

TEACHERS' PLAYGROUND: ENHANCING TEACHER PROFESSIONAL DEVELOPMENT THROUGH THE USE OF TECHNOLOGY

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Abstract

The paper describes innovative uses of educational technology such as electronic response systems (clickers), real-time data collection and analysis software and hardware (Logger Pro), computer simulations, and tablet computers. Our goal, however, is not a mere description of these technologies and their applications. We outline big pedagogical ideas that should drive the use of these technologies in the classroom to make a significant impact on science or mathematics learning. Four case studies showcasing the use of these technologies in science classrooms are discussed and the theoretical background behind their use is outlined. We suggest that technology-enhanced pedagogy has a potential to impact profoundly students' and teachers' learning and motivation. We suggest that these technologies should get integrated into in-service and pre-service science and mathematics teachers' professional development.

Keywords - Innovation, educational technology, tablet computers, electronic response systems (clickers), real-time data collection and analysis, computer simulations, conceptual learning, science and mathematics teaching and learning.

... In any situation where education and learning is involved, you first have to develop curriculum based on ideas, not on media. Media can be amplifiers of these ideas, but we have to have the ideas first.

*Spoken by Dr. Alan Kay, from "Doing with Images marks Symbols", 1987,
http://www.youtube.com/watch?v=bC7x_qntM0g*

1 INTRODUCTION: OVERWHELMED BY TECHNOLOGY?

Like many of your colleagues, you probably often feel overwhelmed by technology. The number of new technological educational innovations "proven to be effective in the classroom" coming on the market grows exponentially and keeping track of them becomes a difficult if not an impossible task. Moreover, not all of the research studies on the effectiveness of a certain pedagogical approach, with or without technology, are equally valid [1-4]. As a result, science and mathematics teachers and teacher educators are often left in the dark with regard to how specific educational technology might be implemented in a particular situation. One of the causes for concern is the way technology-based educational reform is often perceived and implemented by school administrators providing very limited support and training for science and mathematics teachers [5-9]. The effective use of educational technologies in K-20 science and mathematics classrooms should be driven by our understanding of how students learn science and mathematics [1-3, 10-12]. We should not assume that exposing a teacher to a new technological tool is equivalent to teacher training where he or she gradually acquires the necessary technological-pedagogical content knowledge and explores how this particular educational technology can facilitate learning in a specific educational context [13]. We strongly believe that future science and mathematics teachers should be trained the way we like them to teach. Therefore, we focus on big ideas behind using various educational technologies in science and

mathematics classrooms and outline their implications on teacher training. Since both of us are physics educators and we are more familiar with the physics teaching context, we embed our case studies in the physics classroom. Yet, the implications of the paper should not be limited to physics teaching and can be extended to science and mathematics learning in general.

2 WILL TECHNOLOGY HELP EDUCATORS CLOSE THE LEARNING AND TEACHING GAP?

During the past half a century a large number of researchers investigated student science and mathematics learning and students' ability to retain information presented in different formats [14-21]. While various sources provide slightly different percentages with regards to the information retained (Fig.1) by the students exposed to different pedagogies, the main conclusion from these data is that lecture-based pedagogy (or any form of instruction where the information is presented in a unidirectional way) is not the an optimal method for teaching critical and conceptual thinking [22]. Yet, lecturing is a very common mode of instruction in science and mathematics both in high school and university, even when class size is relatively small. Thus, there is an obvious mismatch between how students learn and how we teach them. This mismatch has been pointed out repeatedly by the proponents of active learning pedagogies [23-26], who suggested possible ways of promoting active learning in both large and small science classes [26, 27]. As new tests for measuring student conceptual learning in sciences became available, such as Force Concept Inventory and Force and Motion Conceptual Evaluation in physics [28-30], science teachers became aware of how little their students learned from traditional expository instruction. These findings strengthened the case for promoting active learning in science and mathematics. However, while theoretically active learning can be fostered even in a large class, practically promoting active learning in science and mathematics disciplines became a reality when the supporting technologies became available. The rest of the paper focuses on four of these technologies: electronic response systems (clickers), real-time data collection and analysis systems (i.e. Logger Pro Vernier Micro-Computer-based lab equipment), computer simulations (i.e. Physics Education Technology simulations [31]) and tablet-enhanced instruction. We describe four case studies delineating applications of these technologies in science and mathematics classrooms. Finally, we suggest how these technologies can be utilized in pre-service and in-service science and mathematics teachers' professional development.

