Excerpt from revised application 167/96 *Experientially based physics instruction — using hands on experiments and computers* to the Council for the Renewal of Undergraduate Education.

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Rationale for change in Physics Teaching

Some findings of Physics Education research

Some years ago I started to include some ”simple” conceptual questions in the exams of the physics courses I taught. These questions could be answered by qualitative reasoning and no calculations was needed. I was first quite surprised of the results: Most students performed very poorly on the conceptual questions which I considered to be almost to ”easy”, while they sometimes solved ”difficult” multiple-step quantitative problems better than I expected. Some of the ”top” students with high scores on the quantitative problems had very low scores on the conceptual part.

My ”discovery” is in good agreement with the results of recent Physics education research which have shown that most students even at the university level do not learn basic concept as a result of standard instruction and often graduates with unaltered misconceptions and may have deep misunderstandings [Many papers, conference proceedings and books deal with student preconceptions and misconceptions in physics. Good reviews can be found in: Arons (1997) and Wilson (1997)]. Research has shown that a majority of students entering and leaving basic undergraduate physics

- do not understand the meaning of velocity and acceleration
- fail to distinguish force from momentum
- fail to distinguish heat from temperature
- have inappropiate understanding of the relation between voltage and current
- fail to distinguish mathematics from physics and
- fail to distinguish a hypothesis from an experiment.

One reason for this can be found in Cognitive science [See, for example Redish (1994)] and it is proposed that people tend to organise their experiences and observations into mental models. The students comes to us with approximately 20 years of real-world experience and this experience have formed strong mental models called preconceptions (ideas held before instruction). These preconceptions may be incomplete and contain contradictory elements and also be misconceptions. This means that our students are not blank slates to be filled with teacher wisdom and that misconceptions in the mental models of students must be effectively addressed in a physics course. Unfortunately cognitive studies and physics education research have shown that it is very difficult to change an established model

substantially. To change an established mental model into a new one the new model must be [Posner *et al.* (1982)]:
1. understandable,
2. plausible,
3. be in strong conflict with predictions based on the existing one and
4. the new model must be seen as useful.

At a meeting at Tufts University, USA, the participating physics education researchers reached an agreement on the following points [See McDermot (1997) or Thornton (1997)]:
- Facility in solving standard quantitative problems is not adequate criterion for functional understanding. *Questions that require qualitative reasoning and verbal explanation are essential*.
- A coherent conceptual framework is not typically an outcome of traditional instruction. Rote use of formulas is common. *Students need to participate in the process of constructing qualitative models that can help them understand relationships and differences among concepts*.
- Certain conceptual difficulties are not overcome by traditional instruction. *Persistent conceptual difficulties must be explicity adressed by multiple challenges in different context.*
- Growth in reasoning ability does not usually result from traditional instruction. *Scientific reasoning skills must be expressly cultivated.*
- Connections among concepts, formal representations, and the real world are often lacking after traditional instruction. *Students need repeated practice in interpreting physics formalism and relating it to the real world.*
- Teaching by telling is an ineffective mode of instruction for most students. *Students must be intellectually active to develop a functional understanding*”

Some effective instructional models in Physics Teaching based on Physics Education research

Over past few years a number of active engagement curricula based on the constructivist model of student thinking and learning have been developed. The common denominator of these curricula is that they encourage active learning and peer cooperation and that they adresses student misconception in a constructivist mode. Active engagement classes can be dividen into fourgroups. In the *full studio* classes, the entire class time is taken up by periods in which the students are actively engaged with exploring the physics using some laboratory equipment. Only a small fraction of the period may be spent with a teacher lecturing to the students. These classes tend to be more expensive, both in terms of faculty time, space, and equipment required than the traditional lecture format. Other models of instruction have therefore been developed that replace one or more of the elements of the traditional structure by an active engagement activity. *Laboratory-based* models replace the traditional laboratory by a discovery type laboratory. *Recitation-based* models replace the recitation in which an instructors models problem solving for an hour by a mini-lab in which the students carry out guided discovery experiments and learn reasoning in groups guided by worksheets. *Lecture-based* models retain the timing and the lecture hall, but modify the activities carried out by the students during lecture.

