting that the header of the message has the information “at 9010/1/1” indicating that when the student sent this message he or she was at lesson 9010, exercise 1, page 1.

The history field contains statistics relating to both student usage and performance. Whenever the student gives a correct answer the computer registers that as an “_r”. Every time the student gets a question wrong, it is registered as an “_w”. The numbers beside the _r’s and _w’s are the time in seconds that the student used to answer the question. Note that it is pointless to register the solution given by the student if it was correct, since this information is already available to the instructor, but it is very useful to register student solutions when they are incorrect. In the example above, a wrong solution of 200 was given in response to the third question of exercise 4 in lesson 9070.

By way of conclusion we would like to briefly mention the data analysis we are beginning to undertake. As was pointed out above, all work done by students during the course is written to a file and ultimately transferred to a computer at Stanford. It should be clear from the sample report file above that the amount of individualized information that we collect is substantially larger than that usually obtained from a teacher in a conventional classroom. During the courses, having this data available enables an EPGY instructor not only to compare the performance of different students but also pinpoint exactly at which subjects a given student is stronger or weaker, and to take actions for remediation as necessary. Another significant use of the data is in making modifications to the course from year to year. By finding questions which the majority of students get wrong, we are able to find weaknesses in our lectures, and to remedy them when revising the course.

1.4.3 Other Asynchronous Communication

In addition to being able to ask questions as part of a report, it should be emphasized that at any point in the course where a student has a question, the student can ask that question of the instructor merely by selecting *Comment* from a pull-down menu in the MS-Windows menu bar. In cases where the question is not essential, it is not sent immediately, but merely added to the remark field of the report to be sent at a later time. Students can also use traditional means to send electronic mail to each other and their instructors.

The exchange of questions and answers between students and instructors, or between students and each other is an important part of any course. We have tried to preserve this by making it easy for such a dialogue to occur via electronic mail.

1.4.4 Off-Line Work

Students are required do homework and laboratory experiments, in addition to the standard on-line work they do. The homework exercises were taken from the text book we used with the course, namely *Physics for Scientists and Engineers* by Paul Tipler [9]. Students were required to write their worked out solution on paper, the way they would for a standard class, but were able to evaluate their own performance by checking their work against instructor provided worked out solutions on-line. (Note: these solutions are stored in a coded form, and students have access to them only after they have submitted their work.) These solutions would often be accompanied by lectures which would work through the steps of the problem in detail, the same way that a course assistant would at a review section.

The experiments the students did consisted of simulations done using the *Interactive Physics* program in the Mechanics class, and in the Electricity and Magnetism class of hands-on experiments using the text *Zap! A Hands-on Introduction to Electricity and Magnetism* by Morrison, Morrison and King [4], developed by the Zap! project, a joint effort involving physicists at MIT and CalTech (see [3]. These experiments and the difficulties we encountered with them will be discussed elsewhere.

1.4.5 Classroom Environment

Throughout the course we have done our best to create a classroom environment among the students. We have encouraged students to work together on the problem sets, and have facilitated this by making available to students a standard DOS BBS which they could use as a forum for discussing aspects of the course. We have done the same thing with the laboratory component of the course, encouraging students to work together on weekends in groups of 2. We have also configured the reporting system to send automatically, once a week, to each student in the class a list of the locations of all the other students. This gives the students a sense of friendly competition and also makes it easier for them to find people at the same position in the course as they are to ask questions of. The final component has been the review sections at Stanford. These sections and ways in which we envision replacing them by electronic means will be discussed below.

2 Results

The results we have received so far have been quite promising. The first group of students, Mech93, scored in a pattern very similar to that of the first group of calculus students. Their exam scores, together with their scores on their previous calculus exam are given in Table 1. As it was in the case of the calculus students, the most striking aspect of the students' scores is that they are generally quite high. Of these students, 88% received scores of 4 or 5, as compared with 47% of students nationally. Moreover, the national numbers are for all students, whereas the majority of the EPGY students have been in 11th grade or below when they have taken exams. Worth particular mention is that fact that of the 8 students in the country in grades 9 or below who took the 1993 Physics C: Mechanics Advanced Placement Exam, five of those students were from our program [1].

