DESIGNING PROBLEM-SOLVING AND LABORATORY CONTENT FOR A WEB-BASED DISTANCE EDUCATION COURSE IN INTRODUCTORY GENERAL PHYSICS.

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ABSTRACT
There is a strong prejudice among physicists, and specialists in other mathematically intensive disciplines, that effective distance education is not feasible in their subject because of the impossibility of teaching "problem-solving" without strong one-on-one interaction and because of the necessity to conduct meaningful laboratories which require expensive apparatus. The advent of the versatile and interactive Internet provides a means of addressing the former; some careful analysis and creative exploration help in overcoming the challenges of the latter.

1. A suite of interactive lessons (applets) is being developed at the Universities of Calgary and Alberta (in western Canada) with careful pedagogical design to address basic concepts in Elementary Physics. These highly interactive tutorials mimic a private seminar experience, combining student exploration of a physical principle with instructor "explanation at the blackboard".

2. At the University of Guelph we have emphasized the development of teaching tools to assist students in their problem-solving skills. The "Socratic Problem Solution" supports students in individual problem-solving by stepping them through typical multi-path problems. By working through more complex problems that are broken down into small steps, students are helped through the solution process bit by bit; they receive enriched feedback about correct—and incorrect—interim choices to ensure that they are applying the correct principle and accurately solving each step of the larger problem.

3. While some lab experiments, e.g., electricity, have proven intractable without specialist apparatus, several meaningful, quantitative experiments have been designed in mechanics and optics using essentially found items in the normal household. These "do-it-yourself labs" contrast with the high-tech use of the computer applets. Physical principles that students find difficult to conceptualize are demonstrated using common objects, turning "esoteric science" into something they encounter in everyday life.

Utilizing these three sets of tools and strategies, an award-winning course, offered entirely at a distance, has been constructed which has had considerable success compared with previous "paper and videotape" versions and whose results in both student persistence and performance rival those of the traditional residential course offerings.

KEYWORDS
Web-based learning, distance education, elementary physics, problem solving, laboratory.

INTRODUCTION.

The larger majority of physical scientists, who are the first to embrace new technology in their research endeavours, have, in the author's experience (JLH), proven to be particularly reluctant to embrace technology as a major part of their teaching. Of course there have been some outstanding examples of using technology in teaching Physics. Two such examples of different approaches are the development of Studio Physics (Wilson 1994) in the USA and the SToMP (Hunt and Bacon 1997) (Software Teaching of Modular Physics) project at the University of Surrey in the UK. The authors' experience, however, is that most Physicists are suspicious of the use of advanced technology in teaching their subject and usually cite two areas of concern: The "impossibility" of teaching "problem-solving" and the necessity to do laboratory exercises. For the former, it is claimed that without constant individual intervention and feedback, the student cannot learn problem-solving alone, and for the latter, there is a strong prejudice against simulations. There are examples of instructors integrating computer technology into their teaching as early as the mid-1980s (Taylor 1987), although what was then available differs substantially from the tools to which instructors now have access.

It is true that an increasing number of teachers have been introducing computer-based applets[1] into their lectures, such as applets to simulate an electric workbench to wire up and operate electric circuits.[2] Not only has this addition of technology not fundamentally changed the face-to-face nature of the lecture, applets have in many cases become a substitute for the classroom demonstration, because unlike a live demonstration with numerous variables, a computer-based applet always works! Applets are usually written by young enthusiasts in their spare time and are chiefly distinguished by their colour, artwork, and flashiness. The same topics tend to be used over and over [3] and very few authors have attempted to prepare comprehensive suites of single concept applets that would at least present the students with a stable appearance and approach throughout a whole course. The suites prepared by Walter Fendt [4] in Germany and Fu-Kwun Huang [5] in Hong Kong are notable exceptions. There is even less material produced that addresses the more abstract physical concepts in an attempt to replace the traditional lecture. Notable exceptions are the SToMP package and MAP (Modular Approach to Physics) developed at the University of Calgary (Martin et al 1999, 2001).