Full Studio Models

- Physics by Inquiry (Lillian McDermott, et al., University of Washington)
- Workshop Physics (Priscilla Laws, Dickinson College)
- The Physics Studio (Jack Wilson, Rensselaer Polytechnic Institution)

Discovery Labs

- Tools for Scientific Thinking (R. Thornton, Tufts; D. Sokoloff, U. of Oregon)
- RealTime Physics (R. Thornton, Tufts; D. Sokoloff, U. of Oregon and P. Laws, Dickinson College)

Lecture Based Models

- Active Learning Physics System (Alan van Heuvelen, Ohio State University)
- Peer Instruction/ConcepTests (Eric Mazur, Harvard University)
- Interactive Demos (R. Thornton, Tufts; D. Sokoloff, U. of Oregon)

Recitation Based Models

- Cooperative Problem Solving (Ken and Pat Heller, University of Minnesota)
- Tutorials in Introductory Physics (Lillian McDermott, et al., University of Washington)
- Mathematical Tutorials (E. Redish et al., University of Maryland)

Summary of some active engagement methods methods used in introductory physics courses taken from a talk given by E Redish, at the 1997 Dickinson Summer seminar: *Teaching Introductory Physics Using Interactive Teaching Methods and Computers*.

Full Studio Models

Physics by Inquiry

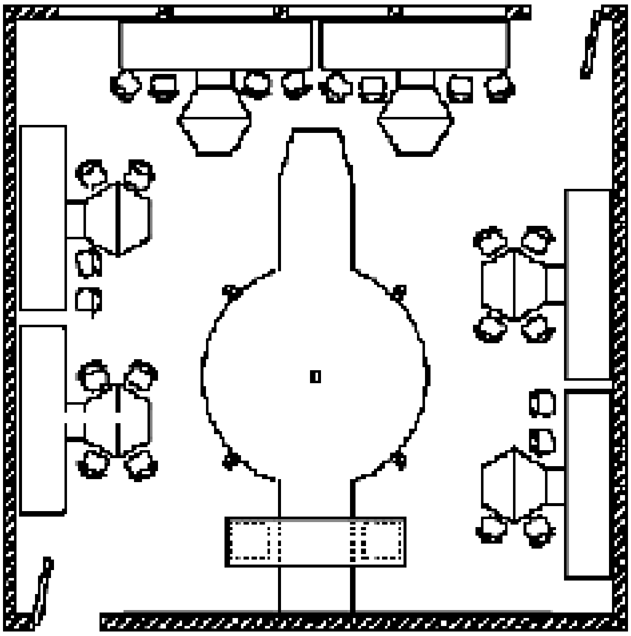
One of the earlier prototypes of the full studio courses was Physics by Inquiry, developed by Lillian McDermott and her colleagues at the University of Washington over a period of nearly two decades. The course was developed for students studying to be teachers (pre-service teachers in the American terminology). The course is a full guided discovery laboratory. There is no lecture, only two laboratory periods of two hours each. During these periods, students work in pairs with simple equipment and are guided to reason through physical examples with simple apparatus and carefully prepared worksheets. The worksheets are based on research in student understanding and try to put the students in situations where their confusions will be elicited in their predictions of how a system will behave. When the system fails to behave as the student predicts, a cognitive conflict results. Trained facilitators (approximately one for every 10-15 students) help students to find their own path to understanding by guiding them with carefully chosen questions.

Workshop Physics/Physics Studio

Among the groups that have developed inquiry style classes for the calculus-based university physics course, two stand out. Both the Workshop Physics class developed at Dickinson College by Priscilla Laws, and the Physics Studio developed at Rensselaer

Polytechnic Institute by Jack Wilson, make strong use of computer equipment to give the student a more quantitative view of the world.

Workshop Physics is an activity-based approach to teaching introductory physics without formal lecture. Students enrolled in Workshop Physics work in small groups to predict, observe, discuss phenomena, derive equations and perform quantitative experiments using MBL-computer interface and equipment, spreadsheets, modeling and digital video analyses.



The workshop physics classroom at Dickinson College.

Studio physics uses newly constructed "studios" in which classes with approximately 50 – 60 students are taught in a novel setting which incorporates lecture, recitation and laboratory in one class. Studio physics make extensive use of tutorial material and during one class short laboratory experiments and computer simulations are introduced.

Lab-based

The lab is the single item in a traditional physics course where the student is expected to be actively engaged during the class period. Unfortunately, in many cases the laboratory has turned into a place to either "demonstrate the truth of something taught in lecture" or a place to "produce a good result". The focus in both of these cases is on the content and not on what might be valuable for a student to learn from the activity. In the USA, "cookbook" laboratories -- ones in which highly explicit instructions are given and the student doesn't have to think -- are common. They are unpopular with students and tend to produce little learning. A number of interesting "guided discovery labs" have been developed in the past few years that appear to be more effective.

