COLLABORATIVE MODES OF UNDERGRADUATE PHYSICS TEACHING

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In this paper we review the literature regarding collaborative modes of physics teaching and report in some detail on the studio physics mode of instruction at Acadia University and the experiential physics teaching method at Mount Allison University.

INTRODUCTION

Every year in September, thousands of fresh new faces turn up in introductory physics courses across Canada. In late April, hundreds of faculty members grade their final exams and wonder exactly how much those students managed to learn. Over the past two decades, the field of physics education research has grown dramatically. Some of the results from this research have confirmed what many physics professors have long suspected - many students emerge from an introductory physics course having learnt very little.

Physics Education Research (PER) has indicated that interactive engagement (IE) instructional strategies are more successful than traditional modes of teaching in promoting conceptual understanding. Integrated instructional strategies and collaborative learning approaches generally achieve higher student satisfaction results as well.

A popular diagnostic used to assess student learning in introductory physics is the Force Concept Inventory (FCI) [1], a 29 question multiple-choice test that was designed to probe conceptual understanding of Newtonian Physics. There is some controversy as to whether or not it succeeds in achieving this goal, with the debate focusing on precisely what the FCI measures. [2,3,4] However, it is agreed that the FCI "is the best test currently available" [5] and that it "can still be used … as a means for evaluating instruction." [6]

Hake [7] has done an extensive study of pre-instruction and post-instruction test results for the FCI for 6542 students enrolled in 62 different physics courses, some taught by traditional methods, with others incorporating various interactive-engagement instructional strategies (IE) [8]. The purpose of his study was to assess the impact of these IE strategies on conceptual understanding and problem-solving skills in introductory physics classes. In order to facilitate comparison of these groups, he defined the Hake factor as

$$\langle g \rangle = \frac{\%\text{Correct}_{\text{post-test}} - \%\text{Correct}_{\text{pre-test}}}{100 - \%\text{Correct}_{\text{pre-test}}}$$

This is the ratio of the actual gain achieved on the test divided by the maximum possible gain. While allowing one to directly compare increases between groups who have different intitial score, the factor has the effect of giving more significance to improvements in classes where the pre-test scores are high.

In his paper, he reports that "fourteen `traditional' (T) courses (N=2084) which made little or no use of interactive-engagement (IE) methods achieved an average gain $\langle g \rangle_{\text{T-ave}} = 0.23 \pm 0.04$ (std dev)." However the "48 courses (N=4558) which made substantial use of IE methods achieved an average gain $\langle g \rangle_{\text{IE-ave}} = 0.48 \pm 0.14$". We find these results to be both sobering, in that the traditional course has such a low score, and encouraging, in that there seems to be a better way. Redish and Steinberg make a fairly compelling case for the superior effectiveness of instructional strategies that incorporate the findings of physics education research [9], such as these IE methods. Those who wish to investigate this further will find an excellent overview of physics education research with references to the relevant literature by McDermott and Redish. [13]

Another area of dissatisfaction that people have tried to address is with the laboratory component of introductory physics. In course evaluations, laboratories typically receive much lower scores than any other part of the course. The students often question the relevance of the lab material to the course material and complain of poor coordination between the lecture and the lab. In most cases, these complaints are in spite of our having chosen lab topics that are designed to enhance and illustrate concepts presented in lectures and detailed in the text. We find this failure to excite the students with the lab to be particularly disturbing.

Numerous approaches have been taken to address some of the issues outlined above. They range from doing things differently in the context of the existing framework of separate

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lecture and laboratory sections to developing new frameworks, such as the studio physics approach developed at Rensselaer Polytechnic Institute (RPI) by Jack Wilson. [11]

The process of developing an alternative approach began at RPI with a meeting which was attended by innovative educators from physics, chemistry, and mathematics, 6 architects who had experience designing innovative educational facilities, and representatives from Perkin Elmer, General Electric, IBM, United Technologies and Boeing. From this meeting there emerged consensus as to what changes needed to be made to the standard introductory courses. These were "the need to reduce the emphasis on the lecture, to improve the relationship between the course and the laboratory, to scale up the amount of doing while scaling back the watching, to include team and cooperative learning experiences, to integrate rather than overlay technology into all of the courses." In this paper, we describe our experiences with approaches that have followed closely these objectives.

Experiential Physics at Mount Allison University

Building on Physics Education Research [12,13], we have made our physics program at Mount Allison University more student centred, incorporating active and collaborative learning. We have termed our approach "Experiential Physics" with the key idea that one learns physics by experiencing physics.