This sceptical view of technology-directed teaching becomes particularly severe when the course offering is a Distance Education (DE) course where the technology is to be used for 100% of the various components of the course (lectures, demonstrations, problem sessions, tutorials, consultation, feedback, etc.) and the laboratory must be either abandoned or satisfied with elaborate and costly take-home kits with all their attendant administration. As a result, Physics DE courses have tended to be simple Textbook-and-Study-Guide versions of their face-to-face counterparts and student performance at the University of Guelph (and we suspect elsewhere) has been generally poor.

Teaching problem solving with technology, which seems to be so strong a deterrent to physicists, does not seem to have heretofore been addressed in any comprehensive way. Simple posting of problem solutions on the Internet, while convenient, does not really confer much pedagogic value. Proprietary systems, which accept solutions of problems from students, check numerical interim and final answers, and return largely generalized feedback, are of some assistance but still involve little pedagogy and are certainly not designed to address the knowledge construction and causal analysis required of multi-branched physics problems (O'Malley and Scanlon 1990).

The laboratory component, which virtually all physicists deem essential to the study of their discipline seems, in the context of a DE course, to be the most intractable (Cartwright and Valentine 2002; Freake Colwell and Di Paolo 2002). Kits of inexpensive apparatus generally yield inaccurate and therefore unconvincing results that undermine the *raison d'être* of the effort. If the laboratory exercise therefore

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[1] We reserve the term "applet" for downloadable dynamic applications with which the viewer can interact and adjust some parameters.

[2] http://www.colorado.edu/physics/phet/simulations/cck/cck.jnlp

[3] A quick search on the Internet produced 14 applets on the superposition of sine waves, all essentially the same.

[4] http://www.walter-fendt.de/ph11e/

[5] http://www.fed.cuhk.edu.hk/sci_lab/ntnujava/

is pursued only for qualitative results, the benefit to the student seems not worth the time spent. There have been some attempts to put together more elaborate kits (McAlexander 2003) but the logistics are, in our experience, overwhelming (assembly, distribution, collection, repair, monetary deposits, etc.). The option of computer simulations of experiments is always available but, the general consensus may be that the credibility of simulations in the teaching of experimental science especially, is suspect (Chetz et al 2002). However, there are many situations in which simulation is the most effective means of expression, even for face-to-face classes, with computer-enhanced, interactive, student-driven virtual reality programs such as the Virtual Solar System Project (Barab et al 2000). Although more sophisticated than a simulation, image processing technology is a computer-based tool where students manipulate images, which may offer "a more attractive entry into science and mathematics than traditional language-based ways of introducing and teaching these subjects" (Greenberg et al 1998).

In the following sections, these major areas will be addressed: concept teaching, problem-solving, and practical exercises, in the context of our DE course in Elementary Physics. In the last section we present some analysis of the level of success so far achieved.

THE PARAMETERS OF THE COURSE

The course is one semester in non-calculus Introductory Physics. The material is not at that of first-year university, but is a make-up course for those entering without the senior high-school Physics. Because first-year University Physics is a requirement of all science students and, has high-school physics as an absolute prerequisite, students enrolled in this make-up course are generally not physics students. Students taking this course are often non-physics majors fulfilling a general science requirement, as part of their program (The University has large enrolments in the life sciences.), or are not regular undergraduate students, but members of the community, such as teachers, who are upgrading for one reason or another. In rare cases, they are potential physics majors who have gotten a slow start in Physics.

Students lack Physics at this stage for a variety of reasons, but by far the most common is because of its perceived difficulty; even students taking a number of mathematics and science classes in high school may opt out of physics in favour of chemistry, biology, and various mathematics courses. The result is a class of largely ill-motivated and ill-prepared students. The situation is exacerbated at our university, as we chose to offer the DE version as the only Physics course available in the winter semester (January to April). Therefore, a large number of the students enrolled in this DE Physics course are those who have failed or dropped out of the standard face-to-face lecture-lab version offered in the fall. As such, these students already carry the emotional baggage of having failed at Physics in the fall, and have not necessarily elected to take the course at a distance, but have found that this is their only option.

