What this paper is all about

In my first synthesis paper entitled “Promoting Understanding of Physics Concepts”, I discussed what it means to understand a physical concept. One of the major points I raised in that paper is that the acquisition of deep conceptual understanding of physical concept involves the mastery of two types of knowledge – quantitative and qualitative. However, despite my best efforts, I failed to discuss a lot of other relevant issues related to the understanding of a physical concept. Consider this paper then, as a supplement to that previous one. Specifically, in here I will attempt to provide answers to the question of how one can facilitate the acquisition of deep conceptual understanding of physical concepts and make learning more meaningful to students. I will do this by using the results of several physics education researches as anchored on some important difficulties physics educators have in teaching physics.

The problems in physics teaching

Over the years, physics education has been beset with a multitude of problems. The most compelling is how to teach physics to the students so that they will understand it, and appreciate it. An offshoot of this difficulty is the problem of retaining in the program those students who have initially decided to major in physics. Seymour and
Hewitt’s (1997) study on why undergraduates leave the sciences revealed that students switch not because they lack the mental ability. The three main concerns for shifting are the lack or loss of interest, belief that a non-SME offers a better education, and poor teaching of SME faculty.

Looking at these reasons, we realize that the situation is not at all hopeless. I believe that we could do something to address these issues. The scenario would have been pathetic if the primary reason for the switch is the students’ lack of mental ability. As I see it, the issue of lack/loss of interest and the belief that SME offers a better education is brought about or aggravated by the issue of poor teaching of SME faculty. If we can address the issue of poor teaching we will essentially be addressing the two other issues. If we can better teach physics then this can be a source of motivation for students to stay in physics.

Another major problem in physics education is that students do not appear to gain as much knowledge out of their physics courses as desired. The most probable reason for this is the over-dependence of physics instructors on using the “traditional lecture”. Lectures in physics can be an incredibly passive experience for students, particularly dangerous for those who believe that if they can follow the professor, they’ve mastered the material (Tobias, 1990).

In this paper I will be presenting ways in which we can improve large lecture classes in order to make learning more meaningful for students. The motivation for this is my belief that lecture halls will still continue to pervade physics departments. Reducing
the number of student-teacher ratio is a far-fetched reality. We will still be seeing large
lecture classes in every physics department in the next decade. There’s much that can be
done in order to improve large lecture classes that will make learning more meaningful to
students. If our goal is to teach so the students will understand, then our instructional
strategy should be designed in such a way that this goal can be realized.

What the existing literature say

The question is: How do we improve on the traditional lecture method?

Researches in physics education had shown that teaching by telling is an
ineffective mode of instruction for most physics students. Furthermore, these researches
(Felder, 2000; Hake 1998, Mazur, 2001; Zollman 1996; McDermott, 1991) suggest that
for teaching to be effective, students must be actively involved in their learning which is
not being achieved through the traditional lecture method of teaching.

In making students more actively involved in large lecture classes, Thorton and
Sokoloff (1996) proposes the use of Interactive Lecture Demonstration. The following
are the sequence of activities done in the interactive lecture demonstration (ILD) class:

1. The class basically starts with the instructor describing a demonstration. The
demonstration is done for the class without microcomputer-base laboratory (MBL)
measurements.

2. Students are provided with prediction sheets for the particular demonstration described
by the instructor. They are also required to write down their name on this sheet. However,
they are assured that these predictions will not be graded, although credit will be awarded
for attendance at the ILD sessions.
3. After writing their individual predictions, students then engage in small-group discussion with their one or two nearest neighbors. They brainstorm about the situation and may change their prior predictions.

4. Students record their final predictions in the Prediction Sheet

5. Instructor elicits common student prediction from the whole class.

6. Instructor carries out demonstration with MBL measurements suitable displayed using multiple monitors, LCD, panel or computer projector.

7. Selected students describe the results and discuss them in the context of the demonstration. Instructor discusses analogous physical situations with different “surface” features- that is, different physical situations based on the same concepts.

Another instructional strategy that has been conceptualized to improve physics teaching is Mazur’s Peer Instruction (PI). Peer instruction involves students in their own learning during lecture and focuses their attention on underlying concepts. Lectures are interspersed with conceptual questions called Concept Tests. These tests are designed to expose common difficulties in understanding the material.

