Remedying Shortcomings of Lecture-Based Physics Instruction Through Pen-Based, Wireless Computing And DyKnow Software

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ABSTRACT

The effectiveness of lecture format of physics instruction has been demonstrated to be inferior to that of more recently developed, research based methods (R. R. Hake, 1997; L. C. McDermott, 1993; E. F. Redish, 2003b). The information retained from traditional lecture frequently has a short lifetime and is unreliable.

Our earlier study identified various types of misunderstandings that may occur in a lecture type setting. They include recording facts incorrectly, concentrating on particularities and details in the instructor's statements at the expense of the more general concept, hearing "what makes sense" while overlooking what was actually stated, using the same terminology that experts use but with very different meaning attached to it and so on (Hrepic et al., 2007). This occurs even when learning conditions are in many aspects better than those during typical lecture. Nonetheless, the lecture is still by far the most widely used format of instruction due to its primary advantage of reaching large numbers of students simultaneously.

In this chapter we analyze the shortcomings of a lecture identified in previous studies and explore opportunities that wireless pen-based computing technology accompanied by DyKnow software offer in addressing these shortcomings. We finally present data on the effectiveness of DyKnow obtained in our and other studies. Metrics include test score comparisons, students' end-of-semester teacher/course evaluations and students' input and feedback related to the instructional value of the software and hardware (Hrepic, 2007).

INTRODUCTION

Research in physics education has shown that traditional lectures, even when presented by good lectures, have limited success in helping students learn physics (Thornton & Sokoloff, 1990) and students who complete a typical traditional lecture-based physics course on average do not have a good conceptual understanding of the material that they have studied (Richard R. Hake, 2002). Knight (2004) described some of the most widespread problems with the typical expository lecture instruction. Lectures often deliver complex information at a rapid rate. Most students have difficulty taking effective notes while listening to such lecture. Also, lectures often reiterate information already covered in the textbook. Further, the information retained from traditional lecture frequently has a short lifetime and is unreliable. When non-intuitive or not obvious information is presented in a lecture, the retention rate may be as low as 10% after just 15 minutes. (Wieman & Perkins, 2005) Knight (2004) summarized current findings related to expository lecture in physics by asserting that "the lecture mode of instruction is simply not an effective vehicle to help most students reach a satisfactory level of understanding". (Knight, 2004, p.46)

The effectiveness of more recently developed, research based methods of physics instruction, have been demonstrated to be superior to the lecture format. (R. R. Hake, 1997; Knight, 2004; L. C. McDermott, 1993; Edward F. Redish, 2003a) However, although only a small percentage of students successfully learn from carefully crafted explanations alone, the lecture is still by far the most widely used format of introductory physics instruction in United States. There seem to be two main reasons for this situation. The first and the most obvious one is the opportunity to simultaneously reach large numbers of students through lectures. The second one is that the large majority of the current physics and science instructors were educated through dominantly lecture-oriented instruction. Those instructors (authors included) represent the small fraction of students for whom this approach worked well (or sufficiently well). This, according to Knight (2004) is likely the reason that it is frequently hard for us to recognize deficiencies of this type of instruction or to adopt alternative approaches. This chapter explores options that pen-based computing systems in combination with interactive software solutions offer toward improving this situation.

LECTURE AS A METHOD - A CLOSER LOOK INTO EFFECTIVENESS

The earlier mentioned 10% level of short-term retention for counterintuitive information presented in a lecture holds true even when the audience is primarily physics faculty and graduate students (Wieman & Perkins, 2005). For example, in an experiment performed in a large Physics classroom at Colorado State University (Wieman & Perkins, 2005), students were presented with a violin after being introduced to the physics of sound. During explanation of the sound production by the instrument, students were explicitly told that strings themselves do not produce the sound coming from the violin because their vibration does not move enough air for this. Rather, via the soundpost, strings set into vibration the back of the violin, which then produces the sound they hear. Fifteen minutes after the explanation, students were given the multiple-choice question asking what mostly produces the sound of the violin and only 10% of students choose the correct answer, shortly earlier presented to them. With 84% choosing the string as the answer.

This example shows one of the deficiencies of expository lectures for efficient learning. Our earlier study (Hrepic *et al.*, 2007) specifically identified various other types of misunderstandings that may occur in a lecture type setting. The study was set up after researchers observed a vast difference in perception of delivered content by several students and by a neutral expert who attended the same lecture. In follow-up research we used a videotaped lecture of internationally acclaimed instructor and a popular textbook author (Hewitt, 1991) and presented it to students who had already completed their in-class lectures on the topic and had taken the course exam related to the topic. The study was conducted at Kansas State University, a mid-western open admission public university. It involved 18 students enrolled in introductory, concept-based physics course. The idea of the study was to present students a short lecture fragment, taught by the best possible instructor and in the best possible circumstances i.e. without any other distraction or interruptions, in order to determine whether or not they learn effectively under those conditions. The chosen video lecture segment was related to sound propagation, the topic recently completed in their on-campus course. We selected six questions related to this topic and requested students to watch the video segment. While watching, they were asked to determine whether or not the lecturer addressed those questions, and if so, to record the answer as given by the instructor.

The questions dealt with the following topics:

1. Nature of sound propagation

2. Dependence of speed of sound on temperature
3. Dependence of speed of sound on movement of the source
4. Dependence of speed of sound on the medium
5. Sound propagation in a vacuum
6. Effect of sound propagation on the dust particle

Not all of the questions in the set were addressed in the video lecture and those that were addressed were not explained equally thoroughly or equally frequently.