Most of the students taking DE courses in the winter semester are, in fact, physically on-campus but there are always a number of off-campus students, some of whom are very distant and have no access to campus facilities. It was decided therefore, that the course would treat all students as if they were remote and there would be no on-campus help, labs, assistance, or lecturer's consulting hours; all the material parts of the course would be dealt with on the web.

It is to our advantage that we have a locally produced textbook of superior quality; (McFarland and Hirsch 1994) thus we avoid the problems associated with commercial publishers such as the introduction of new editions without notice, or even cancelling publication. This is important as it was decided that the course should have a textbook as its central learning tool. The students do not get their basic information by reading from a monitor; the course website provides structure as a study guide and is also the sole source of enrichment, explanation, testing, even entertainment, through various computer-based activities and simulations and multimedia segments.

The course website alternates among brief introductory comments, instructions to read sections in the textbook and work through problems, and a variety of activities. By "activities," we mean anything that serves to expound or explain single concepts and breaks up the presentation of the core material. We take seriously the generally held belief that a student's attention span is about 10 to 15 minutes of concentrated learning and we have tried to introduce some interesting, active, or thought-provoking "activity" at frequent intervals to achieve this end. An activity can be anything from a single photograph to ponder in the light of what the student has just learned, to an interesting question relating the topic to the real world, to a demonstration or simulation clarifying the topic, to an interactive applet chosen both for its pedagogical value and its attractiveness.

The course is divided into 12 units; one for each week of the semester. They are divided into various topic areas; each one has a number of computer-based activities, readings and problems from the textbook, short self-tests, and a final assessed quiz. At the end of each week, a short multiple-choice quiz is made available online which the student must pass at the 80% level to get full credit. They are given three attempts and failure to achieve 80% results in zero credit for the quiz. This mastery testing has a substantial literature showing that material retention is improved (Mager and Pipe 1984; Carroll 1963) and has been used for over 25 years in the department's large face-to-face introductory course (McFarland, Hallett and Hunt 1978, 1983). Online quizzing is something of a risky endeavour; the instructor never knows if the student who signed up for the course is really doing the work. Additionally, students have been known to gather in computer clusters and work through quizzes together. We do not worry at this stage about collusion or collaboration. The students know about the University's policy on academic misconduct and any collaboration probably contributes something to the student's learning. Because questions are randomized, it is impossible for students to simply send out a list of answers, so even the most dedicated would need to interact and discuss the questions, and would probably end up learning more through their collaborative efforts than they had intended. Because only a total of 20% of the final grade is allocated to this activity, a student could cheat for the whole portion but would almost certainly fail the course in the end.

Communication with the lecturer, teaching assistant (TA), and other students is provided by a number of online asynchronous conferences where all students can read, follow, and contribute to the threaded question-and-answer sessions. Most students' questions are common and making these exchanges public forestalls a large number of repetitive questions if students were to email instructors privately every time they had a problem. To this end, the lecturer and TA, between them, check conferences questions at least four times per day and usually more; checking in late at night seems to be particularly important, as many students do not begin their homework until late in the evening.

Finally, we feel that it is important that the website be logically laid out, tidy, and attractive without being fussy; unusual fonts and outré wallpapers are to be avoided. The presentation of the various components should be consistent across the units, with a set of icons that the student can get used to and trust. The units are book-ended with interactive "What do you think" and "What do you think now" pre- and post-tests, the former challenging students' conceptions as they begin the unit and the latter reaffirming what they learned in the unit, while offering enriched feedback to jog students' memories. The pre- and post-tests are more than simple navigational cues, however. Because "alternative conceptions" of physical phenomena (also called "gut science") are so tenacious (Osborne 1987), every opportunity to address students' previous misconceptions and rectify them is employed.

TEACHING THE CONCEPTS.

For the student, the source of the important concepts (e.g., conservation of linear momentum, Ohm's Law, etc.) is the textbook. However, it is generally recognized that, except for a talented few, simply reading about physics concepts does not often lead to understanding. The less motivated student has difficulty sorting the concept from its justification and discussion. If anything justifies the classic face-to-face lecture in teaching Physics, it is this: guidance in interpreting the material in the textbook and showing just what the basic physical concept is.