This strategy modifies the traditional lecture format to include questions designed to engage students and uncover difficulties with the material. The strategy is implemented in the following manner:

- **Before coming to class, students are required to read the topics that will be discussed. In place of reading quizzes and short summaries, students are required to answer a three-question web-based assignment due before each class. All three questions are free response. The first two probe difficult aspects of the assigned reading and the third asks, “What did you find difficult or confusing about the reading? If nothing was difficult or confusing, tell us what you found most interesting. Please be as specific as possible.” Students receive extra credit for accomplishing these tasks.**

- **At the start of the class the teacher does a mini-lecture on some topics that the students indicated in their response to be confusing.**
For each topic, the instructor poses a concept test for students to answer in one or two minutes and report back their answer to the instructor. This is accomplished by either raising hands, or using flashcards. A newer option is the use of Class talk system in which students send their answers to the instructor via a classroom network of palmtop computers.

Students discuss their answers with others sitting around them. The instructor urges students to try to convince each other of their own answer by explaining the underlying reasoning.

During the discussion, which typically lasts two to four minutes, the instructor moves around the room listening. Finally, the instructor calls an end to the discussion, polls students for their answers again (which may have changed based on the discussion), explains the answer and moves on to the next topic.

A fully interactive physics lecture strategy is likewise proposed by Meltzer and Manivannan which is a variant of Mazur’s Peer Instruction. It carries the transformation of the physics lecture-room environment several step further, aiming at achieving a continuous instructor-student interaction through a “fully interactive” physics lecture. It maximizes the potential for instructor-student interaction in the large-classroom environment.

A typical class usually proceeds in three phases- mini-lecture, interactive-question sequence, and follow-up activities.

In the mini-lecture, the instructor talks about the outline of the principles and concepts for the day’s activities. One or two key ideas are sketched, along with relevant diagrams and mathematical formulations. A demonstration might be shown (soliciting students’ predictions of the outcome) and an example problem solved at the board. This usually takes about 3-7 minutes.

The class then proceeds to the interactive-question sequence. In this phase the teacher basically asks a series of questions to which students will respond. Questions may be presented through a Workbook, the board or with an overhead transparency. The sequence starts with easy questions proceeding to the more complex ones. The instructor also takes any available opportunity to interject a question requiring a “free response” For example, in discussing about electrical charges, a teacher may provide a diagram of charge distribution. Students were first asked about the net electrical charge on the object represented by the circle. The instructor then drew in a nearby positive charge and asked students to draw set of arrows representing all electrical forces acting on that positive charge due to each of the protons and electrons.

As the students worked at their desks, the instructor roams around the room to assess how well the students were handling the activity.
Periodically, the instructor may go to the board and offer hints and partial solutions to the whole class as they continue to work.

When it appears that majority of the class is well on the way to solving the problem, the instructor goes to the board and provides answers, giving emphasis on the aspects of the questions proved particularly troublesome.

Flash Cards are also used to provide feedback to the instructor on students’ misconceptions regarding the topic under discussion and pace of student understanding in the class as a whole. Flash cards also enable students to assess the level of their understanding of the topic under discussion.

At some point, there is likely to be significant split in opinion reflected in the students’ responses. In this case the instructor informs the class about it and encourages them to further discuss with each other their responses. Almost always, an animated class-wide discussion ensues. Eventually students will come to a consensus with the correct answer.

In cases when the split in opinion persists, additional exercises and questions are provided by the instructor.

The sequence of interactive questions may be followed by another sequence, perhaps preceded by a new mini-lecture. Mini-lectures may also be judiciously sprinkled into a class at various moments, allowing an opportunity for motivational or philosophical comments, or simply to provide a break from problem solving.

The three techniques presented above are examples of ways in which we can improve the teaching of physics concepts to students. Another aspect that we need to look into is the teaching of problem solving to students. Traditionally, teachers usually solve problems highlighting just the necessary mathematical steps in getting the final answer. But this method has proven to be quite ineffective. Because of this students usually come to think that physics simply consists of equations to be memorized. When given a quantitative problem students tend to use formulaic approach otherwise known as the plug-and-chug approach of problem solving. Students can’t be blamed because in most cases they become successful in finding the final answer to problems given to them. Studies had shown that even though students are successful in solving quantitative problems they usually fail in conceptual questions (Jackman, 1999). It’s about time then
to wean students from using this problem solving approach if we want to develop deeper conceptual understanding among our students.