Just before the video lecture, students took a survey in which they answered these questions to the best of their knowledge. This survey served to gauge their initial knowledge i.e. to determine whether or not they knew the correct answers before the experiment. The survey also alerted students and mentally warmed them up to the lecture topic. The familiarity with questions on which they were supposed to find answers during the lecture made it easier for participants to focus on specific questions, rather than on everything that the lecturer may say. While watching the video, students were allowed to pause/stop and rewind the tape at any time during the lecture. This eliminated possible misunderstandings due to the pace of the lecture, difficult terminology, lapses of attention due to do note taking or wandering thoughts. Also, the “lecture time” was approximately 14 minutes, which required considerably shorter attention span than the typical 50-minute classroom lecture. In this experiment the instructor as well as all students were native English speakers which is not always the case in introductory physics classes. Finally, during the video lecture there were no typical classroom distracters such as noise, conversations and other interruptions. The combination of these conditions made this lecture in many aspects “idealized" when compared to the regular classroom lecture. Most notably, unlike in any normal circumstances, students had already covered the topic.

At the end of the video lecture the participants were asked to determine if further answers to any of the questions could be inferred from the content presented in the video lecture. This follow-up question ensured that students recorded answers that they might have perceived as implicitly given in the lecture but possibly not explicitly stated by the lecturer.

While recording answers to questions as they perceived them given in the lecture, all participants rated the thoroughness with which they perceived any of the questions addressed. As a reference for comparison, a set of nine experts was also included in the study and they went through the same procedure as students. The main results of the study are shown in the Table 1 below:

Table 1: Comparison between students and experts in understanding lecture content

Question	Researcher's position on which questions were addressed	# experts-participants who thought the question was addressed	# students-participants who thought the question was addressed	# of correct (and relevant) answers recorded by participants: During and after the video lecture	Already before the video lecture	Only as an inference	Total number of inferences
Q1. Nature of sound propagation	Yes.	9 (100%)	15 (83%)	2	1	0	3
Q2. Dependence of speed of sound on temperature	Yes. Fully and multiple times.	9 (100%)	18 (100%)	17	8	0	0
Q3. Dependence of speed of sound on movement of the source	No. No possibility to infer the answer.	0 (0%)	5 (27.8%)	1	1	1	3
Q4. Dependence of speed of sound on the medium	Yes. Fully and multiple times.	9 (100%)	18 (100%)	17	12	0	0
Q5. Sound propagation in a vacuum	No. But with the possibility to infer the answer.	7 (77.8%)	3 (16.7%)	2	2	2	3
Q6. Effect of sound propagation on the dust particle	No. But with the possibility to infer the answer.	7 (77.8%)	3 (16.7%)	2	1	1	2

Table 1 specifies the questions presented to participants and also the extent -- as perceived by researchers – to which they were addressed in the lecture. Input from the lecturer himself was similar to that of researchers. (Hrepic et al., 2007)

So what did students learn? Although the entire video segment was about nature of sound propagation, three out of 18 students did not realize that question on sound propagation (Q1) was addressed in the segment. Of those students who perceived the question as being answered in the video segment, only one actually grasped the correct answer. Question three, in view of researchers and experts was not addressed in the lecture either explicitly or implicitly. However five of the students perceived it as addressed and wrote their perceived answers to it.

When comparing correctness of students' answers given before and during the lecture, one can see a noticeable improvement only for Q2 and Q4. These questions differed from others in that they required short, simple answers and were addressed multiple times during the lecture.

Researchers and experts considered Q5 and Q6 not directly addressed in the lecture but thought both questions could be inferred from the content of the lecture. However students did not. For all of the questions students made 11 inferences at the end of the lecture, but only four of them were correct. More interestingly, correct inferences were made only by students who knew the correct answers to respective questions before the lecture. In another words, a correct inference was never made due to the knowledge obtained during the lecture. Thus, lectures will likely not enhance a student's knowledge or understanding of a topic as much as desired.

The study also showed that students perceive same questions addressed in the lecture less frequently and less thoroughly then experts do. Detailed analysis of specific answers recorded and explained by students during and after the video lecture revealed the following sets of traits:

1) While learning in a lecture-type setting students may hear and record information incorrectly and off the target. Students may concentrate on particularities and details in the instructor's statements at the expense of the big idea. Further, they may record those details incorrectly. Students may hear "what makes sense" to them based on their preconceived ideas while they overlook or ignore what was actually stated. During a lecture students also may hear or understand exactly the opposite of what the instructor have said and even hear what was never said.

2) Students may attach wrong meaning to correctly repeated statements or terminology in a way that they correctly repeat the instructor's statement but without making sense of it – sometimes without even realizing that the statement did not make sense to them. They may also correctly repeat the instructor's statement while interpreting it very differently than intended. This typically leads to false positive answers i.e. to correct answers given for wrong reasons. With respect to terminology, students often use the same language and terms that experts do but with a different meaning attached to them. This happens both before and after the lecture.

3) Based on the lecture content students may make unjustified extrapolation leaps by making inappropriate (e.g. too broad) generalizations. At the same time they do not make extrapolations expected by instructor - as presented earlier.

Consequently, after listening to a lecture, students may incorporate new information presented in the lecture into existing incorrect concepts and models. They may retain their previous ideas and mental models although they change their answers to specific questions after listening to the lecture. Ultimately, they may be less sure about their correct answer after the lecture than before. All of the above results are especially discouraging when one takes into consideration all the advantages of the 'idealized experimental lecture' in our study mentioned earlier.

Is lecture "bad"?

So, based on the presented findings, should we conclude that lecture is a poor way to teach? This question was posed by Donovan et al. in "*How People Learn: Bridging Research and Practice*" (1999), a highly acclaimed National Academy of Sciences report. Based on extensive body of knowledge related to human learning and current research into science teaching, the authors of the report suggest that this is a wrong question to ask. The lecture is a tool and its utility, just like that of any other tool (a hammer, screwdriver, drill…) depends on the task at hand and the material one is working with. Accordingly, lectures just as books, *can* be very efficient in transmitting new information, exciting imagination and honing students' critical thinking skills (Donovan et al., 1999). At the same time, for example, hands on experiments can ground developing knowledge but on their own they do not induce underlying conceptual understanding or generalizations (Donovan et al., 1999).