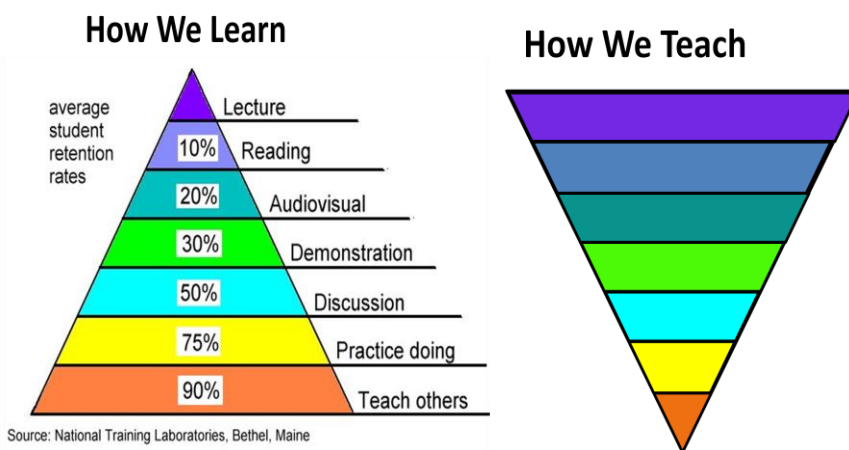


Figure 1: Two pyramids illustrate the mismatch between how we teach and how students learn. While the most effective way of learning appears to be the one where learners teach each others, the most common pedagogy employed in science and mathematics classrooms is expository learning.

2.1 Clickers: Finding out if your students are with you is only one click away

Electronic response systems (clickers) are gradually becoming wide-spread in science and mathematics university classrooms and more common in North American high schools. A clicker, as an educational technology, is a relatively new phenomenon [32-34], the flashcards and other low-tech methods to poll students and monitor their understanding, have been used for more than a decade [35, 36]. In physics, this technology was pioneered by a Harvard Physics professor, Eric Mazur [37],

who started implementing flashcards and then clickers in the late 90s. Mazur called this pedagogy Peer Instruction, as it was based on student pre-class textbook reading and consequently in-class collaboration on conceptual questions (concept tests). This pedagogy shifted the use of class time from reciting the textbook to the discussion of conceptual questions based on prior reading. There have been different adaptations of Peer Instruction. The model that we have been using in our science courses is described in Fig. 2. We call it “Modified Peer Instruction” as it does not follow Mazur’s method exactly. For example, unlike Mazur, we mix clicker-based pedagogy with expository teaching. So we ask on average 4-5 clicker questions per period (50 minutes) and use the rest of the lecture time for other activities. Another important pedagogical decision is how to mark students’ answers to clicker questions. On one hand, we do not want the students worry about answering all questions correctly; on the other hand, not giving any participation marks for clicker-based activities might deter less motivated students. The answer to this question should be given a serious thought by the instructor employing a clicker-based pedagogy.

