My Introductory Physics Class: An Analysis
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I taught university physics for 13 years before studying the research on teaching university physics which has been presented in Physics 620. Considered by my peers and students as a very active and innovative instructor, I was also very passionate about working to improve my courses. However, it never occurred to me that there might be a systematic body of research available which I could have studied and adapted to the benefit of my classes. The only resources I utilized were review materials which had been sent from publishers for possible course adoption. Beyond that, my approach was one of trial and error.

What follows in this paper is an attempt to evaluate my former approach and techniques retroactively in light of the body of work we have studied in Physics 620. I will concentrate on the introductory, 1 semester course which I taught many times. The Physics 101 class attracted a wide variety of students. Over half of the students took the course as a requirement for their nursing degree. Some students took the course to prepare them for the more advanced courses in physics. The rest took it to satisfy a science requirement for general studies.

PART 1: Directed Arguments

We have studied many approaches to teaching physics in this course. But, the technique which resonated most deeply with my own approach was that described by Eric Mazur in his book and video entitled “Peer Instruction”. Early as a physics instructor, I too discovered the power of student interaction in their development of conceptual understanding.

Since I encouraged all of my students to take full advantage of my office hours, I would typically have 2 – 5 students in my office at any one time. Because the students would come in and out on their own schedules, I would often find myself explaining the same question to a newly arrived student in the presence of other students who had already heard the explanation. As I would go through my routine, the waiting students would often interject comments and insights when the new student faltered in their understanding. Like Mazur, I quickly found that the waiting students often had deeper insights than I did into the misconceptions of their peers. I developed an approach to tutoring where I would involve the students in what I called “directed arguments”. “Arguments” because the students would try to persuade each other with arguments. “Directed” because I would be observing and refocusing if necessary. Not only did the new students learn quicker, but the “explaining students” would reinforce their own knowledge and often confront new misconceptions as they worked to persuade other students of their arguments.
As the students would interact, I would interject comments only as a last resort, and then only to redirect their argument back on track. And as the students interacted, I would always take notes on their comments. I took notes for two reasons. First, I was studying student misconceptions to find new conceptual questions that I could use to provoke discussion. And second, since I made all of my past tests available to my present students for study, I was constantly in the process of developing new questions. The students themselves proved to be an inexhaustible source of ideas for conceptual distracters which I could never have imagined on my own.

The “directed arguments” were so successful in my office hours, I sought to include them into my lectures. Eventually, I moved to a form of teaching similar to Mazur’s Peer Instruction. I organized each class around a series of questions to elicit class arguments. The students would buy the collection of questions in the form of a “Class Notebook” in the school bookstore. My intent was to make my entire class follow the pattern of the directed argument. I hoped to maximize student interaction while minimizing my own input. As you will see, there were two big differences between my approach and Mazur’s. First, I did not “lecture” at the beginning of class. Instead, I imbedded the lecture material in the body of the directed questions. When I was introducing something that was new, I would be the one answering the question. Secondly, it never occurred to me to have the class break into discussion groups so every student could participate in every question. Instead, I acted as a moderator to move the argument along and try to include as many students as possible.

See attachment 1 for a complete sample taken from my Class Notebook. Annotations are provided to indicate what would be going on in class.

My technique worked well in small classes. When I would have larger classes (over 60), I found myself working with the 30 or 40 students in the front of class, relegating the rest of the students to spectator status.

I often found there were students who initially scored very well on the problem oriented exercises, but very poorly on the conceptual multiple choice questions. The scenario was always the same: They would come to my office to express their frustration at having scored so badly on the multiple choice questions included with the first exam. They could understand the answers “perfectly” once I explained them, but they seemed incapable of finding the right answer on their own. They knew how to study for the standard types of formulaic questions they had encountered in previous courses, but they wanted my advice on how they could study for the conceptual questions. I would tell them the truth: I didn’t know exactly how students improved their conceptual understanding, but I had seen them do it over and over. I told them that the students I had seen in their position who had been able to drastically improve their performance had done so by talking about the questions with other students in study groups. I told them there was something magical about talking and arguing that helped people understand the concepts. I had discovered by trial and error the same thing that Mazur did in his systematic study – peer dialogue is a very effective way for students to learn concepts.
In figure 4.7 on page 31 of Peer Instruction, Mazur plots his student’s score on conceptual problems verses their score on conventional problems for a part of a test on DC circuits. By “conventional problems”, Mazur is referring to the traditional way of presenting problems in a numerical format. Students are expected to analyze the problem, decide on an appropriate formula, and calculate a numerical answer. The conceptual problems involve a purely conceptual interpretation without numerical calculations. Most physics instructors would believe the conventional problems are much more challenging since they involve both a conceptual understanding and numerical manipulations. Mazur discovered the opposite to be true during a time when he was still using traditional teaching methods. He compares the plots for his Peer Instruction class to an earlier class in which he did not use peer instruction. The difference in conceptual understanding is quite impressive. In the 1991 data, there is a large group of students who score well on convention testing, but poorly on conceptual. In 1995, the average on the conventional part of the same problem was approximately constant, but the conceptual average was increased by 70%.