During the 1993-94 academic year we had 8 students take the Physics C: Mechanics Exam and 13 students take the Electricity and Magnetism Exam. Again, these students all did quite well, with everyone passing and over 80% scoring 4 or 5. While the College Board has not yet released its statistics

Student	Grade	Sex	Prior Calculus Exam & Score	Physics C Mechanics Score
1	8	M	BC–5	5
2	9	M	BC–5	4
3	9	F	BC–5	5
4	9	M	BC–5	3
5	9	F	AB–5	5
6	10	M	AB–5	5
7	10	M	AB–4	4
8	11	M	AB–4	4
9	11	F	AB–4	4
10	12	F	AB–4	NA

Table 1: 1992-93 Physics C: Mechanics Exam Results

for the 1993-94 academic year, we expect to account for about 15% of the students under grade 11 who took Physics C Examinations. Given the small number of students in our program, this figure is quite significant. In the next five years we expect to account for over half of the students taking these examinations while in their first two years of high school.

3 Towards the Future

The main problem we face as our student population increases in size and geographically diversity is how to supply tutorial support to students in cases where the asynchronous, text only, aspect of e-mail prohibits effective communication between student and instructor.

For the last two years we have addressed this problem by offering students the option of attending discussion sections at Stanford, given about once every three weeks during the course, and increasing to once a week for the 3 weeks before the advanced placement exam. Attendance at these sections has run at about 50% with the some students attending more frequently than others. Attendance in the final three weeks has run at about 80% with almost all students showing up at least twice. Several points need to be made about these sections and the role they have played in order to adequately assess

Student	Grade	Sex	Prior Calculus Exam & Score	Physics C Mechanics Score
1	10	F	BC–5	4
2	10	F	BC–5	4
3	11	F	BC–5	4
4	11	M	—	4
5	12	M	—	3
6	12	F	AB–5	3
7	12	M	BC–5	5
8	12	M	BC–5	5

Table 2: 1993-94 Physics C: Mechanics Exam Results

ways in which they may be replaced.

These sections were initially conceived of as a safety net. We felt that it would be irresponsible to our students to force them to rely entirely on electronic mail as their only means of tutorial support, especially in the case of courses being offered for the first time. We did not want to take the risk of the students not performing to the level of their ability because of using a program still in its alpha version. The sections also provided us with an efficient way of isolating weaknesses in the students understanding of the material. While it is possible to gauge this from the student reports and their performance on on-line quizzes and tests, we felt it was safer to meet with the students in person and make sure that they were learning the material.

The point that these meetings with students drove home, was one we had learned during our work on the calculus courses, namely that developing effective software to teach entire courses is an iterative process. Once must not think of the first version of the course as the final product. Rather one designs a working version and sees how it does. As weaknesses are isolated, one can address them in the present at the review sections, and in the future by revising or expanding the course software. Moreover, if one tracks questions that come up in section, one can add material to the next iteration of the course to address these questions before they arise in the next group of students.

This is not to say that we envision the software running without any kind

Student	Grade	Sex	Physics C Exam & Mechanics Score	Physics C El. & Mag. Score
1	9	M	5	5
2	10	F	5	5
3	10	F	5	5
4	10	M	3	5
5	10	M	4	5
6	11	F	5	5
7	11	M	5	5
8	11	M	5	3
9	12	F	4	3
10	12	M	4	4
11	12	F	4	5
12	12	M	5	5
13	12	M	5	5

Table 3: 1993-94 Physics C: Electricity and Magnetism Exam Results

of review sections, for this process of course improvement is one without a clear limit, and as mentioned above, having such sections goes a long way to foster the feeling among the students of being in a classroom environment. The difference is that the review sessions we have in mind for the future will utilize an important new feature which we are currently adding to our courses, a feature we have dubbed, in accordance with the trends of the day, "the virtual classroom."

This software is essentially shared whiteboard software combined with voice conferencing. In the virtual classroom, students and their instructors will use graphics tablets and digitized sound to communicate with each other. Students will be presented with the voice of their instructor and classmates (the digitized sound), together with a shared chalkboard (the graphics tablets). The result will is dynamic, interactive, versions of the lectures we currently have presenting the voices of the students as well as that of the instructor, without their physical presence. This fall we will begin our first experiments with this new feature, using IBM's Person to Person conferencing software.

The virtual classroom will let us transform the review sections into remote dynamic lectures, which will accomplish the same ends, but which will not require that students live in the proximity of Stanford and therefore, which will accomplish the purpose of making these courses truly computer-based. It does not matter that a human instructional component is needed, as long as the location of this component does not limit the accessibility of these courses to students. The primary mode of instruction remains computer-based, with human instructors allowed to concentrate on what they do best, namely address individual student difficulties as they arise.

4 Conclusion

It should be evident that the tutorial role of the computer in EPGY courses is considerably more central than the role technology frequently plays in mathematics or science education. The computer in our program is no mere computational aid, electronic textbook, or drill assistant. Rather we have sought and will continue to seek to exploit the technology as fully as possible to produce stand-alone courses that capture and maintain students' interest while efficiently teaching college level subject matter. With the addition of the virtual classroom we have hopes of making university level courses in physics widely available to advanced students in secondary school. Finally, because we have put the entirety of the course on-line, our program makes it possible to offer college level physics instruction to students in situations where they usually would be unable to obtain it. This is something which programs designed to be supplementary material cannot do.