Our choice to replace the lecture, i.e., the teaching of the concepts, is the MAP system of concept-driven applets produced by a consortium headed by educators at the University of Calgary. These multilayered, highly interactive applets are assembled into a comprehensive set of tutorials in elementary University Physics. Although written for a level one step above our requirements, they are so versatile that they can be adjusted to suit our needs. They use the full panoply of web tools (Flash, JRE, etc.) but do not flaunt the resources of the web; their consistent appearance, language, and approach make the technology transparent and bring the lesson and its learning to the fore. MAP is not a completed curriculum yet but had important material for 10 of our12 units.

PROBLEM SOLVING

J. Hayes (1980) describes what a problem is: "Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap, you have a problem." This definition provides a basis for distinguishing between two closely related concepts: exercises and problems. According to this definition, if you know what to do when you read a question, it is an exercise not a problem.

Chamoso, Sanchez et al (2002) define problem-solving as an endeavour where the student does not have a procedure or an algorithm to rely upon in order to solve the problem automatically, but must rely upon heuristic strategies: "The capacity and ability to solve problems is not only acquired by solving many problems but is also favoured by acquiring ease and familiarity with different solving techniques and by discovering the mental processes used in solving one of them. These processes can be learned and assimilated when they are known and practised."

Most physical scientists believe that the problem-solving ability is something that can be taught and that they somehow always teach it in their courses. That they see this as a major and difficult part of their responsibility is evidenced by a search on the web for "Problem Solving". This will disclose literally hundreds of recipes, essays and guidelines produced for the benefit of students in a particular Physics course.

The usual pattern for learning this art is thus: students are presented with problems and work toward solutions in four major settings.

1. Example problems worked out in lectures or tutorials,
2. Individual or group work in tutorials,
3. Individual consultation with the lecturer or TA, and
4. Informal peer instruction out of formal class hours ("Coffee Shop" learning).

The latter, while not much discussed by instructors, may well be the most effective means for developing skills in this area.

In the DE course, we have sought ways to effectively address these four settings. With the use of the online conferences, we have provided a vehicle for addressing items 3, 4 and some aspects of 2 in the above list. The immediacy of the response is not as satisfactory as live interviews and face-to-face conversation and will gradually be replaced with some form of "chat-room" with its more open structure (although a constructivist viewpoint would limit immediate feedback to the student, allowing him or her time to reflect and reason through the problem rather than emphasizing the correct answer immediately. For a discussion of this technique using a computer-based intelligent tutor system, see Murray et al. 1970). Several commercial and free services for synchronous discussion and diagramming already exist such as MSN Messenger or Yahoo Messenger. Because different tools offer different ways of accomplishing various pedagogical goals, we hope to eventually employ a combination of asynchronous conference tools as well as synchronous "instant messaging" ones.

In order to provide for the first item, certainly one of the most important in the eyes of the average instructor as it is almost the only occasion where the student sees example problems analyzed and solved as models, we have expended considerable effort on what we call the "Socratic Problem

Solution" (SPS). Almost everyone agrees that the mere posting of problem solutions has very little pedagogic value; this is little more than the answers at the back of the textbook, and certainly does not use the interactive capacity of the web. Students usually look at such answers to find out why they lost marks but rarely to examine and correct their misconceptions. Indeed, the static steps are not engaging and do not capture the flow of work as the student has experienced it. The student must be actively involved in the solution to gain benefit from it.

The SPS presents a problem from the textbook and proceeds with the solution by a sequence of questions that the student must answer from a multiple-choice list before proceeding to the next step. Wrong choices are provided with reasons and hints and return the student to the question; right choices lead on in the solution. The problem and the accumulating correct solution are visible at all times. The method is somewhat similar to the Programmed Instruction Manuals current in the 1960s (Taylor 1970) but which are so much easier to use on the computer. The problems include text descriptions, equations, and diagrams, and range in number of steps from three or four to thirty. Over 50 of these have been constructed so far, covering all major areas of the course just as the lecturer would select a range of problems for demonstration in class.[6] As it now stands, they are constructed of simple HTML screens but could be produced in Flash or other programs.