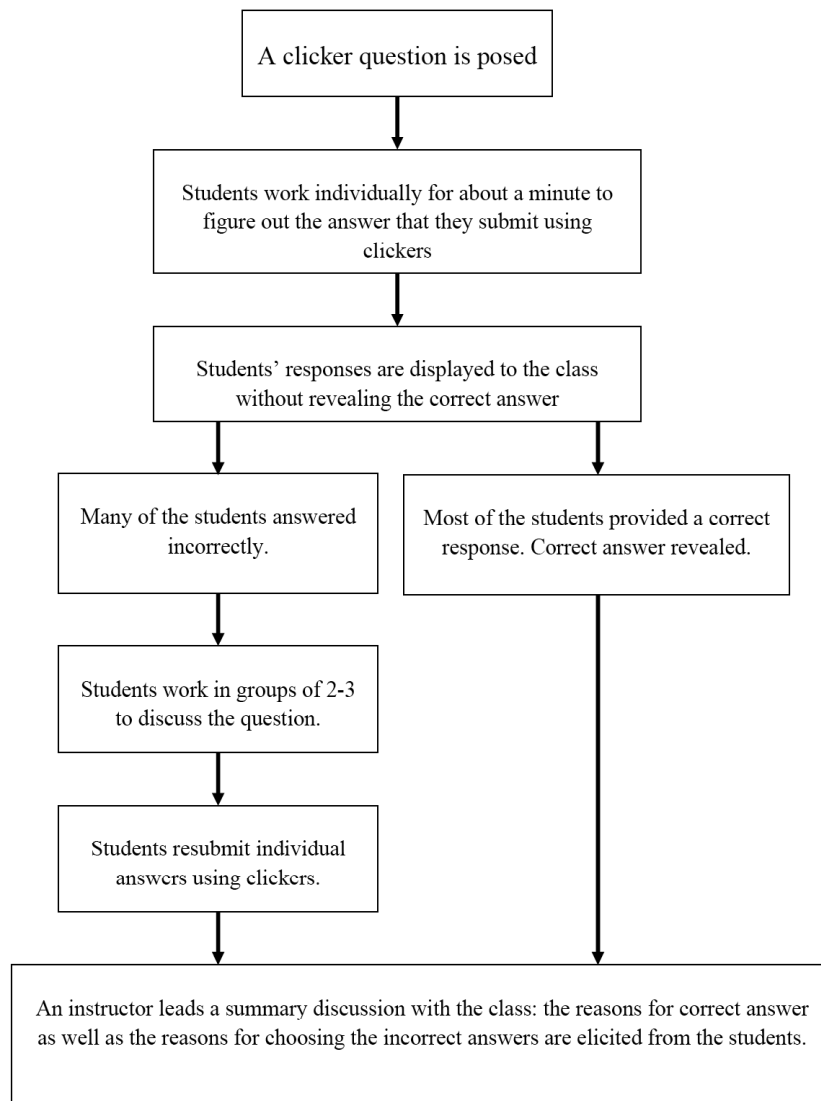


Figure 2: A flow chart representing Modified Peer Instruction pedagogy.

The technical side of clicker technology is rather straightforward. However, the pedagogical side of the clicker-enhanced teaching is a different story. In order to use clickers effectively [38-41], the teacher has to clarify (a) What are the big ideas behind using clickers? What is the pedagogical motivation behind using this technology? The answers to these questions depend on the teacher and the classroom context. Below we show our answers to these questions. We use clickers because:

- (a) Clickers allow us to collect formative assessment about student learning in real-time, elicit student difficulties and modify instruction to address these difficulties when they arise.
- (b) We want to teach our students independent and critical thinking. Thus presenting the students with our answers to concept questions is going to be counterproductive. They should learn how to figure out these answers for themselves and clickers are a great tool to achieve it.
- (c) We want the students to be engaged in explaining the problems to themselves and to their peers [42]. Clickers help us foster active learning pedagogy in our courses.
- (d) Clickers allow us to record students' answers and analyze them later on with the purpose of either conducting further research or designing relevant materials to support student learning.

In summary, the big idea behind using clickers is using continuous formative assessment to enhance student learning and providing students with ample opportunities to get engaged. It is important to emphasize that the challenge of using clicker-enhanced pedagogy is not learning how the technology works, but learning how to ask meaningful conceptual questions and how to react to students' answers. This is the place where teacher's pedagogical knowledge becomes apparent. Science and mathematics teachers should be aware of student conceptual difficulties in the subjects they are teaching. This is much more than just knowing how to explain the concepts correctly [43]. Very often student difficulties are hidden and it might take awhile for a novice teacher to figure out how to design a powerful sequence of clicker questions (Fig. 3). This is the pedagogical-technological content knowledge that should be built during effective teacher professional development. Future teachers should not only be exposed to clicker-based pedagogy in their courses, but they should also have a chance to practice designing clicker-questions. We recommend a paper by Betty and his collaborators on creating effective clicker questions [44]. This is a valuable learning experience for teachers as it forces them to use multiple representations of the phenomenon, clarify the concepts involved, and think ahead about possible student difficulties. Clicker-based pedagogy is an excellent vehicle for helping teachers expose their students to multiple representations and help the students develop critical thinking skills [45-49]. As McKendree and her colleagues pointed out [46]:

Being able to think about why a representation may or may not be good in a particular context is a big part of being a critical thinker. If a student can realise that the problem they are working on is best represented in a particular way, it can help them identify the most important aspects of a situation and analyse what should be done next. If they know what the 'accepted' transformations of a problem type are, then they can begin to think at a higher level about why those are the ones that are used and why, perhaps, it might be interesting to try a different representation. They can begin to understand why problems are the way they are (p.62).