I was curious to see how my classes would compare to Mazur’s. Would they look more like his before plot or his after plot? For convenience in grading, I had separated all of the physics 101 tests into conventional and conceptual parts. The conceptual multiple choice questions were easily graded by Scantron sheets, while the conventional parts necessitated my personal attention. (I have included a sample test as an attachment) Figure 1 shows plots for several Physics 101 exams.
Fig 1: Plots to Illustrate Strength of Correlation Between Conceptual and Conventional Performance on Exams:

While none of the plots shows a perfect correlation between conceptual scores and conventional scores, they are much more correlated than Mazur’s 1991 plot. Absent from my plots are the students who were aces on the conventional problems, but totally inept on the conceptual problems. However, with the exception of Spring 99 Test 1, students tended to have a much lower percent score on the conceptual aspects. I believe
this may be mostly an artifact stemming from the way I graded the conventional problems. Partial credit was liberally granted for conventional problems, whereas no partial credit was given for conceptual multiple choice questions. Plus, the conceptual multiple choice questions have powerful distracters aimed at student misconceptions. In spite of the 20% random chance of guessing the right answer, students were more likely to pick the wrong multiple choice answer if they did not know the right answer because of the distracters. A similar effect was noted by Hestenes in his assessment of the Force Concept Inventory.

With that said, I also believe the conceptual questions were more challenging than the conventional problems on my test. I can justify this statement by my experience teaching the calculus based course. I used many of the same multiple choice questions for the 200 level course and found they had as many difficulties as the lower level students. Had I given the calculus based students the same conventional problems, they would have found them trivial.

An indication of the level of the conceptual questions in my Physics 101 course is that many of Mazur’s questions from his calculus based course are virtually identical to my questions. Here is a question from page 38 of Peer Instruction compared to a question from page 15 of my Class Notebook:

A ball is released at the top of a curved inclined as shown here. How would the ball’s acceleration change as it rolled down the incline?

I have used Mazur’s concave slope as a test question to see if students are able to formally process the knowledge learned in the class argument. The concept deals with the relationship between the tangential component of gravity (which is directly proportional to the acceleration) and the shape of the incline. When making up a test, I would not include many questions which require this level of formal thought. The students not only have to understand the specifics of the class problem, but also generalize the concepts to a new circumstance. This is, of course, the essence of conceptual development, but my students would be exhausted and frustrated if the entire test was at this level. For every one of these high level questions, I try to include 3 or 4 which are at a more concrete level.
PART 2: Teaching to the Second Tier

Much of the Physics 620 course has been devoted to difficulties encountered by students who are in what Shiela Tobias has called “The Second Tier”. These are the students who have the potential to earn scientific degrees, but are often turned off by traditional approaches to science education. As pointed out in the Shaping the Future report from the National Science Foundation, there is widespread and sharp criticism of university science instruction from the university students. Specific criticisms of instructors have focused on:

• Lack of student-teaching dialogue
• Lack of adequate preparation for lectures
• Monotone presentations
• Focus on memorization instead of processing of information
• Negative and intimidating attitudes of instructors for students
• Weak relationship between lab work and class work

In his acceptance speech for the 1999 Oersted Medal, David Goodstein suggested that physics teaching, as it is currently practiced, has but two purposes: to produce more physicists and to discourage apparently weak students from continuing in scientific careers. In her landmark piece, “They are not Dumb, They are Different”, Tobias showed that the traditional notion that most students drop out of physics because it is too difficult is a fallacy. In her study, Tobias found that only 31 percent of students switched out of science and engineering because they found the subjects too difficult. Clearly, there is a large body of competent students who are being turned away from science, and physics in particular, through their negative experiences with the traditional science educational system.

I started my teaching career as a high school science teacher. My students were responsive to my enthusiasm for teaching and my accessibility, but they did not pave my way with palm fronds. I had all of the usual student discipline and motivational problems that are familiar to all high school teachers. But, coming to the university to teach, I suddenly realized I was in a completely different situation. I felt as though I were a miracle worker coming to visit a leaper colony. My students came to my class expecting to be intimidated, frustrated, and bored. When they discovered I was truly interested in serving their needs, there was an incredible outpouring of relief and gratitude. When they discovered that studying physics could be interesting and even enjoyable, they were amazed. As was pointed out in Seymour and Hewitt’s study, “Talking About Leaving”, 90% of students who opt out of science education cite the poor quality of teaching as a primary reason. Perhaps even more startling, 75% of the students who tough it out and finish their science majors point out the same difficulties! My students had such negative prior experiences with science education, and such low expectations from their science instructors, working with them was like shooting fish in a barrel for a former high school teacher.
By sending observers into physics classrooms in “They are not Dumb, They are Different”, Tobias revealed many insights into the problems with the traditional approach of teaching physics. While I did not have one of Tobias’s observers visit my classroom, I did have many student observers present in every class, a large fraction of whom wrote comments in their course evaluations which I still retain in my files. In an effort to describe how my course addressed issues which have been brought out by Tobias, Seymour, and others, I will follow Tobias’s example and defer to the sentiments of student observers to describe their experience with my class. I have collected 25 written comments which are typical of the comments I received which relate to the problems which have been identified with the traditional approach to teaching physics. Most comments are obtained from my 1991-92 and 1999-00 school years.

1. **Boring and lifeless presentations**

As Dean Zollman has described in his Millikan Presentation, “Do They Just Sit There?”, the traditional format of the university physics class is “teacher-centered”, where the student is a passive observer. When a teacher does not elicit continuous participation from students, the teacher is not able to adapt their class to suit their audience. Rather, the students are expected to adapt their learning to suit the instructor. I was never comfortable as an instructor standing in front of a class and lecturing. Whenever I would talk for more than 90 seconds without getting some type of feedback from my students, I would feel myself becoming detached from the student’s attention. One way I maintained my dynamic connection with the students was using members of the class to participate in my presentations.

By far, the most frequent comments made by students relate to how stimulating and fun they found my course. I could easily find hundreds of comments which are virtually identical to the ones presented below. While I was adept at creating a lively environment which encouraged student participation, I was not a Robin Williams. Students come to university eager to be intellectually engaged and challenged. They are quite willing partners in creating a dynamic classroom environment, but all too often their enthusiasm is wasted through the traditional approach to science teaching.