In light of this perspective as well as our earlier presented findings, we further examine the issue below. Later in the paper we draw on presented conclusions and examine possible benefits of tablet PC technology and accompanying software packages as facilitators in overcoming the lecture deficiencies while building on its advantages.

Key findings for effective science teaching

According to Donovan *et. al*. (1999) the following key issues must be kept in mind when considering approaches to effective teaching and learning:

(1) Students come to the classroom with preconceptions about how the world works and this initial understanding has to be drawn out and engaged in order for students to grasp the new concepts and information" (Donovan et al., 1999).

(2) "To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application." (Donovan et al., 1999) Experts, regardless of the field, always draw on a broad and richly structured information base of factual knowledge. But knowledge of a large set of disconnected facts is not sufficient and in case of experts it is combined with deep understanding (Donovan et al., 1999).

(3) A "metacognitive" approach to instruction can help students learn to take control of their own learning. (Donovan et al., 1999) Therefore the teaching of explicit, and subject-tailored metacognitive activities (such as predicting outcomes, improving understanding by explaining to oneself, noticing own gaps in understanding and failures to comprehend, planning next steps in learning etc.), must be incorporated into the curriculum in a variety of subject areas. (Donovan et al., 1999; White & Fredrickson, 1998)

TO LECTURE OR NOT - THE (RE)SOLUTION

Keeping in mind our discussion above, the obvious question is how do we bypass the limitations of the lecture while making use of its advantages. At this point we also disclose our theoretical pedagogical stance which is best described as social constructivism - lead by principles that knowledge is constructed gradually, in complex processes (Bransford *et al.*, 1999) and that learning is mediated by social interactions (Vygotsky, 1986). Accordingly, and based on substantial research into effective teaching methods in physics (Knight, 2004; Edward F. Redish, 2003a) and sciences in general (Handelsman *et al.*, 2004), we propose that the resolution for our question is interactive engagement, sometimes referred to as active learning (Knight, 2004). Students can be engaged with the instructor, with peers and with themselves and all of these different forms of engagement are necessary to efficiently address all three critical components of effective learning as proposed by Donovan et al. (1999) -- addressing pre-existing misconceptions, achieving depth and breadth of understanding and factual knowledge and improving critical and metacognitive skills.

These three engagement venues require diminishing of the role of instructor as supplier of information and increasing his/her role of a facilitator and a scenographer i.e. a stage-setter for productive learning. Is that requirement compatible with lecture-based instruction? We propose the answer to that question is yes, although this has not been the case with a typical traditional, noninteractive lecture format with one way information flow (hence the problems with traditional lecture described above).

Knight (2004) identifies characteristics of active learning based on common features of research based teaching methods in physics. All research-based teaching methods are student centered. Students spend much of class time actively engaged in doing, thinking, and talking physics rather than listening to someone else talk about physics. All of these research-based pedagogies emphasize students interaction with their peers. The role of the instructor is also different from that in traditional instruction as s/he is more a facilitator and less a conveyor of knowledge. Students take primary responsibility for their knowledge, they participate in activities, study the text and complete the assignments. Important characteristic of these methods is also that students receive immediate feedback on their work. (Knight, 2004,p.48)

Redish (2003a) calls for more interactive approaches to traditional lecture and suggest variety of simple strategies that one may apply toward that end in a typical classroom such as chunking the material, facilitating note-taking, asking authentic questions, getting students to vote on a choice of answers, promoting discussion etc. Further Redish (2003a) lists various lecture-oriented, research-proven teaching methods such as: Peer Instruction (Mazur, 1997) Interactive Lecture Demonstrations (Sokoloff & Thornton, 2006) and Just-In-Time Teaching (Novak *et al.*, 1999). There is also a variety of other research-based methods which effectively improve the quality of recitation sessions and the lab instruction, both of which are traditionally part of introductory physics courses (Edward F. Redish, 2003a). These methods include Socratic Dialogue Inducing laboratories (Richard R. Hake, 1992), Cooperative Problem Solving (Heller & Heller, 1999) and Physics by Inquiry (L.C. McDermott, 1996).

The names of these successful methods clearly indicate the focus i.e. principles that make foundation of their success. The common thread in all of these successful methods is (justifiably) the buzz phrase "interactive engagement". However, they differ in focus and setting for which they are primarily intended. For example, the thrust of the Peer Instruction method as used by Mazur (1997) is usage of Conceptual questions during the lecture. Students are presented a carefully constructed conceptual question, and are given a minute to individually think about the problem before submitting their first answer. They are allowed to discuss the problem with their peers for another minute before submitting their answer for the second time. The collection of answers is facilitated by personal response systems (PRS) so that the distribution of answers can be immediately displayed on the glass screen. The method works extremely well even in large lecture halls, highly engages students and improves their conceptual knowledge as well as problem-solving skills. Just-In-Time Teaching (Novak *et al.*, 1999), combines modified lectures, group discussion problem-solving and Just-In-Time delivered web content/questions. Both described methods rely on cognitive principles that students learn more effectively if they are intellectually engaged, and instructors teach more effectively if they understand what their students already know.

IMPLEMENTING EFFECTIVE TEACHING STRATEGIES - TECHNOLOGY AS A LEVER?