One approach of problem solving that can possibly address the development of both qualitative and quantitative knowledge among students is proposed by van Heuvelen (1999). Van Heuvelen outlined the following steps of solving a problem in physics:

1) construct qualitative representations of physical processes and problems
2) reason about the processes using these qualitative representations
3) construct mathematical representations with the help of the qualitative representation.
4) solve the problem quantitatively

*How these techniques translate to learning*

So what makes the Thorton and Sokoloff’s Interactive Lecture Demonstration, Mazur’s Peer Teaching, Meltzer’s Interactive Lecture more effective than the traditional lecture? These lecture methods make students actively involved in their learning. When I say actively involved, students are not just physically engaged but more importantly they are mentally engaged. The mental engagement of the students is the key for all learning to become meaningful.

The techniques presented above are anchored on the constructivist point of view of learning. They recognize that fact that the students’ minds are not blank slates that have to be filled with information. The traditional lecture method of instruction as practiced in most physics courses assumes that the student can accept clearly presented
knowledge as given. This strategy had failed to make students’ learning meaningful because they failed to account for the students’ prior knowledge. Physics researches had shown that students come into our classroom with preconceptions in almost every topic that we present. Prior knowledge of students greatly affect how new knowledge is being assimilated in one’s schema. The process of making appropriate the linking of different concepts, facts, rules and formulas in a particular schema is greatly affected by the students’ prior knowledge. I believe that an effective instructional strategy should take into account the students’ preconceptions and subsequent learning should be built upon these preconceptions. The instructional strategies presented above are some examples of strategies that address this issue of learning.

I further believe that the students themselves make the final decision whether to discard their misconceptions or not. However, the teachers have the power to influence this decision. It is the primordial role of the teacher to provide learning situations/opportunities for students that challenges their misconceptions. The instructor should seize every opportunity to encourage students to reflect on what they are doing. Thus, during the teaching process, the teacher can further engage the students during problem solving.

Students should be given problems which will force them to do qualitative analysis before doing any mathematical computations. Problem solving that highlights both qualitative and quantitative knowledge is I think the way to go. It is not enough for the students to simply know what equations to use but more importantly know the
underlying principles imbedded in them. The strategy proposed by Van Heuvelen is an appropriate technique towards this end.

The big challenge for the success of Van Heuvelen’s strategy lies on the teachers ability to design problems that would force students to employ qualitative analysis of the problem before doing quantitative analysis. The website mentioned below contains a pool of questions that can be adopted (or modified by instructors to suit their specific goals) by instructor when teaching problem solving to their physics students.

In employing the above problem strategy we are actually engaging students to reflect on what they are doing like what experts usually do. Expert problem solvers are aware of what they are doing and frequently monitor, or self-assess their progress or adjust their strategies as they encounter and solve problems. This ability is what is referred to as metacognition. Metacognition is much more likely to develop in a classroom environment that supports them. [http://standards.nctm.org/document/chapter3/prob.htm](http://standards.nctm.org/document/chapter3/prob.htm). To help students learn how to think like a physicist they should be given an environment where they are encouraged to do reflective thinking during problem solving.

The development of coherent understanding requires the acquisition of both types of knowledge. Problem-solving is one way of promoting deep conceptual understanding of students. The problem solving strategy described above will be an effective way of attaining this goal.
I think it is also important note that we need to explain to students what the teacher is doing and why. Active-learning methods may not be welcomed enthusiastically by all students (Felder, 2000). Some regard it as a game the instructor is playing at their expense. So we need to spend some time to explain the reasons for using the approaches we plan to employ in our class. Convince them that by participating enthusiastically in the activities they would greatly benefit from it.

To facilitate the employment of these techniques in large lecture classes, the use of more hands-on activities is a big help. I would hope to see in the future that lecture halls are no longer just filled with chairs but filled with tables as well where students can work in groups and do hands-on activities (see figure 1). I believe that the

![Figure 1. A transformed lecture hall](image-url)
use of hands-on activities would further improve the teaching of physics concepts. Aside from the motivational power of these hands-on activities they also provide a good scenario for teachers to make students reflect on what they are doing. The hands-on activities can be designed in such a way that students will be guided in discovering for themselves the concepts that we want to teach them.

To wrap things up

Certainly, there are a lot of things that an instructor can do in order to teach effectively and make students’ learning more meaningful. If changes are made in the way we teach, we can make students appreciate the intricacies of physics and make them realize the importance of physics concepts in their everyday life. Who knows, we can even attract more students to major in physics, and of course, keep them there. The realization of this dream greatly depends on the instructors’ willingness to devote much time and effort in the teaching-learning process. To make one’s teaching more effective and make students’ learning more meaningful, one needs TCE- **time, commitment and effort.**
References