“**You always looked forward to coming here.**”
“… made boring and tedious physics seem interesting as it well should have been until I looked at it in a different way.”

“… loves what he is doing and it rubs off on the students”

“… keeps all students involved in classroom activities.”

“makes learning fun without playing down the importance of the material”
“Physics is a hard subject, but Mr. James made it enjoyable.”

“... you can tell he really enjoys what he does.”

“He made the class fun, and you wanted to learn.”

“I loved the class. I’d take it again if I could.”

2. Negative attitudes of science instructors for students.

Another frequent motif found in the student comments reflects their negative past experiences with other science instructors. These experiences are very consistent with those described in the *Shaping the Future* document.

“... he treats his students with respect and not like they are idiots.”
“Thanks for making physics not as scary as I thought it would be. I can actually understand and do this stuff.”

“.. very enthusiastic and considerate.”

“… he simplifies things for idiots like me.”

“I would never had taken a physics course had I not had Mark…”

3. Unfriendly to women

In her “Problem Iceberg” series of articles, Jane Seymour has described how many of the problems in physics education have been particularly troubling for women. In many cases, females become fatally discouraged in circumstances where males are typically able to disregard. Since a large fraction of my Physics 101 students were nursing majors, a large fraction of these comments are certainly from women. Here is
a comment which, judging from color of ink and handwriting, is apparently from a woman in class.

“… I found I could relate to the teacher and he could relate to us.”

Whitten and Burciaga have suggested 20 guidelines for female friendly science. I found the following points particularly relevant to my course.

2. **Increase the number of observations.** I tried to have something to observe and demonstrate in class for every new topic – preferably 3 or 4 demonstrations per topic. When it was practical, I would pass items out through the class: diffraction gratings to observe spectra, a can which had been crushed by the atmosphere in a class demonstration, etc… Some students would snicker when I would pass something which had been used in a class demonstration around the class as if it had some mystical significance. But I felt it was worth the effort to give the students a tactile experience of the physical phenomenon. Of course, if they were doing the demonstration themselves it would have been better. I should also note that I had individual students participate in the demonstrations as actively and often as possible.

3. **Incorporate and validate personal experiences women are likely to have had.** I do this as frequently as possible. Two examples immediately come to mind. When I introduce pressure, we compare the pressure under the heel of a high-heel shoe to the pressure under an elephant. I will pick the smallest, lightest looking woman and use her weight to calculate the pressure which is always much higher than the pressure under an elephants foot. I then relate the pressure to a story about a woman I once saw beating her boyfriend over the head with her high-heel shoe. Another example is when I introduce the development of static electric charge through friction of dissimilar materials. Here is how I would introduce it:

   Me (to class): “Do you know what I hate? When I am going out, all dressed up for some fancy occasion, and my dress starts clinging to my legs! (to a female student) Don’t you hate when that happens?!?

   Female student: (nods)

   Me: Darlene, has that ever happened to you?”
Darlene: Yes.

Me: Why do you think it happens?

Darlene: Static electricity.

Me: OK, but where do you think the static electricity came from? (I use “where do you think” instead of “where does” because it is less intimidating. There is no wrong answer to “where do you think”.)

And so on…

4. Avoid military examples and include examples with social concern. I have been aware of the military issue since I was a high school teacher and I avoid focusing on the physics of war except in the context of some social issue, for example nuclear weapons. When talking about the physics of a bullet, I refer to the work of a WWII vintage German gun maker whose dream was to create a cannon that could fire projectiles into orbit. His dream was almost perversely realized with the help of Saddam Hussein who was interested in more destructive uses for the cannon. Other social issues I include in the course are global warming, radioactive waste, ozone depletion, energy consumption, etc… The trick is to include the issues without preaching my own ideology.

9. Include females as subjects of experimental design. If I can stretch the definition of experimental design to suit my course, I satisfy this guideline by including females in the class demonstrations.

10. Use more interactive methods. As stated elsewhere in this paper, I use many interactive methods to involve individual students.

14. Be open to alternate critiques and conclusions. Sometimes students would make comments which at first struck me as coming out of left field. For example, during a “class argument” on conservation of energy, a woman made a remark about how the idea related to her decisions about what clothes her children would wear. My response was, “Hmmm, that sounds interesting… could you explain what you mean?” She turned out to have a philosophical analogy between conservation of energy and conservation of clothes. While I did not include her idea in my class notebook, (maybe I should have!) I did validate her thoughts by considering them.

17. Use less competitive models. I try to take out the pressure from grading in the course at the beginning by telling the students that they are not competing with one another. I also let them know that I personally offer each one of them as much time that is needed to help them individually to earn whatever grade they want. I also give students my home phone number and encourage them to call me anytime for help. I work with students who have test anxiety by
administering mock tests in the days before an exam. I give them a sample test and they pretend it is the real test. After a few of those experiences, the students are not only less anxious, but they also know more physics!

20. **Discuss practical uses of science.** I endeavor to include many applications of the physics in the student’s everyday life. The student comments are emphatic in their appreciation of this aspect of the course. *(See particularly item #7 below)* No topic is presented without some tie in to student’s personal interest.

5. **Lack of student-teacher dialogue**

   Often students feel intimidated and distanced from their science instructors. They do not feel their instructor has a personal interest in teaching them. As stated on page 38 of the *Shaping the Future* document, some teachers view teaching as an irksome necessity of employment. I made it clear in all of my classes that it was my mission and passion to do everything I could to help each person in class learn to love physics. I frequently encouraged them to come to my office for help in the course, or to just talk about physics. The result was that I very seldom had any time to “work” when I was in my office. The office hours of most other professors were rarely taken up by students since they generally felt that their professors were unapproachable.