The next important question to tackle is: Can technology serve as a lever in implementing effective teaching strategies, and specifically implementing them to create lecture more interactive and engaging? Nobel Prize winner Carl Wieman seems to suggest that answer to this question is a resounding "Yes". (Wieman & Perkins, 2005)

Weiman and his colleagues (Wieman & Perkins, 2005) strongly consider advantages offered in particular by electronic personal response systems often referred to as “clickers”. These devices enable effective collection and display of students’ answers even in largest classes which help promote better conceptual understanding through peer discussion. Another highly promising technology in the view of Wieman & Perkins (2005) are interactive computer simulations.

Authors of this chapter echo the belief that technology can serve as an effective tool in promoting instruction. Below we examine a relatively novel technology that seems to go above and beyond opportunities offered by popular clickers. This is combination of wirelessly networked tablet PCs and accompanying software that enables real-time exchange and display of information among all participants in the learning process. This technology appears, at least in principle, to facilitate integration of vast number of effective learning strategies incorporated in successful teaching methods described above.

Wireless technologies and pen-based computing

Computing technologies are ubiquitous in higher education, and rightfully so. This development recently reached two separate milestones: (1) campuswide wireless coverage and (2) wide commercial availability of Tablet PCs (accompanied by fast growing number of Tablet PC specific software products). Tablet PC is a notebook-type computer that can be operated with a stylus in addition to a keyboard or mouse (Microsoft Corporation, 2005). When compared to the laptop, it owes its additional educational utility primarily to the capacity of recognizing and displaying handwritten input (see Figure 1.). This advantage is critical in fields were hand annotation, formula writing, graphing, schema sketching or free drawing play an important role. These fields include mathematics, sciences, engineering and art (e.g. Karatsolsis & Mills, 2007; Schulze *et al.*, 2007; Toto *et al.*, 2007).

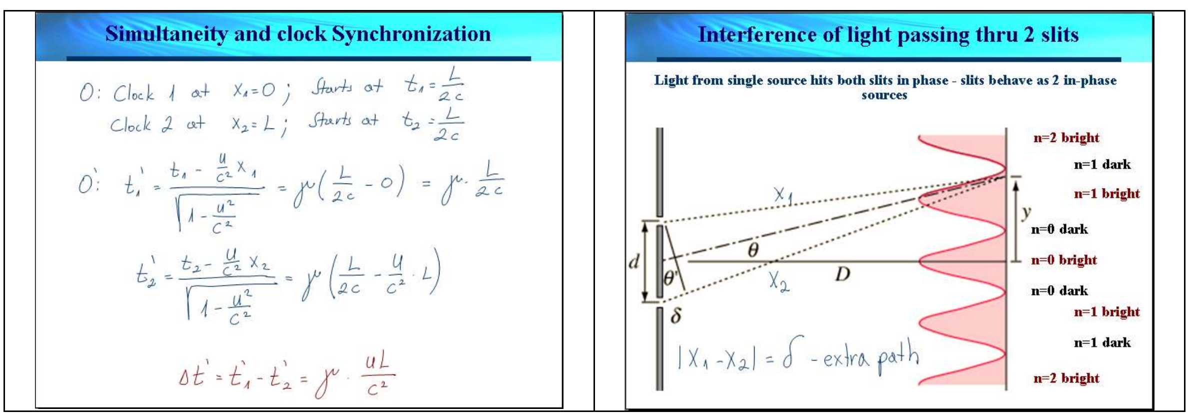

Figure 1: Writing formulas or modifying graphs in electronic format is as simple on a Tablet PC as it is on a paper

Use of tablet PC technology in higher education instruction is emerging and potential for large-scale deployments exist. But this technology is far from commonplace (Tront & Scales, 2007). In order to explore the advantages offered by wireless technology and tablet PCs, Fort Hays State University (FHSU), a public university in state of Kansas, initiated a campus-wide mobile computing program in Fall of 2005, with intention to investigate and promote effective ways of using these technologies in teaching and learning. The class implementation of the program started in summer of 2006. One of the authors was involved in the program from the very beginning and implemented the technology in several introductory physics courses (Hrepic, 2008). Based on two years of experience in implementation we explore the advantages and limitations of this technology for improving physics teaching in a primarily lecture-type setting. Later in this chapter we also report on learning gains and attitudinal improvements obtained as a result of using this technology in two different introductory physics courses.

Exploring utility of tablet PCs in education

With wireless infrastructure in place and with tablet PCs in the hands of all students, the goal of the FHSU mobile computing program was to determine the impact of this technology on instructional strategies, student satisfaction and to capitalize on these findings to improve student learning. It was also necessary to determine what type of software would best facilitate learning with this hardware and what teaching strategies would be optimal in this setting. In order to address these questions the physics department faculty at FHSU defined three guiding principles for implementation of this technology. The technology would facilitate

- Engagement: as opposed to passive reception (or not) of information
- Collaboration: as opposed to individual work
- In-class learning: as opposed to coming to the classroom to find out what information should be learned and/or memorized later

These guiding principles then, together with available hardware defined some novel teaching strategies applicable to the lecture-type setting. For example, we envisioned student group work during which individual students would simultaneously annotate the common group slide by writing and erasing the content from their respective tablet PC screens. The instructor would monitor the progress of all groups simultaneously from his/her own tablet screen and would be able to accordingly intervene, provide scaffolding, draw attention to possible mistakes or assign follow-up work as necessary. (Figure 2.) At the end of the session groups would be able to exchange the annotated files.