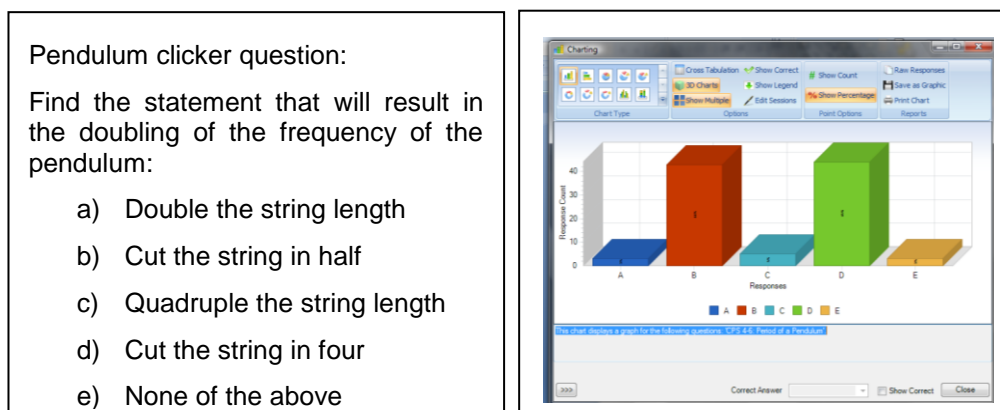


Figure 3: An example of a conceptual question. Student answers reveal their difficulty: the students understand that the string's length has to be shortened, but they are unsure by how much.

2.2 Live Data Collection and Analysis: Do your students ask you WHAT-IF Questions?

Like mathematics, science requires a high level of abstraction, yet the highest judge of the truth of scientific theories is an experiment [50]. Unlike mathematics, science is an empirical field: scientific method relies on experimental evidence, rather than on internal logical consistency alone. The most beautiful scientific theory will not hold if there is reliable contradictory experimental evidence. Anybody who studied the history of science [51, 52] remembers the excitement of scientists who lived to witness the experimental evidence supporting their hypotheses. For example, as much as Einstein believed that the General Theory of Relativity he proposed in 1915 was correct, as it had internal consistency and mathematical beauty, the experimental evidence brought by the astronomers after observing a total solar eclipse on May 29, 1919, was the trigger that sent the message to the scientific community that the General Theory of Relativity was indeed a correct theory.

Science students in high schools and universities soon realize that due to the complexity of the world around us, every scientific theory makes certain assumptions that put limitations on its applicability. The fact that scientists have the tools allowing making certain predictions, does not mean that these tools can be easily applied into practice. Moreover, scientific models are often simplified in order to understand the main effect or the central phenomenon. For example, while studying mechanics, the effects of friction and air resistance are often neglected. While studying electricity and magnetism, scientists calculate electric and magnetic fields created by infinitely large capacitors and coils. Those models can describe real life phenomena very accurately provided we account for their limitations. In addition, while understanding a new phenomenon, scientists often start with a simplified model and then extend it to the real life situation. As a result, textbooks often present unrealistically perfect graphs or unrealistically “clean” data. While this is done to make the precise analysis possible, it often conveys the wrong message: what is learned in the science classes has very little to do with the real world. Many science teachers attempt to address this problem via bringing science demonstrations to class to help the students relate science knowledge to outside world [53-56]. Yet it has been pointed out that lecture demonstrations have limited effectiveness in promoting conceptual understanding. Moreover, traditional classroom demonstrations involve little opportunity to collect and analyze data and are mainly aimed at increasing student motivation.

So is there another way of making classroom demonstrations more meaningful? The answer to this question lies in the use of data collection and analysis software and hardware that allow easy collection and analysis of real-time data, such as Vernier Logger Pro technology [57]. Technology simplified the process so much that it takes seconds to collect and display real-time data while leaving time for data interpretation and analysis. Fig. 4 (a) shows an example of the data collected during the pendulum experiment referred to in the previous section. Fig. 4(b) shows an example of a graph traditionally shown to the students during the periodic motion discussion.

