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ABSTRACT

The last two decades have witnessed a growing trend away from the traditional modes of instruction in physics courses at all levels, from high schools through universities. The reasons for this, as well as some commentary on several non-traditional styles of physics instruction, are presented in this paper. The article does not attempt to promote any one style over another because it is clear from numerous sources that almost any form of interactive learning produces improved conceptual understanding. The purpose of this paper is to discuss some of what is currently being done in physics education and to impart some quantitative results. The paper also reports on the following non-traditional teaching/learning styles: (1) Peer Instruction (Lectures consisting of short presentations on key points followed by a Concep Test, which students formulate answers for and discuss with each other); (2) Collaborative Instruction (Students taught using a non-traditional style make use of collaborative exercises based upon lecture materials); (3) Overview Case Studies and Active Learning Problem Sets; (4) Tutorials; (5) Workshop Physics; and (6) Expert versus Student Problem Solving. Overall assessment and recommendations for community colleges are presented at the end of the paper. (Contains 42 references.) (VWC)

NON-TRADITIONAL TEACHING STYLES IN PHYSICS

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Introduction

The last two decades have witnessed a growing trend that is away from the traditional modes of instruction in physics courses at all levels, from high schools through universities. The reasons for this will be mentioned in the following section. In addition, this paper will provide some commentary on several non-traditional styles of physics instruction. This is not to be viewed as an attempt to promote any one single style over another because it is clear from numerous sources that almost any form of interactive learning produces improved conceptual understanding.[1] The purpose here is to present some of what is currently being done in physics education and to present, as much as is possible, some quantitative results. Overall assessment and recommendations for the community colleges are presented at the end of the paper.

The Eye Opener and Peer Instruction

Now, imagine that it is 1990 and you are a professor of physics at Harvard University who has been teaching the calculus-based physics courses for six years. You firmly believe that your students are receiving the best instruction possible, and furthermore, you also firmly believe that your students have not only developed problem solving skills but they are also capable of answering questions about the most basic and elementary physics concepts. After all, you taught them.

You read a series of articles by Halloun and Hestenes[2] that more than arouses your curiosity about your "firm" beliefs concerning your students' basic knowledge of physics. The authors claim that traditional teaching styles do not improve the students' understanding of the basic concepts in the first semester of a calculus-based physics course. The misconceptions that students have concerning physics before taking a class in physics seem to persist after traditional instruction even for physics majors on and into graduate school.[3] The students are capable of answering algebraic and numerical problems but they have a great deal of difficulty with conceptual questions. These authors provide a Mechanics Diagnostic Test that may be used to explore students' concepts in physics. You decide to use their diagnostic test to prove to yourself that your students could not possibly do poorly on this type of exam. The results of the test come to you as a complete shock. How could your students do well on conventional problem solving and, at the same time, have no basic understanding of the underlying physics? Even good students had trouble with the test. You begin to realize that, your thorough, complete, and coherent lectures notwithstanding, there is a serious problem in physics education using traditional lecturing styles.

This "eye opening" realization confronted Professor Eric Mazur who has subsequently published a book[4] concerning his efforts to fix this deplorable situation using non-traditional teaching and learning styles. His lectures consist of short presentations on key points followed by a *Concep Test* containing short conceptual questions on the previous material. Students are given time to formulate answers and discuss them with each other. The *Concep Test* has the following general format;[5]

1.	Question posed	1 minute
2.	Students given time to think	1 minute
3.	Students record individual answers (optional)	
4.	Students convince their neighbors (peer instruction)	1-2 minutes
5.	Students record revised answers (optional)	
6.	Feedback to teacher: Tally of answers	
7.	Explanation of correct answer	2+ minutes

The *Concep Tests* take up about one third of each class so that a choice must be made about coverage of the material for the course. Mazur selectively covers certain key topics leaving the rest of the material, including worked examples and most derivations, for the students to read and study, just as they must do in other courses.[6] This may not work as well at the community college level where practically every student works at least 20 hours per week.

Collaborative Instruction

Attendance at the Faculty College in 1992 gave me exposure to the idea of non-traditional teaching styles from many disciplines, but none from physics. The topic that summer focused on the results of research done by educators on the learning styles of students. I, like Mazur, thought that my lectures were the best possible for student instruction in physics. The papers that Mazur read had slipped by me. However, attendance at the Faculty College made me curious, so I subsequently developed a series of conceptual questions to be used as pre- and post-semester tools for assessing the value gained by the students in the first semester of the calculus-based physics sequence. The pre- and post-semester tests were administered to classes taught in the traditional style as well as classes taught in a non-traditional style. The non-traditional style made use of collaborative exercises in physics which the students worked on in six groups numbering about four students per group. These exercises were generally on material previously lectured upon and discussed in class, or in some cases, on material from reading assignments. About 10 to 15 minutes of time was allowed for each exercise with the instructor walking around to each group offering corrections to work already done or suggestions as to how the students should proceed. The students became active learners rather than passive ones.