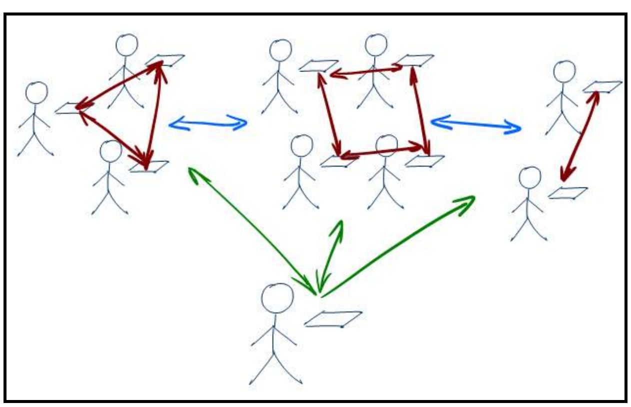

Figure 2: Engagement, Collaboration and In-class learning - wireless Tablet PC style

Implementation principles and teaching strategies such as these served as a basis for defining the properties sought for in software application (Hrepic, 2007) . After a thorough search and testing of variety of software solutions (such as Microsoft's Live Meeting, Groove Virtual Office, Blackboard Virtual Classroom, Microsoft's One Note, UW Classroom presenter, Lotus Virtual Classroom and CrossTec SchoolVue), we tried DyKnow Vision and Monitor (DyKnow, 2007). We found that DyKnow met and in many aspects exceeded our expectations.

Utilizing Tablet PCs accompanied with DyKnow software

DyKnow Vision software was designed to promote the interactive classroom instruction and has a variety of features that work toward that goal. The software is primarily oriented toward pen-based and wirelessly networked computing environment, however, many of its features are applicable also with laptops and stationary computers. In order to present the software's features more effectively, we group them into three major categories (feature sets) according to their functionalities.

Feature set 1: New dynamics of the note taking

Feature set 2: Multiple channels of real-time feedback

Feature set 3: All in control: Students in charge of the teaching/learning game

Each of these feature sets defines a further advancement toward more interactive and dynamic classroom environment as elaborated below.

Feature set 1: New dynamics of the note taking

DyKnow works in a way that instructor's annotations (or previously prepared slides) are wirelessly and in real time automatically transmitted to the students' computers. This way each student can take notes and write customized annotations on top of and in addition to material delivered and annotated by instructor.

This feature eliminates the class time spent on copying of material either onto the chalkboard (by instructor) or in the notebooks (by students). The time can instead be spent on analysis, discussion and reflection of the content. The notes that students take become only clarifications and additions to notes provide by the teacher. These features can help address variety of the aforementioned deficiencies of the conventional lecture instruction: First, in this setting the accuracy of students' notes is independent of vagaries of misheard or incorrectly and incompletely recorded information. As earlier elaborated, students may hear and record information incorrectly, off the target and may record information and terms that were not stated. (Hrepic et al., 2007) Second, students can concentrate on understanding the concepts and big picture explained by instructor rather than on copying (perhaps even incorrectly) everything written on the (possibly distant) blackboard. Anyone who has taken any science course was likely frequently faced with the dilemma whether to follow the instruction or to take comprehensive notes. This software feature effectively eliminates this dilemma. This technology eliminates the cognitive load associated with copying reduces the problem with possibly fast rate of information delivery. Finally, this technology allows for a variety of current issues or interesting aspects associated with the topic that can be effectively overviewed to provoke further interest and excite the imagination (Donovan et al., 1999). As an additional benefit associated with the first feature set is that the software records the pen strokes so students can later view annotations appearing in the same order in which they were written. This can be very helpful for understanding steps involved in the problem solution.

Feature set 2: Multiple channels of real-time feedback

DyKnow has four distinct channels of real-time feedback and they enable effective formative assessment and continuous feedback to instructor.

The first of these channels is "students' status" through which students indicate their level of understanding as high, medium and low continuously during the lecture. The teacher monitors the overall class status and adjusts the teaching pace and the content delivered based on changes in students' status. The second feedback channel is the chat feature which opens a venue for students to submit a written message to instructor (or to the rest of the class). Unlike with the status feature, while using the chat option each student can tell instructor exact nature of their difficulties without raising a voice, which can be intimidating, especially in large auditoriums. The third real-time feedback channel is the pooling option used to elicit multiple-choice answer distributions from the classroom. This channel offers all the advantages attributed above to classroom response systems (or clickers). As such, it can be very effectively used to promote classroom discussion or in a more structured peer-instruction mode. (Mazur, 1997) The instructor can incorporate the distribution of students' answers as the content of the slide distributed to everybody. This feature can be effectively used to show students their progress during the class time - by eliciting and recording their answers at the beginning and at the end of the time spent on a particular concept.

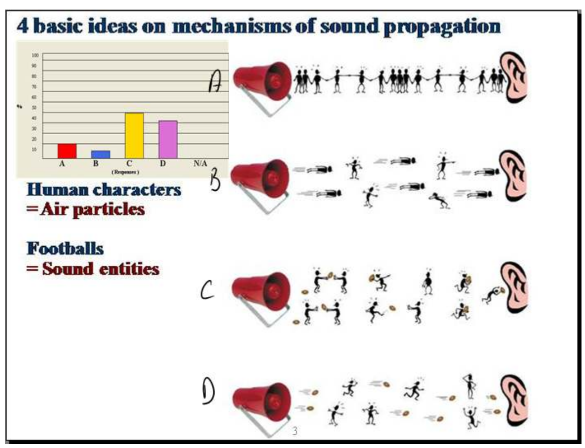

Figure 3: A multiple-choice question and obtained distribution of students' answers incorporated into the panel

Finally the software enables students to submit hand annotations such as responses to open ended questions, graphical or vector solutions and hand written solutions to numerical problems. This is the fourth channel of the real-time feedback and together with the pooling option represents an open-ended set of possibilities in terms of retrieving students work.