Finally it is worth addressing which student populations can benefit from the courses described in this article. While the students mentioned in this report all scored in the top 5% on the mathematics portion of the Scholastic Aptitude Test, it is our belief that our courses are probably suitable for students scoring in top 20%. This probably encompasses all students who are ready to take the Physics C courses while still in high school. Students taking these courses will have had to have had calculus while still in high school and as such are almost assuredly in the top 20% of students in the country as far as mathematics ability goes. This is not to say that the instructional model we have used could not be adapted to use by other students. In fact we have used the same model to teach courses in Beginning Algebra, Intermediate Algebra and Precalculus to adult students at Community College with some success

(Ravaglia, forthcoming). What we have discovered is that such students have different needs and different pedagogical approaches are warranted. Ideally one would be able to design a course which had several paths through it for students of different ability. In such a course the performance of the student would determine which lectures the student received and at what level these lectures were pitched. In this way the course could adapt itself to fit the needs of the student. The result would be a course which actively engaged students regardless of their ability level. As we revise and improve our existing software, we hope to make some progress in this direction.

5 About the Software

While we do not at the present time plan to market our software as a stand alone commercial product, we are happy to make arrangements with individuals or schools to use these materials either as complete instructional packages, or as supplements to existing physics courses. A main goal of EPGY is to make advanced courses available to qualified students who are otherwise unable to take them. People interested in the possibility of participating in EPGY or using the EPGY course materials are invited to contact the author for more information. Inquiries can be sent via electronic mail to ravaglia@epgy.stanford.edu or sent to the address given below.

A demonstration version of the program is available from the author. For a copy, send $10.00 to Demonstration Program, EPGY Ventura Hall, Stanford CA 94305-4115. The demo is also available via anonymous FTP from epgy.stanford.edu, as is additional information about EPGY. The URL for the EPGY mosaic page is http://kanpai.stanford.edu/epgy

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A Mechanics

Lesson Number	Textbook Chapter	Subject or Title
9010	2.1-2	Motion in one dimension. Velocity.
9020	2.3-4	Motion in one dimension. Acceleration.
9030	3.1-5	Motion in two or three dimensions. Vectors.
9040	3.6-7	Relative Velocity and Projectile Motion.
9050	3.7	Projectile Motion. Examples.
9060	3.8	Circular Motion.
9070	4.1-2	Newton's Law I.
9080	4.3-4	Newton's Law II.
9090	4.1-4	Newton's Law. Examples.
9100	4.5	Forces. So What are they?.
9110	4.6	How to solve physics problems.
9120	4.6	How to solve physics problems.
9130	5.1	Friction.
9140	5.1	Analysis of Car's Motion.
9150	5.2	Drag Forces.
9160	5.3	Problems with more than one object.
9170	5.4	Pseudoforces.
9180	6.1	Work and Energy.
9190	6.1	Work and Energy. Example.
9200	6.2	Work Done by a Variable Force.
9210	6.3	Work and Energy in Three Dimensions.
9220	6.3	The Dot Product.
9230	6.4	Work and Potential Energy for Systems of Objects.
9240	6.4	Potential Energy and Work Done by a Conservative Force.
9250	6.5	Work, Energy and Equilibrium.
9260	6.6	Conservation of Mechanical Energy.
9270	6.6	Conservation of Mechanical Energy - Examples.
9280	6.7-9	Work-Energy Theorem with Non-conservative Forces.
9290	7.1	Conservation of Momentum.

Lesson Number	Textbook Chapter	Subject or Title
9300	7.2	Motion of the Center of Mass.
9310	7.3	Conservation of Momentum.
9320	7.4-5	The Center of Mass Reference Frame.
9330	7.6	Collisions in One Dimension.
9340	7.6	Completely Inelastic Collisions.
9350	7.7	Collisions in Three Dimensions.
9360	7.8-9	Impulse and Average Force.
9370	8.1	Rotational Motion.
9380	8.2	Torque.
9390	8.2	A Rotating Pulley - Example.
9400	8.3-4	Rotational Kinetic Energy.
9410	8.5	Angular Momentum.
9420	8.5,8.7	Conservation of Angular Momentum.
9430	8.6	Rolling Objects.
9440	8.8	Precession of A Gyroscope.
9450	8.9, 9.1-5	Static Equilibrium.
9460	10.1	Gravitation.
9470	10.2-3	Newton's Law of Gravity.
9480	10.5	Moon Falling Towards the Earth.
9490	10.6	Gravitational Potential Energy.
9500	10.7,10.4	Gravitational Field of a Spherical Shell.
9510	12.1	Oscillations.
9520	12.2-8	Examples for Simple Harmonic Motion.