“… he was always willing to help his students. His time and efforts outside of class allowed me to do well in this course.”

“It was a great experience for me.”

“He also made himself available for any assistance that I need.”

“I look forward to attending more classes here at Parkside…”
“His enthusiasm encourages student participation”

“always willing and available to help students out of class”

I would often use “staged” Socratic dialogues between myself and a single student who would come and stand with me in front of class. This was usually in conjunction with some demonstration, but I would also use it to liven things up whenever I felt things were getting slow. Here is how a dialogue might evolve:

Me:  I need a class volunteer….  
   (students raise hands)  
   OK, Linda!  Let’s have a big hand for LIIINNNNDAA!  
   (Class applauds, Linda comes to the front of the class)  

Me:  Linda, take a look at this drinking bird and tell us what you see.

Linda: A funny looking ostrich with a hat that wobbles back and forth and then dips down.

Me: OK, what we want to do is figure out why it wobbles and eventually takes a drink. What is happening to make it wobble?

Linda: After it drinks… The weight of the blue stuff flowing to the bottom pulls it back.

Me: Good! Now what happens to the blue stuff when the bird is rocking?

Linda: It goes back up the bird’s neck.

Me: OK, good. Now if we can just figure out why it rises back up… What do you think?

Linda: I don’t know.
Me: OK. I want you to do something. Put your palm around the bulb at the bottom and let's see what happens.

Linda: (smiling) OK….
(picks up bird and notices the heat from her hand makes the fluid rise like a thermometer)

and so on…..

This sort of thing really grabs the student’s interest. Their attention is drawn to the demonstration because of social interest in the “human drama” unfolding in front of them. What will she say? What would they say if they were in front of the class? Is she going to get it right? (I make sure they always get it right by leading them with questions.) So, I am using the social aspect to focus the student’s interest on the physics.

6. Unrealistic pacing

“As nice paced.”

As Eric noted in Tobias’s “They are not Dumb, They are Different”, the intensity of the pacing for physics courses is “excessive and almost insane”. Topics change from one to another without allowing the student any time to reflect upon, or master the content. The emphasis is on breadth, not depth. Early in my attempts to teach physics, I realized that most students were incapable of mastering the number of topics they are typically presented. Without departmental consultation, I unilaterally decided that I would omit a number of topics from my courses to make the number of ideas presented conform better to the capabilities of my students. For example, I did not cover conservation of momentum. I felt that most of the concepts were recapitulations of the 2nd and 3rd laws and my course was internally consistent without its inclusion. I did not talk about entropy. In optics, I covered lenses, but not curved mirrors because of time constraints. I picked lenses instead of curved mirrors because lenses are closer to students common experience, and also because there were many people in class who were majoring in health related fields.
My philosophy guiding what to include and what not to include in order of importance:

**DO’s**
1) Pick topics that compliment one another so that concepts get recycled in as many contexts as possible to give students an appreciation for the interconnectedness of physical ideas.
2) Cover topics that students can find a wealth of personal experience to relate to the new concepts.
3) Cover topics that are of interest to the students. An example here is nuclear physics. My inclination is not to cover that topic since it does not evolve naturally from previous material and it is not essential to future material. But my students are very interested in these ideas since most of them will become nurses – they want to know about isotopes, half lives, etc… Another topic I include because of student interest is the physics of music, which evolves nicely out of waves, but is not essential to the course – just fun and interesting.
4) Cover topics which will give them a foundation for further studies in physics. I do this as much as possible, but it is a lower priority.

**DON’T’s**
1) Don’t cover anything superficially, without being able to convey a degree of conceptual depth.

While I have only anecdotal evidence, I believe the students in my introductory courses tended to do much better in more advanced courses and on standardized tests such as the MCAT than students who had completed more traditional introductory classes. I am in total agreement with Philip Morison’s idea of “less is more” which he delineated in "Reflections on a Decade of Grade School Science". My philosophy is that it was better all around for the students to have deep understanding about a few things rather than a superficial understanding of many. I often conducted informal surveys of upper division instructors to see how my students did in comparison with others. I also received feedback from the pre-health advisor that students who had taken my introductory course were scoring higher on the MCAT. It would be interesting to do an objective study which would use student records to track my students and compare them with a control group.

7. **Focus of science educators on memorization of facts**
The essence of physics is in understanding the concepts. Virtually all physics instructors are in agreement on this statement. As McDermott pointed out in “What We Teach and What is Learned”, the need for conceptual understanding and processing in science has been widely acknowledged from the time of Sputnick. Yet, traditional physics instructors persist in using techniques of teaching which
focus on memorization of facts and algorithms which can be applied to stereotypical problems. As Tobias pointed out in “Breaking the Science Barrier”, students typically blithely look for “the formula” which can solve a problem before they stop to think about the physical aspects of the problem. The traditional physics instructors lament this state of affairs, but they do nothing to change it. In my courses, I made a concerted effort to address student’s conceptual understanding of the physics. The students realized they were learning something significant and responded to the challenge.

“… actually taught instead of giving us just formulas to struggle with.”

“I went to the class thinking it would be boring and confusing…”

“I especially like the way he related the topics to everyday life..”

“…I have found myself using what I’ve learned outside of class.”