THE LABORATORY.

The earlier and highly unsuccessful text and study-guide version of this DE course had a rather elaborate and expensive lab kit. This kit had to be sent to the students, collected and repaired and refunds sent out from the student's deposit. For the present course, it was decided that the expensive lab kit would not be used. We presented ourselves with the challenge to devise meaningful, quantitative Physics experiments that could be performed with readily available items in the household along with the use of a computer. The exercise was very fruitful and several experiments were devised. By relaxing the stricture of "no special equipment" somewhat, a curriculum was devised in which the lab kit which was distributed to the students was so inexpensive that it was not worth collecting.

The experiments that were finally performed were:
1. Timing an object in free-fall and the measurement of "*g*".
2. The summation of three vector forces in equilibrium.
3. Conservation of momentum in two dimensions.
4. Ohm's Law and the series-parallel combination rules.
5. The diffraction of laser light and the measurement of wavelength.

For the first offering of the course the free-fall experiment had to be done as a simulation. A real home experiment was being prepared but was not ready in time; it will be substituted in the next offering. Electricity proved intractable to this approach (at least one electric meter is needed) and the experiment on Ohm's Law is done as a simulation with the very realistic workbench created by the Physics Technology Education group at the University of Colorado (see footnote 2). For details of the individual home-experiments (including the free-fall experiment) see the recent paper by Hunt 2005).

There is much discussion about the actual purpose of a practical component or laboratory session in science education (Millar, LeMarechal and Tiberghian 1999). Are the objectives of doing labs related to the actual process of doing experimental work or to the conceptual content of the practical work, or both (Scanlon et al 2004)? Still other educators feel that practical work is important for the student in that it brings the budding scientist into the community of practice of scientists; this is what scientists do, and so this is how we will work and learn (Chetz et al 2002).

[6] The SPS for this course can be seen at: www.physics.uoguelph.ca/phyjlh/SPS/

There is a move in some institutions toward remote experiments: a consortium in the U.K. and Europe has developed a series of experiments where students manipulate apparatus remotely via computers. Students in Portugal are able to view on their computer screens the electron microscope they are controlling from afar. Another experiment has students testing digital circuits remotely (Scanlon et al 2004). A similar project at Athabasca University has students performing remote experiments in chemistry.[7]

OUR STUDY

In an effort to collect some information about what tools and strategies students were using and finding most helpful in the course, we conducted a brief evaluation of the first offering of the DE Physics course. All 30 students enrolled were invited to participate in the study; six students returned the 20-page survey. Of these six, three were male and three were female; five were full-time university undergraduates and one was someone who worked full-time and was not enrolled in a degree program but taking the course for personal interest or upgrading. For five of the students, this was the first time they had taken the physics course; the sixth student had taken the course in the fall but had either withdrawn or failed.

Students reported their primary reason for taking this course to be upgrading; they needed the course as a pre-requisite. They report anticipating challenges with physics because it had been a long time since their last course (if ever) or because they remember it being difficult in high school. When asked about encountering challenges that they didn't expect, two students reported some difficulties with labs, although they said they eventually understood because the "prof was good at explaining things over the net." Students were asked about the usefulness of the SPS, the online activities, the self-tests, the MAP activities, and the demonstration video clips. Four students reported that the SPS were very helpful; one student said it was somewhat helpful (one student did not respond). One student reported using them rarely, but found it helpful when he did. The others used them regularly and one wanted more problems to be covered with this activity. The various activities and the self-tests were rated as somewhat helpful by four students and very helpful by two students. The MAP activities, interactive tutorials meant to replace the lecture and constitute the bulk of the learning, were rated as very helpful by four students; one thought they were somewhat helpful and the other thought they were not helpful at all. The video clips were very helpful to three students, somewhat helpful for one student and not at all helpful for two students. See Table 1.