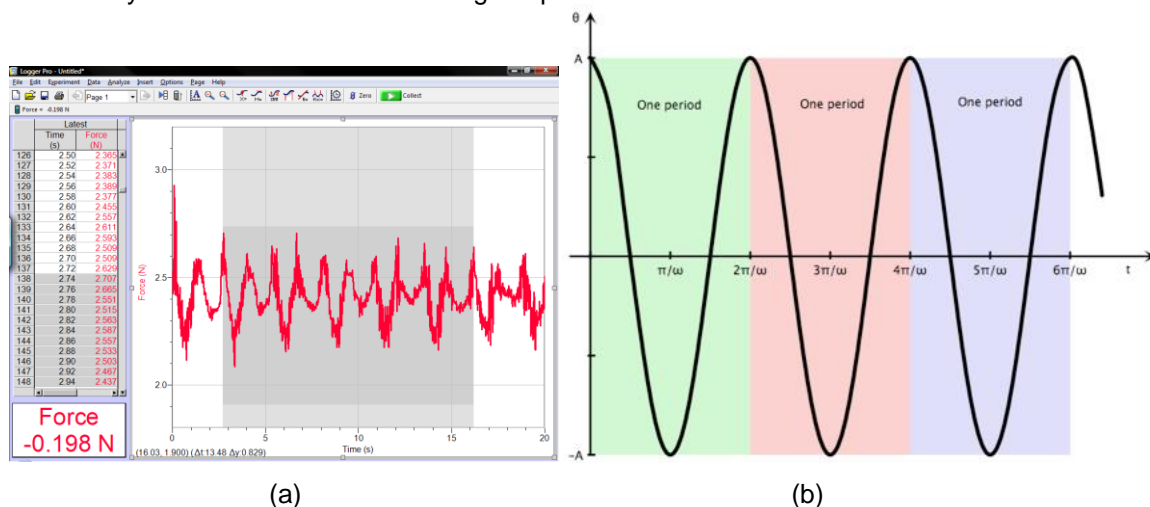


Figure 4: (a) Real-time recording of the tension in the string of an oscillating pendulum as a function of time. Notice, the graph illustrates the beats phenomenon: the amplitude of the pendulum periodically changes with time as a result of the superposition of pendulum oscillations in different planes; (b) A theoretical graph showing the time dependence of the amplitude of the periodic motion.

While it should be a teacher's decision when to use "clean" theoretical data and when to use real-life data, it is clear that data collection technology opens opportunities for the students to test their conceptual understanding in real life. The use of real-time data collection technology was pioneered almost two decades ago by the "Interactive Lecture Demonstration Team" [58-60]. The pedagogical idea behind the Interactive Lecture Demonstrations is to ask the students to predict the outcomes of scientific experiments (the written predictions are submitted to the instructor prior to seeing the demonstration), thus eliciting students' underlying concepts and making them verbalize their thinking and commit to their prediction. Then relevant testing experiments are conducted in front of them either confirming or disproving their predictions. Science educators who have used this pedagogy reported significant improvement in student learning [61-64]. Moreover, real-time data collection opens doors for asking and resolving new authentic science questions. In the example above, the Logger Pro data shows beats, generated by the superposition of two oscillations since the pendulum oscillates in a 3-D space. Nowadays, the Interactive Lecture Demonstrations coupled with clicker technology, simplify the process of collecting, recording and summarizing student predictions. It also leaves time for the students to ask IF-THEN questions, discuss alternative explanations and test their hypotheses.

It is important to notice that this technology can be used by teachers to help students transfer the knowledge from mathematics courses into the sciences as data analysis becomes a significant part of the experiment. Moreover, motion detectors and other sensors can be successfully used in mathematics courses to help students visualize various graphical representations of motion and make abstract mathematical concepts, such as derivatives and integration, more relevant.