Tools for Scientific Thinking

Ron Thornton at Tufts University and David Sokoloff at Oregon State have developed Tools for Scientific Thinking -- a series of guided discovery laboratories in the areas of mechanics and thermodynamics. These units focus on concept building and overcoming those student misconceptions and difficulties that researchers have found to be common. These laboratories rely on computer-data-acquisition equipment similar to that of Workshop Physics but are created as modules which can be used in a more traditional laboratory format. They make extensive use of cognitive conflict and peer interaction. Thornton and Sokoloff have done extensive research to demonstrate the effectiveness of this approach. These materials are appropriate for the high school and introductory university level and focus on a conceptual rather than quantitative approach.

RealTime Physics

Thornton, Sokoloff, and Laws have recently combined to develop a new series of mechanics laboratories that can be used in a traditional structure. These are similar in spirit to both Tools for Scientific Thinking and Workshop Physics. Heavy use is made of computer assisted data acquisition and the results of research on student difficulties. A more quantitative approach appropriate for calculus-based physics is developed.

Lecture Based Models

A number of interactive-engagement classes have been developed that work within the lecture format.

Peer Instruction/ConcepTests

Eric Mazur at Harvard University has modified his lectures by including three to four "concept tests" in each hour of lecture. After a 10-15 minute lecture segment, he presents a challenging multiple choice question to the class. This question is concept oriented and the distractors are based on the most common student difficulties as shown by research. Students answer the questions at their seats. As a result of the careful choice of question and distractors, the class usually is divided as to what they believe is the correct answer. Mazur then instructs the students to discuss the problem with their neighbor for 2-3 minutes. At the end of this period, the students answer the question again. Usually the discussion has produced a substantial improvement. If not, Mazur presents additional material. The combination of research-based concept tests with peer interaction makes these lectures into an active-engagement environment for the student.

Interactive Demos

One recent development that may prove both effective and efficient is a series of interactive lecture demonstrations for mechanics by Thornton and Sokoloff. They have adapted their successful microcomputer-based laboratory curricula and used the results of their research into student learning to create a series of demonstrations that focus on the issues that are fundamental to student understanding of mechanics. These demonstrations are delivered to a large lecture by trained demonstrators for a few lecture periods during a semester. In order to get the students actively engaged, they have each student fill out a worksheet during the demonstration. The students are called on to make (and write down) their predictions and are led to discuss the results for a few minutes with their neighbors as in the Mazur method.

Preliminary results show very strong improvement compared to normal non-interactive lecture classes.

ALPS
Alan van Heuvelen at Ohio State has developed a series of worksheets for use in a large lecture format. Small bits of lecture are alternated with individual student activities and peer discussion, as in Mazur's model. This is similar in spirit to the other two lecture models discussed above but does not rely on heavy (and expensive) doses of technology.

Recitation-Based Models

Two models have obtained significant improvement in building students' conceptual understanding with a limited amount of modification of the traditional model. They only introduce interactive engagement activities in place of the recitation section, one hour per week.

Cooperative-Problem Solving
Pat and Ken Heller at the University of Minnesota and their collaborators have developed a group-learning problem-solving environment in which students work together in recitation on problems they have not previously seen. These problems are "context- rich", that is, they involve realistic situations, may contain incomplete data, and may require the students to pose a part of the problem themselves. The problems are intended to be too difficult for any individual student to solve. Groups are formed to include students of varying ability and students may be assigned specific (and rotating) roles to play in each group. Recently, the Hellers have extended their method to include the laboratory and have modified some lectures to be more interactive. The combined results seem to be highly effective.

Tutorials in Introductory Physics
McDermott and her group have developed a method for introducing inquiry type sessions into recitations. The traditional "the instructor models problem-solving while the students watch passively" is replaced by group learning activity with carefully designed research-based worksheets. These worksheets emphasize concept building, qualitative reasoning, and make use of cognitive conflict with trained facilitators to assist in helping students resolve their own confusions.
At the University of Maryland a series of tutorials have been developed that uses the data acquisition tools of the studio classes and focuses on the use of mathematical concepts in physics. In tutorials, specific student conceptual difficulties are targeted.

References

(Only papers and books referenced in the application are listed below. The application were based on a much more extensive reference list)

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