Table 1. Student ratings of various learning tools

Tool	Not at all helpful	Somewhat helpful	Very helpful
SPS	0	1	4
Online activities	0	4	2
Self-tests	0	4	2
MAP	1	1	4
Video clips	2	1	3

In an attempt to determine both the workability and the pedagogical usefulness of the at-home experiments, the students were also asked in-depth questions about each of the labs:
1. How clear were the instructions to perform the experiment?
2. How easy was it to get good results with the experiment?
3. How easy was it to report the results of the experiment?
4. Did performing the experiment help you in answering the questions at the end of the exercise?
5. Was your overall experience of the experiment that you learned a lot?

[7] http://www.remotelab.ca/public/project_desc_2.htm

6. Did you enjoy doing this experiment?
7. Did this experiment, overall, help your understanding of the topic?

They were asked to respond in three categories: 1. Not at all; 2. Somewhat; 3. Very much. The results for the five experiments are shown in Fig. 1.

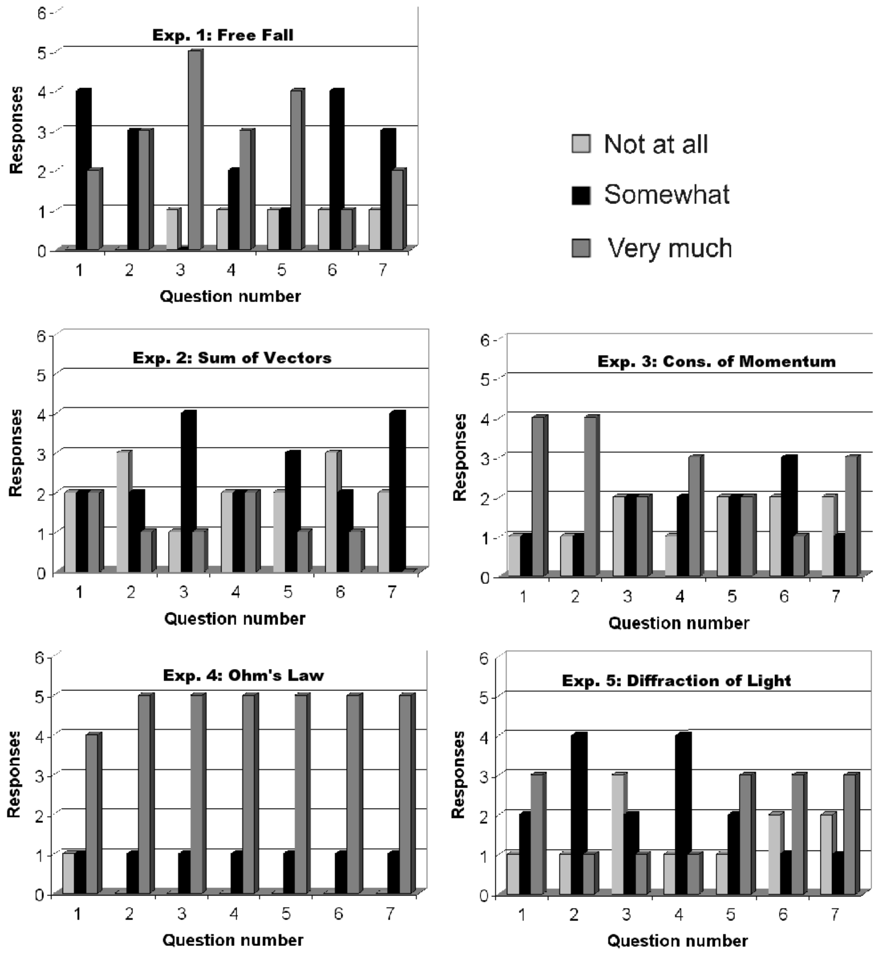

Figure 1. Student evaluation of the Experimental Exercises.

From the figure it can be seen that there was overall satisfaction with the experiments; a minority (or none) of the students reported in the "not at all" category for any of the exercises. Experiments 1 and 4 were computer simulations and show a generally greater level of satisfaction than the experiments where the students had to assemble apparatus on their own. Experiment 4 was even described as: "It was fun, playing with the simulation on the computer. Like a video game."