“… using real life examples to demonstrate the concepts.”
“His use of real life situations & examples make physics an understandable topic”

8. “Is the measure of a course how much a bright student learns, or how much someone who is “lost” can be made to comprehend?” (Eric from “They are Not Dumb, They are Different”)

I found this quote particularly germane to my approach to teaching. The exceptionally bright students tend to learn the material in spite of the instructor’s methods. The challenge of teaching for me was to find ways to reach the students who were not as gifted or prepared when it came to science, who would not have been reached using traditional methods.

“ I’m not a physics person and hated it in high school, but Mr. James has made it interesting and bearable for those of us who would prefer not to take it but have to.”
“… created a good environment to learn a subject most people suffer through.”

Seymor has shown that by changing courses to focus on the needs of women physics students, the course becomes more accessible for everyone. My methods turned many students on to physics who would certainly have been discouraged in a traditional setting. The class inspired an inordinate number of students to pursue a major in physics.

“… really challenged me to all levels of intellectual stimulation.”

“I never thought physics could be fun…”

“I am thinking about becoming a physics major.”

“Mark is the person who got me interested in Physics.”

(Comments of a physics major in an advanced physics course who was introduced to physics in my Physics 101)
"He took a course I enrolled in just to meet a prerequisite requirement and turned it into a subject that I would love to continue to learn more about"

9. A final word.

As Mazur and others have pointed out, positive attitudes about a course and or instructor does not always correlate with student learning. In “Peer Instruction”, Mazur pointed out that he consistently got favorable student evaluations in a course in which he later identified serious problems with student conceptual understanding. With that said, I feel the substance related above in the comments of the students brings insight into the condition of science education as it is currently practiced. Beyond the simple positive tenor of the comments, there is a resonance with the sentiments which were summarized in the *Shaping the Future* document. Also, the simple proportion of students who were moved to write comments is significant in itself. The written comment portion of the questionnaire is merely an optional part of the back of the student evaluation of instruction:

The typical return rate for written comments for a science faculty is approximately 15%, but over 60% of students in my classes returned written comments along with their numerical evaluations. I believe that main reason students to write with such frequency and intensity is because of the stark contrast between my course and the types of courses which have been criticized by so many of the readings in Physics 620.

I should note that I have not included statistics on the numerical responses in the questionnaires because I feel they do not afford the depth of insight which is reflected in the extemporaneous comments from the students.
PART 3: Confronting Misconceptions: Conceptual Learning and Constructivism

Much of the material in part 1 and 2 of this paper deal with my efforts to promote conceptual learning. My technique of “directed arguments” which I applied to small and large group learning, omitting parts of the curriculum, constantly stressing conceptual ideas behind problems, and the correlation of conceptual performance with what Mazur calls conventional performance have all been discussed. In this section, I will focus in more detail on the particular aspects of my course which relate to the construction of knowledge.

In Rochelle’s paper on Interactive Environments, he discussed the paradox on continuity in constructivism. The issue is how to perceive prior knowledge. Are prior “misconceptions” to be viewed as impediments to student learning, or are they the building blocks upon which new knowledge is constructed? As Rochelle points out, prior knowledge is both necessary and problematic. I knew both of sides of this issue: I knew that a student had to confront their misconceptions to learn, but I also knew that they could usually use their prior knowledge to figure things out themselves with just a little help from me. When a student would come to my office and say they had no idea of how to even start thinking about a particular question, I would respond by saying, “I will bet you that you already know the answer. Let me prove it by just asking you a few questions about what you already know.” And I would proceed to pose questions with minimal physics content that would lead the student to reassemble and reassess their prior knowledge until their perspective was consistent with the physics. I would ask things like:

“This question is about _______. What do you already know about that?”

“OK… if that was true, what would happen to the _____?”

“OK, now think about what you just said in light of what you said earlier about ________. Could both of those things be true?”

The scaffolding process is much slower than just telling students the answer. It was always much easier for me to be patient because I was not the one struggling to understand. It takes a lot of energy to really think, and if the process went on too long without resolution, students would start becoming frustrated. Each student had a different level of tolerance. When I would sense the students getting close to their threshold, I would change my tactic and start again by giving them the solution, then working backward to see how their prior thinking was inconsistent.

Upon reviewing a fraction of my past evaluations for this paper, I discovered a very interesting and extensive comment which relates directly this issue:
“At times—the lecture did not clear up confusion for me about the topics discussed—I felt more confused afterward….”

“… but I don’t think it was the lecture itself, but the fact that I had never had any thought or exposure to the topics before in my life—so my “logical” reasons for things occurring in physics went out of my mind and had to be erased & new thoughts put in—difficult but not impossible.”

“I learned a lot in this class but I still feel inept at being able to explain my answers appropriately, but I do seem to think more about things, but I still can’t answer questions but I try to find out—I feel that’s learning.”

This student is describing the type of cognitive conflict and resolution which Piaget first described. In order to come to grips with the new knowledge she/he was being presented with in my class, the student felt that she/he first had to “erase” the previously held conceptions.

To confront misconceptions, I often presented the class with discrepant events to provoke cognitive conflict. For example, to introduce the section on falling bodies, I presented the students with a pipette which was dripping milky water from a high ladder into a metal bucket. The students could hear the drips hitting the bucket at regular intervals and they could see the drops leaving the pipette at regular intervals. I then posed the following question to the class as a directed argument:

1. a) A leaky facet drips at regular intervals. Does the distance between successive drops increase, decrease, or remain constant as drops fall from a facet? WHY!

The students would then embark on a directed argument to try to figure out what happens to the distance. Many students would think the distance remains constant since the dripping rate is constant. Others will recall the class argument about a ball accelerating down an inclined plane. They would not have previously calculated distances for accelerating objects, but they were aware from class discussion that the ball traversed the second half of its incline in less time than it took to cover the first half. Others would try to imagine real life circumstances where they have seen falling objects. The students would have fun trying to think it out, and after several minutes of speculation and
justification, I would reveal the answer using a strobe light to shine on the falling drips. We would then continue by making some detailed calculations about the position of the drops as they fall.