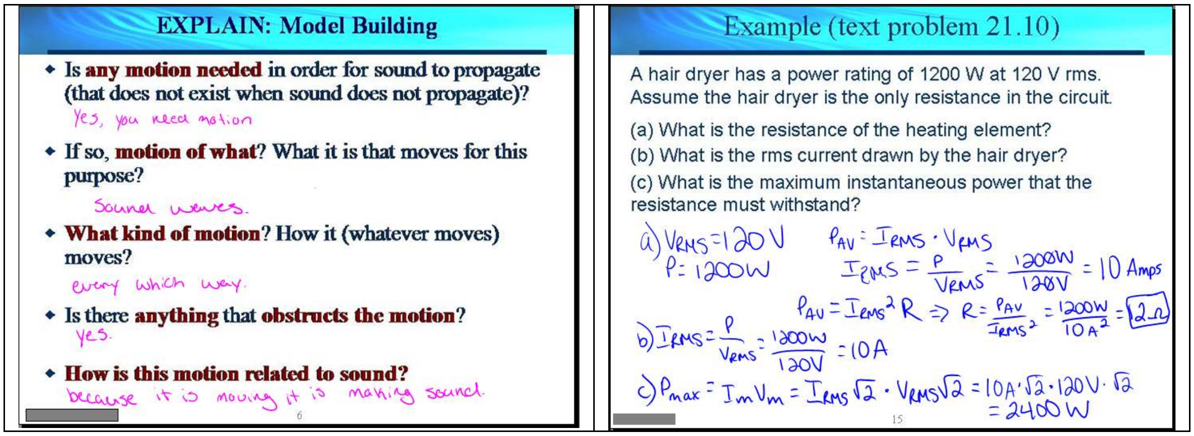

Figure 4: students submissions with handwritten input (left) and numerically solved problem (right)

Students can submit their work by themselves, in which case instructor can see the order in which the slides were submitted. This can be than used as an extremely powerful incentive for extra credit. Instructor can also, during the class session, retrieve panels with students' work at any time for summative grading. Graded panels can be distributed back to all individual students with one click and they find the returned work online, possibly much before the next class period.

These four feedback channels together make it possible for students to be heard by instructor without raising their voice in classroom. To the instructor, these channels offer all benefits of formative assessment which include student engagement, immediate feedback, adjusting of teaching well before the exam and according to specific needs of his/her students.

They facilitate interactive learning and peer instruction (especially in large enrolment classes were those forms of the instructions are particularly difficult to accomplish). Finally, they enable summative testing with close to immediate feedback and can be a powerful tool in promoting effective extra credit incentives.

In terms of earlier described lecture deficiencies, this set the features can significantly diversify activities for both students and the instructor during the lecture time and thus help overcome the problem with the limited concentration span. Peer instruction (Mazur, 1997) can be used to challenge and effectively deal with students pre-existing ideas and this technology can efficiently facilitate the process by easily collecting answers, incorporating distributions to students' notes and by collecting answers not only to multiple-choice questions but also to open-ended questions. The option for students to ask questions in a non-intimidating way, to discuss issues with pears can, together with the first set of DyKnow features (i.e. accurate notes) help eliminate attaching the wrong meaning to content terminology or to instructor's statements (Hrepic et al., 2007). Those two sets together can finally facilitate establishing a structured information base of factual knowledge in students. (Donovan et al., 1999)

Feature set 3: All in control: Students in charge of the teaching/learning game
In this mode of learning, a group of students share the same slide and together ink the annotations on that slide. This way they can either solve a problem together or perform an investigative activity. The Figure 5. shows students working in this mode of learning.

Figure 5. Investigative activity with slinky in physical science course for elementary education majors. Tablet PCs and DyKnow software are used to record observations which are later projected onto the main screen and compared to results from other groups.

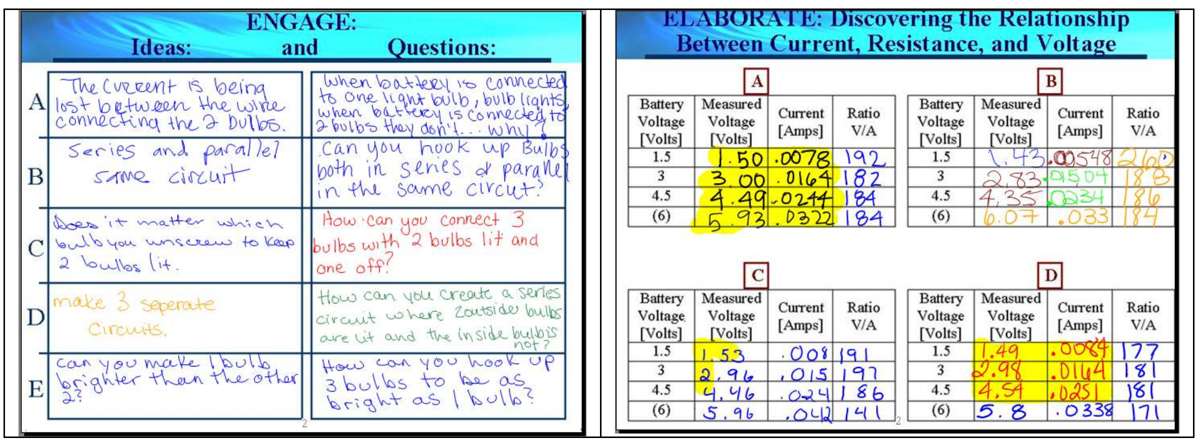

Figure 6: Slides collaboratively annotated by whole class, with each group writing to their respective spaces

This final feature set offers unparalleled interaction opportunities, ranging from group problem solving, collaborative experimental investigations, interaction and discussions within the group and class-wide, brainstorming, and automatic result sharing. Also, while groups work on their problems, instructor can monitor progress of each group from his own screen and intervene in order to scaffold as necessary or appropriate.