Professor Paul D'Alessandris at Monroe Community College is the only other person that I know nearby who uses something similar to collaborative exercises.[7]

Overview Case Studies (OCS) and Active Learning Problem Sets (ALPS)

Alan Van Heuvelen originally at New Mexico State University and now at Ohio State University has been deeply involved with a departmental effort involving 30% of the faculty to improve all introductory physics courses. Use is made of collaborative peer instruction and employment of undergraduate students to augment the instructional staff.[8] In addition, use is made of Van Heuvelen's Overview Case Studies[9] and his Active

Learning Problem Sets[10] with context-rich problems, and interactive simulations with worksheets.[11]

Professor Ronald Gautreau at New Jersey Institute of Technology has been using OCS and ALPS for a number of years with great success. The ALPS are used in the first semester of the calculus-based physics sequence for a period of about four weeks to develop solid conceptual understandings of motion. He is convinced that student learning has greatly improved because of his change to a non-traditional teaching and learning style.

Tutorials

Lillian McDermott and her collaborators of the Physics Education Group at the University of Washington have made careful studies of students' understanding of Newton's laws of motion, particularly Newton's third law of motion (action and reaction).[12] Conceptual and reasoning difficulties of the students were identified using carefully designed questions. McDermott's group has successfully diminished those difficulties by designing research-based worksheets which guide the students through the kind of questioning, analysis, and experimentation that is necessary to solidify the concepts involved. Although the University of Washington still uses the large lecture format, they have replaced recitations by tutorials where students work in groups of three or four on the carefully designed research-based worksheets.[13] Students must make predictions and consider various lines of reasoning in order to gain an understanding of the basic concepts in physics.[14]

Workshop Physics[15]

On February 19, 1999 I visited one of the workshop physics classes at Dickinson College in Carlisle, Pennsylvania. The class was taught by Hans Pfister who graciously permitted me to sit in on the two-hour session. This class was in the second semester of a two-semester calculus-based physics sequence. The subject was Kirchhoff's Laws, related to electric circuits. The room had six work stations equipped with microcomputers and the apparatus necessary for the students to conduct their inquiries. The room also had a very large open area in the middle. I learned later that this large open area was used for kinesthetic experiments and demonstrations. The kinesthetic experiments were done mostly in the first semester whereby students became actively involved in various experiments dealing with motion and forces. The students experienced motion and forces acting on them in a very direct way through a series of carefully designed activities.

During my visit, Professor Pfister explained the nature of electric circuits and Kirchhoff's Laws at the beginning of the class using a lecture style not too different than anyone else's, using straight lecture, simple board techniques, a model circuit, all interspersed with leading questions to individual students. When the explanation was completed the students began working on questions in their workshop physics activity guides.[16] They then began building some simple circuits to test the validity of Kirchhoff's Laws. During this time Professor Pfister and teaching assistants (upper level students who previously took the course) visited each group to help with concepts and the correct use of the equipment.

The students are graded on homework assignments, the activity guides, and regular examinations. The classes meet three times per week for two hours each. There was a very friendly and open atmosphere between the students, the TA's and the Professor. Most of the "real" learning was done by the students in the social atmosphere of the peer group. Unfinished experimental data could be obtained after class hours because the workshop physics room was continually "manned" by the TA's.

Expert versus Student Problem Solving

A study was conducted by Larkin and Reif at the University of California, Berkeley and later at Carnegie-Mellon University to compare the problem-solving approach of an expert with that of an excellent student.[17] They discovered that the expert made use of an understanding of physics concepts and a well-developed knowledge structure of how the physics fits together as opposed to the student who used superficial mathematical manipulations without deeper understanding.[18] Consequently much effort has been expended over the last 20 years into identifying the fundamental concepts and the difficulties that students have with them. Lillian McDermott and the Physics Education Group at the University of Washington have spearheaded research in this area.[19] It is to be pointed out that additional research must be done on many topics. including students' ability to apply concepts in problem solving, students' reasoning and their use of mathematics in problem solving, as well as the impact of technological improvements on what students learn.[20]

Results

Because of the previous research on the conceptual component necessary for problem solving, David Hestenes, Malcolm Wells, and Gregg Swackhamer[21] have developed the best currently available conceptual assessment test[22] to be used in the first semester of an introductory physics sequence. It is suggested[23] that this 29 question test, the Force Concept Inventory (FCI), be given at the very beginning of the semester and then later on at about mid-semester or toward the end of the semester for evaluating students' conceptual gains in understanding basic physics principles.