2.3 Computer Simulations: Modern "gedunken" experiments

Let us return to the pendulum experiment. Although rather simple equipment is needed in order to build a pendulum, the derivation of the formula describing the dependence of the period of the pendulum T (the time for one oscillation) on its physical properties is rather complicated.

$$T = 2\pi \sqrt{\frac{l}{g}} \quad \text{Where } l \text{ is length and } g \text{ is acceleration of free fall} \quad (1)$$

For the students whose mathematical knowledge prevents them from understanding the derivation, the formula (1) might look intimidating or at least mysterious. It might also leave them in the dark about the disappearance of the mass of the pendulum from the equation. While it is easy to show experimentally that the period of the pendulum is proportional to the square root of its length and is independent of its mass, it is much harder to experiment on Earth with the different values of the gravitational acceleration g . This is the place where educators can turn to simulations like the one shown below (Fig. 5) [31]. The *Pendulum Lab* simulation allows the students to place the pendulum on different planets, change its mass, string length, or add air resistance or friction to make it more realistic. The ability to vary different parameters of the experiment easily helps the students gradually build their science intuition and get into the habit of making and testing their predictions. While simulations are based on the scientific models and cannot be used to prove the same model they are a powerful tool in helping students be engaged in a real scientific discourse, develop a scientific way of thinking, motivate them in learning and help generate and test new hypotheses.

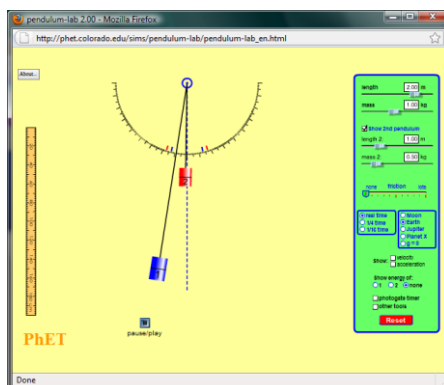


Figure 5: A screen shot of a Physics Educational Technology Simulation called *Pendulum Lab* (http://phet.colorado.edu/simulations/sims.php?sim=Pendulum_Lab).

There is another advantage of using computer simulations in a science or mathematics classroom. Numerical simulations allow learners to solve problems “experimentally” that could have been difficult for various reasons to solve analytically. We already pointed out that real-life data collection and analysis software helps students discover unexpected effects and make interesting observations, such as beats in case of a pendulum (Fig. 4). However, the fact of discovery does not ensure that students understand why the phenomenon happens. In that case, a computer simulation might be useful. For example, the beats simulation [65] is a powerful tool for helping students understand why and how the beats phenomenon occurs and what the physical applications of beats are.

2.4 Tablet Computers: Making students’ problem solving visible

The educational technologies described above have a potential to engage students in authentic science and mathematics learning. Yet, the way students think about concepts and approach problem solving tasks might still remain hidden. There is another educational technology – tablet computers, that helps making students’ problem solving process visible. Tablet computers employ ink technology that allows one to use a special pen to write on a computer screen the same way one would write on a piece of paper. However, unlike regular pen writing, computer inking can be easily modified, different images can be imported and ink annotations can be saved and shared with others. Hewlett Packard, a world leader in the tablet computer technology has sponsored a number of world-wide educational initiatives aimed at promoting educational applications of this technology. In 2008, we were the recipients of the Hewlett Packard Educational Technology Grant [66] and have had two years of experience in using tablet computers in science classrooms. We used tablets in two modalities: Tablets as a tool for the teacher; tablets as tools for the teacher and the students.

Initially we used a tablet to annotate prepared in advance “skeleton” PowerPoint lecture notes. The notes included pictures, diagrams, problems, definitions. During the lecture, the instructor completed the lectures with derivations, explanations and additional diagrams. This allowed the students (many of whom brought printed out skeleton notes to class) to follow the instructor’s thinking process versus just being exposed to a prepared in advance completed slides.

During the second stage of the process, we moved from the teacher-only use of a tablet computer, to having every two students share a tablet. Once again, this became possible due to the Hewlett Packard Grant that provided us with 21 tablets. During this implementation we used a Classroom Presenter software [67] that allowed the instructor to share her presentation with each one of the students in real-time. In addition, the students could collaborate on problem solving and submit their solutions to the instructors to be shared with the entire class in real-time (Fig.6). This capability of the all-class collaboration opens doors to discussing multiple solutions to the problem, debating the pros and cons of various approaches and allowing students to learn from each other [68-70]. At the end of class the instructor can save all the solutions and share them with the students to extend the discussion outside of the classroom walls.