Introductory physics courses at Mount Allison University had long been taught with three one-hour lectures for introducing the material and a three-hour lab every week for experimental verification of some of the principles of physics. This time-honoured tradition had a few 'problems'. It was never possible to have all the students come to the lab just after they had covered the requisite material in the class a day or two earlier. In fact the problem was even worse. For many students very often the lab covered material that was yet to be broached in a lecture. The students often viewed physics as something that had to be 'learned' from a lecture or a textbook, which would, once in a while, be verified in a lab. For a science, which is so intimately connected with experiencing various phenomena, a book/lecture bound traditional approach seemed a bit limiting and of course it never fully conveyed the pleasure of learning by actual experience. Another problem was that the learning was more tuned to individual effort related activity than a collaborative activity and we were missing out on the benefits of collaborative learning. Last but not the least concern was with the success rate and the general satisfaction level of the students that caused many students to view physics as a 'hard' subject.

To make changes we commenced with visits to some innovative physics programs [14], and also consulted the extensive literature on methods of teaching physics which lead to more active learning. We designated our approach experiential physics since the key idea was that students would learn physics by experiencing physics. Having an opportunity to build a new classroom and equip it in a way that lent itself to the discovery approach in learning greatly facilitated the transition to this style of instruction. Our move to experiential physics was initiated in the fall of 1997 in two upper level classes, followed by the conversion of our large first year course in the fall of 2000.

Experiential Physics in First Year

The most apparent change is the way in which our first year courses are taught - rather than separate lecture and laboratory components all learning is done in our experiential lab which includes an integrated mix of demonstrations and succinct lectures followed by collaborative learning experiences. The collaborative learning experiences frequently utilize computerized data acquisition and analysis tools. Individualized instruction and rapid feedback are key to the success of the program. Similar methods are used in a number, but not all, of our upper level physics courses.

The experiential offering of first year physics at Mount Allison impacts all science students at the university and has been the most widely recognized symbol of our new way of teaching and learning. Our experiential laboratory, shown in Figure 1, has 22 learning stations (class capacity is 88 students per section). Each station is equipped with an iMac computer, a PASCO data interface for both digital and analog inputs, a digital camera eye, and a variety of other instruments and equipment. The room has a document camera, two data projectors, VCR, Mac and PC computers at the instructor bench.

Fig. 1 Experiential Physics Laboratory at Mount Allison University

Each workstation accommodates up to four students and is equipped with apparatus and data acquisition and analysis facilities. Note that although there are data projectors for presentation purposes, there is no "focus" to the room.

A typical class starts with a concise lecture, which emphasizes key concepts and techniques. The major part of the period is spent with students working collaboratively in groups through lab experiences, conceptual activities, derivations, and problems. Each student records her or his work, but collaboration is encouraged and works well. We assign groups randomly and change groups about every two weeks. Each student has six hours of instruction per week (the same as in our previous lecture-lab mode). In addition to the professor, we typically have two undergraduate teaching assistants and the teaching technician in the room during activities, with all members of the team helping groups upon request. A key advantage of the approach is that theory and experiences are always well coordinated which was not always possible in our previous lab-lecture format.

We have anecdotal evidence from several informal student responses and course evaluations that the approach works well for a significant majority of students. For example, in the second year of the experiential offering of the Physics 1551 course (2 classes, total 131 student responses) students chose a mean satisfaction rating of 4.3 on a 5 point scale, and 78% responded that they preferred the experiential mode of instruction (9% preferred traditional teaching and 13% expressed no preference).

To have a quantitative measure of how well this approach worked in terms of student mastery of physics, we have compared student results with those from previous years (when a conventional 3 hours of lecture plus 3 hours of laboratory approach was used). Over the five-year period studied, the marking scheme was not altered and we were careful to maintain a similar difficulty level for the tests and exams. The data from the last five years (see Table 1) show the impact of the new approach on academic performance.

TABLE 1

Comparison of student final grades under conventional (lecture+lab) and experiential modes of instruction

		percentage of students					
		Fs	Ds	Cs	Bs	As	Total
Pre-Experiential (2 Yrs)	1999-2000	19.2	14.2	15.3	28.2	23.1	100
Experiential (3 Yrs)	2001-2003	10.0	9.0	18.5	33.2	29.3	100

A study of the results for each of the terms the course has been offered (six times so far with multiple sections and a variety of instructors) reveals a very encouraging and significant drop in the failure rate and general upgrade of the marks level. We have also noticed an increase in the attendance of classes which, although driven by the way the course is handled, could be a contributor to the gratifying result of moving to this way of teaching. Over all our experience with the introduction of this approach has been very positive and we intend to continue to use it in our courses in the future.