Figure 7. Collaborative problem-solving in atomic physics class. Students discuss and work simultaneously on the same problem while annotating the same slide, each from their respective Tablet PC.

These three described sets of software features, when working together and in synergy bring about the three goals of instruction with this technology that we set forward: engagement, collaboration and in class learning[1].

EFFICIENCY OF PEN-BASED TECHNOLOGY AND INTERACTIVE SOFTWARE IN TEACHING - DOES IT WORK?

DyKnow Vision has been successfully utilized at all educational levels including the pre-primary (Lindroth, 2006) and the tertiary (Roland, 2005). Research increasingly shows variety of beneficial effects of the software use on student learning and attitudes. Promising results have been demonstrated also in variety of academic fields. Not only in those in which annotation and visual representations play an important role - such as mathematics (Hubbard, 2006), economics (Dixon *et al.*, 2007) or computer science (Huettel *et al.*, 2007) - but also in fields like psychology (Berque *et al.*, 2008) Japanese language learning (Itoh, 2006) and special education (Exter & Ochoa, 2006). The benefits include improved learning of concepts, higher levels of student engagement, higher rates of homework completion, and fewer absences (Rockman et al., 2005).

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[1] DyKnow is a commercially available product but for our discussion it is important to mention that there is another, similar and freely available software package called Ubiquitous Presenter (2007) developed at University of California at San Diego. The Ubiquitous Presenter shares all of the main features with DyKnow but lacks some of the fine tunings and is slightly less user-friendly. However, at this point it can be used anyplace at no cost.

Effect of tablet PCs and DyKnow software on students' attitudes - FHSU deployment

The Dyknow software was deployed at Fort Hays State University (FHSU) for the first time in summer of 2006 and has been implemented ever since on a voluntary basis on instructor's part. FHSU is one of the six public institutions in the state of Kansas, USA. In order to establish the justifiability of deploying this technology and possibly extending its usage on a wider scale, we continuously (and especially in early semesters) solicited students' feedback in order to determine:

1. What are the positive and negative aspects of using tablet PCs and DyKnow software as perceived by students – users?
2. What are student's recommendations for future use of Tablet PCs and DyKnow software in that same course and in other courses?

The feedback from students has been obtained through anonymous surveys. One of the authors implemented the software in all of his courses except labs (this includes several introductory physics courses, introductory astronomy and science teaching methods). In this chapter, we report results obtained during DyKnow implementation in two introductory physics courses in which tablet PCs were used by students consistently and on one-on-one basis. The first course was Physical Science, a concept-based introductory physics course for non-science majors.

Students' feedback and attitudes obtained in Physical Science course at FHSU

DyKnow was implemented in this course for the first time during summer semester of 2006 (U06) on the pilot basis. In this pilot study number of participants was small (N=10) but the results were very encouraging. Nine out of 10 students stated that their experience with DyKnow was enjoyable and none of them thought it was a waste of time. In students view, DyKnow enhanced their learning (9/10) and facilitated their interaction both with the instructor (10/10) and with their peers (8/10). Without exception, students recommended (with majority strongly recommending) future usage of both DyKnow software and tablet PC in the Physical Science course as well as in other on-campus courses.

Encouraged by these results in the pilot semester, we continued using DyKnow in this and other courses while continuing to collect feedback from students. Here we show cumulative results obtained from students taking physical science course in summer 06 (U06), fall semesters of 2006 and 2007 (F06; F07) and spring semester of 2007 (S07). The response rate ranged between 80% and 100% in different semesters except in F06 when it was 40% due to the administration of the survey outside the class time that semester. The cumulative results obtained from 52 out of the possible 66 students in these four semesters (78.8% response rate) are displayed in the Table 2.

Table 2: Students' end of the semester evaluation of DyKnow software in Physical Science course (Summer 2006 – Fall 2007). N=52/66

Category of DyKnow Evaluation	General Positive Aspects		General Negative Aspects			Cognition			Communi-cation		Motivation	
Statement: Using DyKnow …	…was enjoyable	…made learning more fun	…was very challenging	…was very frustrating	…was a waste of time	…helped me take better set of notes	…facilitated my learning	…enhanced my understanding of the course material	…enhanced my interaction with classmates	…enhanced my interaction with the instructor	I was more attentive when DyKnow was used	I was more motivated when DyKnow was used
Strongly Agree %	46.2	40.4	3.8	0.0	0.0	21.2	26.0	15.4	30.8	33.3	30.8	25.5
Agree %	48.1	55.8	9.6	5.8	1.9	48.1	66.0	71.2	50.0	58.8	44.2	49.0
Disagree %	3.8	3.8	51.9	50.0	40.4	28.8	8.0	11.5	19.2	5.9	23.1	23.5
Strongly Disagree %	1.9	0.0	34.6	44.2	57.7	1.9	0.0	1.9	0.0	2.0	1.9	2.0
% answered (N=52)	100	100	100	100	100	100	96.2	100	100	98.1	100	98.1

The data show that 94% of all the students who took physical science course in four semesters between U06 and F07 enjoyed using DyKnow and for 96% of them, DyKnow made learning more fun. At the same time 13% stated using DyKnow was challenging and one student (out of 52) considered using DyKnow was a waste of time. In their view, DyKnow helped students take better notes (69%), it facilitated their learning (92%) and enhanced their understanding of the course material (87%). It also enhanced their interaction with classmates (81%) and their interaction with the instructor (92%). 75% of students reported being more attentive as well as more motivated to learn when DyKnow was used.

Figure 8. shows students' recommendations related to continued usage of DyKnow software and tablet PCs in this and other on-campus courses. 88% of students recommended keeping DyKnow in physical science course, and of the rest of them were neutral with no negative answers. About 50% of all respondents strongly recommend each of these implementations. One out of 50 students who answered this set of questions would not recommend implementing DyKnow in other courses or implementing tablet PCs in this and other on-campus courses.