They were also asked how many times they performed the experiment before reporting their results. The responses are summarized in Table 2.

In a regular course with laboratory these numbers would nearly all be "1" with only a few "2". Under the supervision of a lab instructor, students perform experiments once and only need to repeat them if they have gone severely astray. This result indicates a severe waste of time and a seeming reluctance by the students to contact the TA quickly and often as would be the case in a regular laboratory. This is something that must be addressed.

Student-instructor interaction is very important in a face-to-face physics classroom. The authors wondered if, lacking the ability to simply raise their hands to ask a question during a lecture, the

Table 2. Number of Attempts at the Laboratory Exercises

Number of attempts →	1	2 -3	4- 8	>8
Exp. 1	0	6	0	0
Exp. 2	0	5	1	0
Exp. 3	0	3	1	1
Exp. 4	1	3	1	0
Exp. 5	1	4	1	0

students would feel impoverished when it came to interaction with the instructor and timely responses to their questions. Students were asked how often they participated in the discussion conferences. Their reading and posting of messages varied significantly: one student reported posting once per day, another posted 2-3 times per week, another once every 2-3 weeks, and three posted only once or twice during the course. Three students report reading messages in the conference one per day; two read 2-3 times per week and one read messages once every 2-3 weeks. All students reported the discussion conferences as being helpful. They appreciated that their classmates posted questions that they themselves might have had about problems, and that their peers often answered their questions. Students reported that “the prof and TA were very quick to respond to questions.”

It is sometimes suggested that an asynchronous discussion forum is too slow or crude a medium in which to do problem-solving or find answers to questions, and that other, more enriched media should be used. Today, students are used to such media (telephone, email, instant messaging, and chat-rooms) in their daily communication. When asked what other communication tools students would like, two reported that the conferences were enough: “having too many tools may be counter-productive.” One requested a chat area, another suggested a web cam “so the teacher can show u [sic] how to do some of the labs” and another wanted to change the look/colours of the course webpage. When asked if they would participate in a real-time question and answer chat session with the instructor, all students said they would.

Because student-student interaction is important in problem-solving and other learning in physics, the so-called “coffee shop” learning that occurs out of class with peers working through the material, the authors considered group activities and assignments to get the students working more together. However, one of the hallmarks of distance education is “anytime, anyplace” and therefore, even when students may be able to “get together” virtually online, their schedules (or time zones) may conflict and it is not the distance that separates them so much as the timing. That is not to say that group work in distance education is impossible; far from it. But it is an instructional method that takes much more planning and careful consideration (Johnson & Johnson 1996). For a number of reasons, the authors decided against formally including group work in the course. However, given that 90% of the students in the course were physically on campus, we asked whether they had gotten together to work either physically or virtually throughout the semester. Five of the six students did not physically get together with other students to work; one did at the end of the semester. Similarly, only one student got together “virtually” with others to work, logging on at the same time and using the conference area to communicate as they worked through the material. When asked whether they would have liked official group work in the course, five students replied “no”; only one said: yes” (the student who wanted group work was not one of those who met physically or virtually with others; the students who met physically and virtually to work with others both said they did not want group work to be an official part of the course). Their reasons are to be expected: conflicting schedules, hard to organize, difficult to communicate online. One student suggested that “working in groups at this [introductory] level without proper guidance in the discussions or work may not be an effective way of learning. Groups should be saved for more advanced courses and theories."

CONCLUSION

In summary, activities in this course were carefully designed to make the most of the computer technology while simultaneously addressing perceived barriers to learning physics at a distance. Students used the dozens of SPS exercises to help them learn problem-solving with immediate feedback. Labs were changed from experiments requiring esoteric and expensive equipment to approachable exercises that student performed on apparatus they built with household materials. Although the course was textbook-driven, it was enriched with over two hundred interactive applets, MAP simulations, practice tests, video clips and other opportunities for students to engage with the material. The result is a course with better retention and a significantly higher class average (65% vs. 60%) than the previous DE version; the retention and grade results are actually on par with the Physics course offered face to face.

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