This activity could be viewed as an exploration in the learning cycle. I present the students with a new circumstance and they explore different aspects through their own reflections and through participating in the class argument. Observing the drops with a strobe light begins the concept introduction phase. I prefer that a student explain the phenomenon after the answer is revealed. My ideal role would be to offer suggestions and guide them along with pointed questions.

The cycle continues by reinforcing the new knowledge through performing several repetitive calculations using the new equation \( s = \frac{1}{2} at^2 \) which is introduced. This could be considered a “quasi” application phase of the learning cycle since the new knowledge is now being applied. As a class we plot a single drop’s position at many times. By graphing the positions, we replicate the strobe light observation. We then consider the plot as we embark on three reinforcing questions in part d, e, and f.

But, unless the students are directly participating in the calculations at this point they will not be applying their knowledge, they will be observing me or a few other students apply the knowledge as they take notes for later consumption. The real application phase for most students comes when they tackle the homework questions which I have designed to directly correlate to the classroom work.
Another such cognitive conflict I pose to the class comes in the section on terminal speed. We have already studied the effect of weight on the terminal speed of two objects of similar size in a directed argument about a ping-pong ball and golf ball. By this point in the lesson, students have a fuzzy idea of the relationship between speed and air friction. They understand terminal velocity in relation to an analogy between a previous directed argument about the net force on a cart moving at constant speed. We now consider identical balloons which have been inflated to different sizes to introduce effect of surface area on terminal speed.

8. Which balloon should fall to the ground in the shortest time?

First, I have the students consider the two smaller balloons. After a brief “argument”, students quickly conclude that the larger balloon with fall slower. From their personal experience with air friction, most are aware that the larger object will be presented with a larger frictional force. I drop the balloons from a high point and their conclusion is borne out.

This is a fairly concrete concept: the bigger the surface area, the more the friction. But then I try to lead students to a more formal level of reasoning. I then ask them to consider dropping the two larger balloons. Since they have no reason to expect any differences in this new case, they all expect the larger balloon to again fall slower. But, when the demonstration is performed, the opposite result occurs. A directed argument ensues about the possible causes for the discrepancy. Eventually, someone directs me to weigh the two balloons on a sensitive balance that “just happens” to be available on the demonstration table. It is determined that the larger balloon weighs more that the smaller balloon. The balloons are eventually deflated and weighed again to see if there was a defect in their manufacturing. Since the deflated balloons are the same weight, it is determined there must have been a heavier gas inside the larger balloon. (It was argon)

So, through this demonstration and argument, students are prompted to think about the subtle interplay between weight, surface area, and drop time. (The drop time is our crude measure which relates to the terminal speed.) They also are introduced to the idea that gases have weight, which ties into a topic which will be covered later in the course.
In March of 1992, Hestenes, Wells, and Swackhammer rang the alarm regarding the conceptual understanding of college physics students with their publication of the Force Concept Inventory. Countless physics instructors were awoken to the fact that their students were not learning the most basic Newtonian concepts underpinning most of the material in their course. How would my students have fared on the FCI? I cannot go back and administer the test to my past students, but I can compare questions that I did administer to questions that are found on the FCI.

Question 1 on the FCI is similar to my directed argument #7.

7. Which would have a higher terminal velocity, a golf ball or ping pong ball? Explain.

Question 4 of the FCI is identical to a question I assigned for homework.

5. A large truck collides with a small VW bug traveling in the opposite direction. Which vehicle experiences the greater force of impact? Which of Newton's laws applies to this situation? Explain.

Question #6 on the FCI deals with the motion of a ball when it is free from constraint. A question from my Homework Notebook is more challenging, but deals with the same general concepts.

This figure shows a cross section of a circular space ship that is rotating counterclockwise in deep space in order to produce an artificial sense of gravity for the crew.

If Zorbo releases a ball while in the rotating space station, Zorbo observes it fall to the floor. What actually happens to make the ball appear to fall to the floor?
Question 7 from the FCI deals with the same concepts as a Physics 101 test question.

12. If the force of gravity between the moon and earth suddenly “shut off”, the moon would
   1) move directly away from the earth
   2) move away along a tangent line to its orbital path
   3) stop moving
   4) continue its orbit around the earth

Question 17 from the FCI deals with the forces on an elevator moving at constant speed. I have put several questions on tests dealing with these concepts.

20. A chihuahua is traveling upward in an elevator. The chihuahua’s apparent weight is
   1) less than its actual weight
   2) more than its actual weight
   3) equal to its actual weight
   4) any of the above depending on the acceleration of the elevator

21. A chihuahua is in an elevator accelerating downward. The chihuahua’s apparent weight is
   1) less than its actual weight
   2) more than its actual weight
   3) equal to its actual weight
   4) any of the above depending on the speed of the elevator

I would like to think my students would fair well on Hestenes’s FCI as a result of my intense efforts to teach for conceptual learning, but all I can do is speculate. From my experience with conceptual questions in 13 years of tests, I have a much better feel for the conceptual understanding of my students than did the traditional physics instructors who had never tested over conceptual ideas. While I retained few test reports which tabulate specific student responses, I do have the results for Spring 99 Test #1. The overall average for the conceptual part was 61%. If this were the FCI, my students would be just passing the threshold of understanding according to Mazur. I would have liked them to perform at a higher level, but most of my students were nursing students, general education students, and biology students. Virtually none of the students would have taken calculus. The true measure of a course is how far the class moved in a “before and after” comparison. Sadly, I never administered a pretest to any of my classes. The data would have been very interesting to analyze. My intuition tells me the class would score pretty close to random guessing before instruction, but the truth is out of my reach at this time. Perhaps in the future, I could persuade the current instructor of Physics 101 to administer
such a test. It would, of course, not be the same students who took my class, but it would at least offer a crude estimate of the student’s conceptual understanding before instruction in my classes.