The conversion of several upper level courses and our large first year course to active learning, collaborative modes of instruction was a less difficult task than some of us predicted. With very few exceptions students embraced the non-traditional mode of instruction, and the atmosphere in our learning rooms is remarkably focused, positive and productive. Undergraduate teaching assistants accepted the challenge of their new and expanded roles, and, while the initial conversion was taxing on staff, once the system was in place teacher demands are not much different from our previous traditional system of instruction.

Experiential Physics Beyond First Year

While one of the signature features of our program is the offering of all first year sections in a collaborative, hands-on style in our "experiential" physics lab, our commitment to experiential learning is much broader than any one course. Essentially we sought to model the way students learn physics after the working lives of professional physicists. We wanted to build in a balance of inquiry, reflection, research, development, teaching, service, outreach, and oral and written communication. While no one of the following distinguishes us from most other physics departments (and indeed many of these are cited in the article on strong undergraduate physics programs by Hilborn & Howes [15]), we have sought to achieve this through the following:

(a) Undergraduate research is emphasized with a strong compulsory honours thesis component (including oral presentation) and other opportunities for special topics and summer undergraduate research. Each year several of our students author peer-reviewed articles based on their research.

(b) A system of undergraduate teaching assistants provides most majors with physics teaching experience. A certificate program recognizes student teaching assistants who meet a series of criteria including TA training sessions.

(c) We encourage our students to attend, and when appropriate to present at, regional, national and international research conferences, and as possible we seek to provide our students with national and international collaboration experiences as part of their undergraduate research.

(d) A strong student-run Physics Society brings faculty, staff and students together for educational and social activities and builds a sense of community.

(e) Students play a key role in the administration and direction of the department. For example, students in second, third and fourth year elect representatives to department meetings, and a student serves as a full member of each faculty search committee.

(f) In a variety of ways students reach out to the local community in sharing their physics expertise (e.g. school visits, presentations, open houses, etc.)

(g) Most of our upper level classes have opportunities for students to do independent work and present the results orally and/or in writing.

Studio Physics at Acadia University

In March 1996, Acadia University introduced the Acadia Advantage, an initiative which now sees all students at Acadia leasing laptop computers. In physics research, computers have had a legitimate role to play for decades. They are used for modeling, simulation, control of experiments, data acquisition, visualizing and analyzing results…. an almost endless list. It seems quite natural that computers should also play a large role in physics education. We decided to implement a studio model of teaching physics that relied heavily on computers.

Studio teaching is unlike the traditional 3-hour lecture, 3-hour lab format used in most universities for the teaching of science courses. In the original studio model, about 50 students are taught by an instructor assisted by a senior teaching assistant, usually a graduate student or demonstrator. An undergraduate teaching assistant may also be involved. There are normally two, 2-hour sessions per week and there is no separate lab component. Typically, a session begins with a review of material assigned the previous day followed by a short introduction to new material. This procedure requires about one-half hour. The students then engage in an activity, computer-based or not, which is designed to explore the new material. The computer is used as a tool to solve problems, run simulations, analyze videos or acquire data from experiments set up on the studio worktable. During this time, the instructors circulate throughout the room, monitoring student progress and giving assistance wherever needed. This activity lasts about one-and-one-quarter hours. The remaining time is spent reviewing the lessons just learned and assigning material to be reviewed for the next day. An important consequence of studio teaching is that greater responsibility is placed on the student to monitor his/her own studies and to review and prepare materials for each studio session.

The integration of lab work directly into the course ensures that the lab and course material are in step and makes the lab work more relevant. The majority of the lab exercises are microcomputer-based labs (MBL). Sensors to measure position, force, acceleration, voltage, current, temperature, etc. are connected directly to the computer, permitting rapid and accurate data acquisition. This allows more time for data analysis and interpretation. In addition, digitized video allows the students to easily acquire 2-dimensional position versus time data for a wide variety of interesting phenomena in mechanics - projectile motion, collisions, rotational motion, energy conservation, the list goes on. Clearly, digitized video allows one to analyze motions that had hither-to been difficult, if not impossible, to do in an introductory lab. A common feature of both the MBLs and the video analysis is that they permit the students to measure directly the quantities of interest. For example, when investigating simple harmonic motion, it is possible to simultaneously measure the force exerted on a mass and the position of the mass. Plotting force versus position permits a determination of the spring constant. The position data is of sufficient quality that it can be differentiated to get velocity and acceleration permitting a wealth of investigations.