B Electricity and Magnetism

Lesson Number	Textbook Chapter	Subject or Title
1010		Explaining some details of the course.
1020		A new interaction - simple experiment.
1030	18.1	The Electric Charge.
1040	18.2	Charging by induction.
1050	18.3	Coulomb's Law.
1060	18.3	Comparing gravitational interaction with Coulomb's law.
1070	18.4	The Electric Field.
1080	18.4	The Electric Field of a System of N Particles.
1090	18.4	The Electric Dipole.
1100	18.5	Field Lines.
1110	18.6	The Cathodic Ray Tube.
1120	18.7	The Effect of an Electric Field on a Electric Dipole.
1130	19.1	Continuous Charge Distributions.
1140	19.1	Continuous Charge Distributions – Example.
1150	19.1	The Electric Field Generated by a Charged Ring.
1160	19.1	The Electric Field Generated by a Charged Disc.
1170	19.2	Gauss' Law.
1180	19.2	Gauss' Law - Follow Up.
1190	19.3	Gauss' Law - Example 1.
1200	19.3	Gauss' Law - Example 2.
1210	19.3	Gauss' Law - Example 3.
1220	19.3	Gauss' Law - Example 4.
1230	19.3	Gauss' Law - Example 5.
1240	19.4	Conductors.
1250	20.1	Electric Potential.
1260	20.1	The eV.
1270	20.2	Potential Due to a System of Point Charges.
1280	20.3	Potential Energy for a System of Point Charges.
1290	20.4	Electric Potential for a Ring of Charge - Example.

Lesson Number	Textbook Chapter	Subject or Title
1300	20.4	Electric Potential for a Disk of Charge - Example.
1310	20.5	Electric Field and Potential.
1320	20.5	Electric Field and Potential - Example.
1330	20.5	Electric Field and Potential: The Gradient.
1340	20.5	Electric Field and Potential: The Gradient - Example 1.
1350	20.5	Electric Field and Potential: The Gradient - Example 2.
1360	20.6	Equipotential Surfaces.
1370	21.1	Capacitors and Dielectrics.
1380	21.2	The Cylindrical Capacitor.
1390	21.3	Dielectrics.
1400	21.4	Stored Energy.
1410	21.5	Combinations of Capacitors.
1420	22.1	Electric Current.
1430	22.1	Electric Current - Example.
1440	22.2	Ohm's Law.
1450	22.3	Resistivity and Temperature Coefficients.
1460	22.3	Batteries.
1470	22.4	Combinations of Resistors.
1480	22.5	A Simple Model for the Theory of Conductors.
1490	23.1	Kirchhoff's Rules
1500	23.2	RC Circuits.
1510	23.2	RC Circuits - Charging the Capacitor.
1520	24.1	The Magnetic Field.
1530	24.1	Units of the Magnetic Field.
1540	24.2	Motion of a Single Change in a Magnetic Field.
1550	24.2	Thomson's Experiment.
1560	24.3	Torques on Loops.
1570	25.1	Sources of the Magnetic Field.
1580	25.1	Conservation of Momentum.
1590	25.1	Forces Between two Protons.
1600	25.2	Magnetic Field Due to an Electric Current.
1610	25.2	Magnetic Field Produced by a Solenoid.
1620	25.2	Magnetic Field Produced by a Long Straight Wire.
1630	25.3	Magnetic Force Between Two Wires.

Lesson Number	Textbook Chapter	Subject or Title
1640	25.4	The Magnetic Equivalent to Gauss' Law.
1650	25.4	Ampere's Law - Examples.
1660	26.1	Magnetic Induction.
1670	26.2	Emf and Faraday's Law.
1680	26.3	Lenz's Law.
1690	26.3	Lenz's Law - Example.
1700	26.4	Motional Emf's.
1710	26.7	Inductance.
1720	26.7	Mutual Inductance.
1730	26.8-9	LR Circuits.
1740	29.1	Maxwell's Equations.
1750	29.2	Maxwell's Equations – Follow Up.
1760		The Differential Form for the Maxwell's Equations.
1770	28.1	AC Circuits.
1780	28.1	RMS Values.
1790	28.2	AC Circuits with Inductors.
1800	28.2	AC Circuits with Inductors and Capacitors.
1810	28.2	LCR Circuits.
1820	28.3	LCR Circuits with a Generator.