Here are a few statistics for 7 specific conceptual questions I put on my Spring 99 Test #1. The entire test is included as an attachment.

3. The graph of velocity vs. time for a bottle rocket launched vertically is shown here. When does the rocket reach its maximum height?
   1) at t = 1 seconds    2) at t = 4 seconds    3) at some time after t = 4 seconds
   1 – 37%        2 – 50% correct answer    3 - 13%

12. In the game of baseball, the pitcher throws the ball to the catcher. The force the catcher experiences as he catches the ball is    1) greater than       2) less than  3) equal to  the force that the pitcher pitched the ball with.
   1-70% correct answer    2- 17%   3- 17%

13. A bowling ball is dropped from rest. If we can ignore the effect of friction, the acceleration of the ball as it falls    1) increases   2) decreases   3) remains constant
   1- 13%  2- 0%  3-87% correct answer

15. Megan weighs 400 Newtons. Standing on a scale in an elevator, Megan notices that the scale reads
   350 N. It can be concluded from the information that the elevator    1) is accelerating upward   2) is accelerating downward   3) may be accelerating upward or downward
   1- 33%  2-63% (correct answer)  3-7%

16. It can also be concluded that Megan's elevator    1) is moving upward   2) is moving downward   3) may be moving upward or downward
   1 – 17%  2- 37%  3-50%  (correct answer)

21. The gravitational force the earth exerts on the moon is    1) greater than   2) less than  3) equal to the gravitational force the moon exerts on the earth.
   1 – 37%  2- 13%  3-53% correct answer

22. When a box does not accelerate when a 10 N force is applied horizontally to it, we can assume that    1) its inertia is too large   2) the force of friction is greater than 10 N   3) Both 1 and 2   4) the force of friction is less than 10 N   5) net force on the box is zero
   1-7%  2-23%  3-43%  4-0%  5-30% (correct answer)
PART 4: Learning Styles

In her article, Tobias pointed out many negative features which most students find in their traditional physics courses: lack of relevance, student passivity, emphasis on competition for grades, and focus on algorithmic problem solving instead of conceptual understanding. These were the same issues that I had found personally problematic as a student, so it was natural for me to focus my efforts in these areas. In regard to learning styles, I approached my teaching in the same manner as most traditional physics instructors - The methods I employed were developed with my own learning style in mind. It just so happened that my learning style was a better match to the profile of the “typical” student in an introductory class. As Barbe pointed out in “What We Know About Modality Strengths”, most of our introductory students are visual learners, yet most physics courses are presented verbally, almost exclusively through words and formulas.

As I will demonstrate, I ended up covering a variety of learning styles with my teaching methods. When I would pass an artifact around the room for students to inspect more closely, it would always strike me as odd when I would get some students who would roll their eyes at me. At the time, I shrugged it off to a “this is kid stuff” attitude. But, after reading Felder’s paper which delineated the various learning styles, I realized the “eye rollers” were probably intuitive preceptors. It was not necessary for these students to hold and see the artifact up close to gain insight into the physical phenomenon. As someone who is a sensory learner, I would experience a much greater affinity with a problem when I could use my senses to examine real world projections of the problem. When I can actually feel the crumpled edges of a can which has been crushed by atmospheric pressure, my brain reacts with “OOOhhhh…. Now I understand atmospheric pressure!” It never occurred to me other people would not experience the same type of epiphany before I read Felder.

Learning styles might also explain the difficulties I had teaching upper division courses. I always felt frustrated when the small group of physics majors would not respond to the type of presentations which worked so well in the introductory courses. I would try to use a lot of visuals, get active participation, etc. But I could see that it was not going over. I ended up relying much more on lecturing than I did in the introductory classes. The physics students just wanted to see the material presented as efficiently as possible. I was trying to use visual and active methods to teach learners who had been sorted by natural selection in the physics department to favor verbal and reflective processing.

Upon reading Felder’s description of sequential verses global understanding in “Reaching the Second Tier”, I realized I was a global learner. Whenever I am faced with a completely new problem, such as in the development of “Plumb Line and the Shape of the Earth” coauthored with Mohazzabi, I do not follow the type of sequential logic which is presented in textbooks. It always seemed to me that I just did not have enough patience. Instead, I would direct my attention haphazardly, reading segments out of sequence from different sources. Nothing would seem to make sense until I would near a point of sudden comprehension. That point on the verge of understanding is analogous to
when one is trying to think of a name. The realization that the name is coming into one’s consciousness actually arrives before the name. As long as nothing distracts one’s attention during this critical moment, the name suddenly becomes available to the conscious mind. But if someone interrupts the process, they will “make one forget”.

After I have had the moment of global understanding, the sequential pieces all suddenly make sense – their interconnectedness now apparent. Interestingly, I always perceived myself as a sequential learner – I just thought I was particularly dim witted. My conscious preferential approach to teaching was usually to present material sequentially because, once I personally passed the moment where I “overcame my stupidity”, the sequence made such perfect sense. Some topics however, do not lend themselves easily to sequential reasoning. An example is the conservation of energy lesson which I have included as an attachment. There are so many ways to think about energy, I thought it best to present the initial concept and then stab around it with various examples.