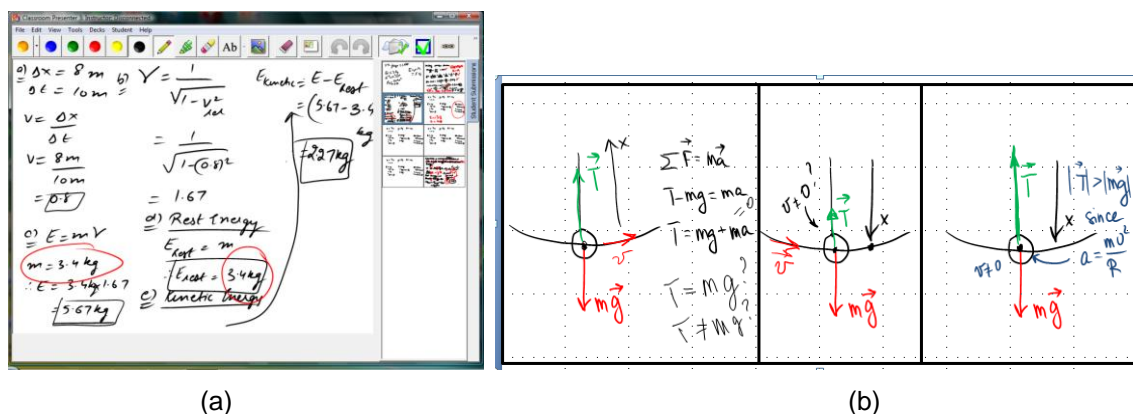


Figure 6: Two screen shots of (a) Classroom Presenter-based discussion in a second year university *Modern Physics* course that dealt with the Special Theory of Relativity. Eight small boxes on the right are submissions of different groups. Each one can be chosen by the instructor to be shared with the rest of the class, and (b) A student-driven discussion of multiple versions of Free Body Diagrams of an oscillating bob. The diagrams represent forces acting on the bob at its lowest point.

In summary, the big idea behind using tablet computers in a science and mathematics classroom is to provide the students with multiple opportunities to focus on problem-solving process while working collaboratively and cooperatively with peers; to share their solutions with each other and with the teacher in real-time; to learn to analyze and critique different problem solving approaches. In addition, tablet technology helps teachers to uncover student problem-solving process and reveal and address their difficulties in a timely manner. As soon as the students submit their solutions (it can be done multiple times during the same lesson), the teacher has an opportunity to follow the work of multiple groups simultaneously, thus providing the students with timely feedback. Continuous use of tablet annotations coupled with the Classroom Presenter environment makes real-time problem solving process explicit and forces students to be more reflective about it. If one asks the students to submit their solutions after class, the students might not show the process of how they arrived at this solution. Many of them will just write-up a “polished” solution, which will hide their difficulties. The real-time annotations address this concern via making the “invisible visible” at the right time. A more detailed discussion of the use of tablet computers in science teaching can be found in our other paper presented at this conference (Antimirova, T., Milner-Bolotin, M., 2010, INTED-2010).

3 CONCLUSIONS: IMPLICATIONS FOR PRE-SERVICE AND IN-SERVICE TEACHER TRAINING

In this paper, we presented four case studies of the implementation of different educational technologies in large and small university science classrooms. Originally, these technologies were aimed at promoting student active engagement in course material with the goal of increasing their conceptual understanding and real-life connections, yet our observations suggest that technology-enhanced pedagogy also promoted the same qualities among science teachers. Based on our preliminary results, technology-enhanced pedagogy driven by big educational ideas opens multiple opportunities for active student engagement and has a potential of promoting higher order cognitive skills among students. In addition, we have evidence that this pedagogy has a positive albeit indirect impact on students’ attitudes towards science and their interest in the subject, which is especially important for underrepresented groups in sciences such as girls and minority students [71]. We strongly believe that if we want science and mathematics teachers to use these technologies creatively and effectively in their classrooms, we should expose the teachers to these technologies during their pre-service and in-service professional development. We have to help teachers gain technological-pedagogical content knowledge, experience, and confidence, such as they feel comfortable and motivated in using these technologies in their future science and mathematics classrooms.

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