Hake[24] has developed a basic measure for evaluating the gain in conceptual knowledge about physics using the FCI test. Boller has previously used the exact same measure for evaluating the gain on his own conceptual exam. This measure is known as the Hake factor, h, as coined by Redish and Steinberg.[25] The Hake factor is defined as follows:

$$h = \frac{\text{post-test\%} - \text{pre-test\%}}{100\% - \text{pre-test\%}}$$

The results are given in the following table.

Instructional Type	Hake Factor
Traditional Instruction	0.16 ± 0.03 [26]
Peer Instruction	0.56[27]
Collaborative Instruction	0.32[28]
OCS, ALPS	0.42[29]
Tutorials	0.35 ± 0.03 [30]
Workshop Physics	0.41 ± 0.02 [31]

It is clear that there is a significant gain in the conceptual understanding for those students enrolled in the non-traditional courses presented in this paper. There are other non-traditional instructional methods that have not been specifically addressed, such as the tools for scientific thinking developed by Thornton and Sokoloff.[32] It is emphasized that this is only the first step in a long process devoted to the identification of those methods which work best to attain the very best in physics instruction.

Traditional Style Comments

One difficulty with the traditional style of teaching lies with the information written down on the board by the instructor. Usually, in physics, this information is in the form of equations. The students carefully copy these equations into their notes but neglect the extremely important words spoken by the instructor about the equations, such as how they came to be, what they mean, how they are to be applied, and their limitations.

Another problem confronting the implementation of non-traditional styles into two year colleges is the perception by physics instructors that such methods are being used to replace work done by the students outside of the classroom because of the extremely high working hours borne by the students. But, it is clear from the recent evidence in physics education research that the students' exposure to non-traditional teaching methods will improve their conceptual and appropriate cognitive attitudes which are necessary to improve their problem solving skills.[33]

Goals of Physics Instruction, Personal Assessment

The following table includes nine important skills that I consider to be extremely important goals for students to be able to achieve in their introductory calculus-based physics courses. The degree of success of the traditional versus the non-traditional styles of physics instruction at achieving the goals are qualitatively compared.

GOAL	TRADITIONAL	NON-TRADITIONAL
Conceptual understanding of physics	poor	excellent (all)
Interpretation and construction of graphs	poor	excellent (all)
Data analysis	poor-average	excellent (Workshop Physics)
Numerical computation	average	excellent (Workshop Physics)
Computer skills and software application	poor-average	excellent (Workshop Physics)
Simple algebraic solutions to problems (one step)	not assessed	not assessed
Involved algebraic solutions to problems (two or more steps)	not assessed	not assessed
Detailed algebraic solutions to problems from first principles	not assessed	not assessed
Derivations of formulae or detailed algebraic solutions to problems involving calculus	not assessed	not assessed

These evaluations have been done on the basis of what is currently being written about in the literature. It is clear that much remains to be done in physics education research to further improve physics instruction.

Summary and Recommendations

There is one common thread that runs through the various non-traditional teaching styles in physics presented in this paper. All of them focus on interactive, experiential, and social models to improve conceptual understanding of the underlying physical principles and reasoning ability.

Four year colleges and universities have been at a tremendous disadvantage because of their large lecture classes. Their recitation classes, although smaller in size, offer no important gains in the teaching of physics if lecturing and problem solving by the instructor is merely "witnessed" by the students. "Serious conceptual and reasoning difficulties cannot be overcome through teaching by telling."[34]

The students at the community colleges have the same conceptual and reasoning difficulties as their counterparts at the four year colleges and universities. The community colleges have been fortunate, in that large lecture classes in physics are not the norm. In this sense, community colleges do not need to restructure large lecture classes. All that needs to be done is to focus upon one of the non-traditional models and implement it. Some models, such as Workshop Physics may be impractical because of the large staff needed to run such a program. Nevertheless, Carolyn Haas at Salem Community College is using a combination of workshop physics and tools for scientific thinking.[35] She is of the opinion that to be 100% successful, a stand-alone workshop physics curriculum needs a staff member for every 6-8 students.[36]

If the reader teaches physics, especially at the community college level, you are strongly urged to read the references cited in this paper. Begin with the articles by McDermott[37] and then proceed to Mazur's book which is a delightful 42 pages of quick but very informative reading, which even includes a sample "lecture." The rest of his book is devoted to various forms of tests, quizzes and exams, one of which was alluded to in this paper, namely the Force Concept Inventory Test (FCI). Mazur also includes a more advanced 26 question test called the Mechanics Baseline Test (MB). In addition to Mazur's book the Force Concept Inventory Test[38] and the Mechanics Baseline Test[39] are available for anyone to copy and use. The articles by Hake[40] and Redish and Steinberg[41] are excellent for their current analyses of the data as well as good sources for references, especially the article by Hake. A paper to be published by McDermott and Redish[42] in the American Journal of Physics promises to be the most comprehensive to date on this subject. It also contains more than 200 references. Look for it, or e-mail Redish for a preprint.

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28. B. Boller, see table and chart at the end of this paper.

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