As a lecturer in our department, I taught a large number of laboratories for lecture sections that were taught by others instructors. I had been teaching a couple of years when a student made a remark similar to the one found here in one of my laboratory evaluations:

“I learned a lot more about this course from Dr. James than I did from lecture.”

Before a student awakened me to the learning potential of the laboratories, it had never occurred to me that students were supposed to really learn anything from labs. The physics labs were mostly designed for students to confirm some physical principle by following a cookbook procedure. The students in a traditional lab never participate in a process of discovery like they are compelled to do in the physics labs at KSU which have been modeled after ideas presented by Zollman in his, “Learning Cycles for a Large Enrollment Class”. It sounds humorous, but even though I had experienced so many personal insights into physics through my own unguided experimentations, I was so acclimated to the way physics labs are traditionally conducted that I did not see any alternative to the status quo. I am certain the reason the above student had such a positive experience in my lab was not because of insight gained through performing the cookbook labs. Instead, they learned from informal personal interactions with me during the lab. As the students worked, I would often start to get bored when no one was asking questions. I would then start walking around and distracting them with questions to break my monotony:

“What do you think would happen if you reversed the direction of the current in the Helholtz coils?”
“Do you hear that crackle sound the spark generator is making? What do you think makes the sound? Is it the electrons banging into the metal?”

With all of the lab equipment stored nearby, it was easy to demonstrate concepts for any students who were interested.

As Felder points out, the lecture format of the typical physics class best facilitates learners who are intuitive, verbal, deductive, reflective, and sequential. All of these elements were in my course since I retained the general lecture format. By making modifications to the standard approach to suit my own learning style, I was able to address multiple learning styles, making my presentations more effective for a larger group of students.

Since the learning styles of students are varied, Felder argues that it makes sense to present information using varied methods. He offers nine suggestions to physics instructors who want to reach students possessing learning styles which are not addressed in traditional approaches:

1) Motivate theoretical with prior presentation of phenomena
2) Treat conceptual aspects as well as the abstract
3) Make extensive use of graphics
4) Always give some numerical examples with abstract problems
5) Use concrete physical analogies to go with abstract concepts
6) Give students data and let them try to ascertain relationship
7) Give students time in class to reflect in class
8) Encourage cooperation on homework
9) Explain how ideas fit in globally as well as sequentially

I will not take further time to discuss each of these suggestions in regard to my class, however I would like to address suggestion #6. Through a compulsion to present some motivation for equations which were presented without derivation in Physics 101, I would often introduce an equation as shown here from an excerpt from my class notebook. Using directed arguments, students were first introduced to the effects of weight, shape, surface area, and fluid viscosity on terminal speed. Before introducing the equation, the notebook posed the following question:

8. We have seen how weight, shape, surface area, and fluid viscosity affect the terminal speed of a falling object. How would you place these variables to compose an equation for terminal speed?

I have a student volunteer come to the blackboard and decide whether each term ought to be directly or indirectly proportional to terminal speed. If it is direct, it goes in the numerator and if indirect, it goes in the denominator. Without much difficulty, the student arrives at the following candidate for the terminal speed equation:
It is almost correct, except “it turns out” they need a square root. My hope is that, even though a derivation would be beyond the scope of the course, the students have some conceptual understanding of the equation which they will use.

Zollman, Biechner, and Felder have all described methods which compel students to determine formulae using empirical data. This is a technique which is new to me and I would like to attempt it when I again have an opportunity to teach this course.

Conclusions:

In this paper, I have taken a critical look at the way I have approached teaching in light of what I have learned in Physics 620. While my critique is rather lengthy, it is by no means complete. After 31 pages and over 30 hours of effort, I feel I have just skinned the surface. I would have like to use the criteria from Clerk and Rutherford to analyze a portion of the hundreds of multiple choice questions I have written. I had also hoped to compare the misconceptions I identified in several sections of my Class Notebook to the comprehensive lists found in Arons’s “Teaching Introductory Physics”.

In retrospect, there are many areas in which I had already been practicing what the prophets of Redish’s “new culture of science” had been preaching. Had I been aware of the great body of hard research which is now available, I could have been bold in trying to affect departmental changes. As a solitary evangelist with no recognized doctrine, I felt impotent to fight the tremendous momentum of our traditional approach. Administering the FCI to colleague’s classes would get their attention as it did for Mazur. If I could demonstrate that my ideas were more effective in promoting conceptual understanding, I would stand a good chance of affecting departmental changes.

I was good at eliciting student participation and social interest, but I feel now I still retained too many vestiges from the teacher-centered model. A specific change I would implement after this assessment would be to include more small group activities in my classes similar those described by Mazur. Springer, Stanne, and Donavan have authored a compelling study of small group learning which offers substantial credibility to Mazur’s findings in his own classes. Small group learning can be extremely effective. I would also take Felder’s advice to allow students more time for personal reflection during class periods. My directed arguments slowed things down and invited students to take part in a collective inquiry, but many students may have been too distracted by the stimulation of the large group experience to reflect on their own thoughts. Providing Felder’s “1-minute” quizzes during class, everyone would get a chance to ponder quietly, giving my
presentations more facets on the learning styles spectrum. I was also very impressed with
the approach to learning cycles and small group learning Zollman described for large
enrollment classes.

Edward Redish has lamented the fact that insights into teaching physics seem to cycle
between fads, instead of building up a community consensus knowledge base. Judging
from the content which has been presented in Physics 620, the consensus appears to me
to be accumulating. Educators quibble about the particular efficacy of a test like the FCI,
but none doubt the hypothesis which inspired the test – the traditional approach to
teaching physics needs fixing if it is to meet the needs of the students in the new
millennium.