The students work in groups of two or three which facilitates discussion and student-student interaction. The instructors can circulate through the class during these activities and the opportunities for faculty-student interactions are excellent. The students spend the bulk of their class time actively solving problems, making measurements, or analyzing data, while very little time is spent listening. The studio classroom is a pleasantly noisy environment where students and their teachers are actively engaged in doing physics.

Our initial pilot of studio physics involved 20 students. It was run in parallel with a traditional class of approximately 92 students and we did an extensive study of student performance in both classes. [16] We compared both classes on the basis of high school performance, assignments, lab work, midterms, lab exam, final exam and Force Concept Inventory. While the two classes were statistically similar in terms of their high school grades and FCI pretest, we found that the studio class achieved statistically higher academic performance on every measure that we used. We also found that course evaluation results indicated that the studio format was judged to be very effective by the students themselves.

However, when we computed the Hake factors, we found $\langle g \rangle_{studio-ave} = 0.21 \pm 0.13$ and $\langle g \rangle_{lecture-ave} = 0.1 \pm 0.1$ for the studio and lecture sections, respectively. This seems to indicate that the studio format does not significantly promote greater conceptual understanding of physics as measured by the FCI. The studio results also agree with a study done at RPI. [17] However, it was quite clear that the studio model was more effective than our traditional lecture model based on all other measures of academic performance.

Based upon this apparent success, we decided to teach all of our calculus-based introductory physics classes in a studio format. However, after our first term of doing this, there was dissatisfaction with the format both from students and faculty. Students reported that they would like to have more lecturing and faculty felt that the introductions to the activities were too brief. In response to this, we have developed and implemented a blended model of instruction which we feel retains the features of the studio model while allowing more lecture time.

The class meets for three one-hour lectures per week on Monday, Wednesday and Friday mornings. On Monday and Wednesday afternoon, students attend a 2-hour studio session that deals with material covered in the morning's lecture. The studio session is still a highly interactive, engaging, collaborative learning experience covering material that is very tightly connected to the material covered in class. With the removal of the introduction to the material from the studio session, we find that we can accomplish more in the studio sessions. On reflection, we feel that it is a more balanced approach that is capable of accommodating a broader range of learning styles than the pure studio approach which had minimal lecturing.

Looking Ahead

The task to revitalize and enhance our physics programs is not complete, however. We would like to briefly cite issues that require future consideration.

FROM COLLABORATION TO INQUIRY:

We have successfully transformed much of our instruction from relatively passive lecture and lecture demonstration modes to having students work in hands-on and minds-on collaborative group work. However, collaboration does not ensure true inquiry, and devising questions for investigation which are educationally instructive, at the right level, interesting, and promote true inquiry learning is a challenging and ongoing task.

PERCEPTIONS ABOUT PHYSICS:

Beyond modifying the instructional experience, there is evidence that indicates that other factors play a significant role in effective instruction. One must take into account not only the students prior physics knowledge, but also their perception of what the learning task is. [18] If students perceive that physics is a collection of weakly connected pieces of information, they may think that knowing facts, formulae and problem solving algorithms constitutes understanding physics.

ASSESSMENT TECHNIQUES:

Tests and other assessments are the most important indicators for students of what the teacher considers to be important in the course - "Is this going to be on the test?" It has been shown that assessment guided the student's judgment of what was important to learn and affected their motivation and approach to studying. [19] If the test focuses on factual knowledge, the student will learn to memorize; if the test requires analytical thinking the student will learn to reason analytically. Clearly, assessment strategies need to be aligned with instructional practice and desired outcomes.

BEYOND THE COURSE STRUCTURE

We have retained a traditional course structure for our upper level courses. Some form of conceptual realignment into a spiral learning style which emphasizes the small number of key concepts in physics, such as that developed at Oregon State University, [20] deserves consideration.

CURRICULUM REVISION

While our program, both at the first year level and beyond, is more modern and less traditional than many physics programs, it is time to consider more radical changes in what we teach to complement the changes in how we teach. The directions recently proposed by the CAP Division of Physics Education Task Force on revitalization of the physics program [21] are currently being considered.

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