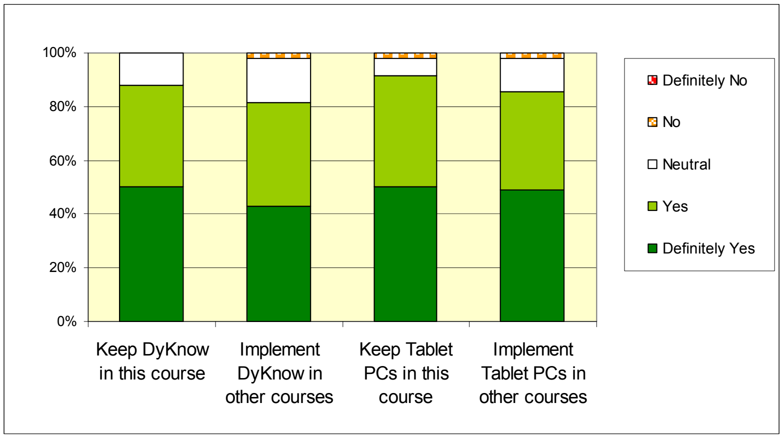

Figure 8: Students recommendations for future usage of DyKnow software and tablet PCs obtained in Physical Science course (Summer 06 – Fall 2007) N=52/66

The same instructor was teaching this course for five semesters before using DyKnow in the course for the first time. From instructor's perspective this technology brought in an unprecedented ease in facilitating and supporting classroom activities, student data collection and exchange and communication in all directions. By using DyKnow the instructor was able to conduct and manage this inquiry-based course more effortlessly and more efficiently than previously possible with two student teaching assistants helping during the class time. The intense level of classroom interaction and discussions in some semesters resulted in deep conceptual understanding (thus bringing the level of the course in some aspects to a level typical for introductory algebra-based physics course). But due to the lack of uniformity in test results, more data collection is needed for conclusive statements. There is indication at this point however that while DyKnow can facilitate virtually any traditional venue of content delivery and student learning it also cannot be used as a replacement for any of them (e.g. extremely rich discussions are not substitute for homework or textbook reading).

Students' feedback and attitudes obtained in Modern Physics course at FHSU

We elicited students' feedback related to of DyKnow and tablet PC usage also in a sophomore level, calculus-based, modern physics course for physics majors. This course is perhaps a prototype candidate for traditional lecture environment. Students' inputs were elicited through the anonymous survey equivalent to one used in physical science course, also administered at the end of the semester. One of the authors taught this course once in F05 (without this technology) and in F06 (with it). The survey results obtained in F06 are shown below (N=9/10).

Table 3: Students' end of the semester evaluation of DyKnow software in Modern Physics course (Fall 2006). N=9/10.

Category of DyKnow Evaluation	General Positive Aspects		General Negative Aspects			Cognition			Communi-cation		Motivation	
Statement: Using DyKnow …	…was enjoyable	…made learning more fun	…was very challenging	…was very frustrating	…was a waste of time	…helped me take better set of notes	…facilitated my learning	…enhanced my understanding of the course material	…enhanced my interaction with classmates	…enhanced my interaction with the instructor	I was more attentive when DyKnow was used	I was more motivated when DyKnow was used
Agree and Strongly Agree N	8	7	1	3	0	6	8	5	8	7	4	3
Disagree and Strongly Disagree N	1	2	8	6	9	3	1	3	1	2	5	6
No. answered	9	9	9	9	9	9	9	8	9	9	9	9

The Table 3. indicates again favorable attitudes toward the software. In this course, all but the one respondent stated that using DyKnow was enjoyable and all but one that it facilitated their learning. Majority of students disagreed that DyKnow was either challenging (8/9) or waste of time (0/10). Three students stated the usage was frustrating, but follow-up comments showed that the source of the frustration was not the program itself but rather the technological issues associated with its usage, such as occasional instability of the wireless network. In students' view DyKnow enhanced their interaction with the instructor (78%) and with their classmates (89%). In terms of students attention and motivation, usage of the software did not appear to make as large difference in this course as in the physical science class (33% of students reported being more motivated when DyKnow was used and 44% more attentive). In regards to continued usage of tablet PC and DyKnow software, majority of students recommended further usage of the technology. Some were neutral but no student gave negative recommendation to any aspect of the technology in this or other courses. Results are shown in the Figure 9.

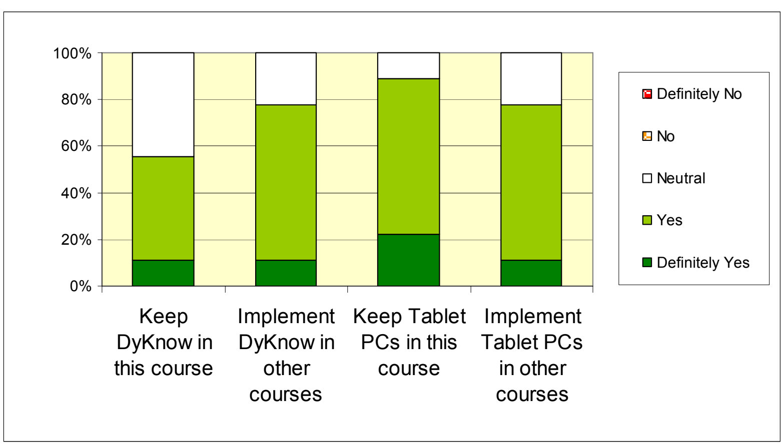

Figure 9: Students recommendations for future usage of DyKnow software and tablet PCs obtained in Modern Physics course (Fall 2006). N=9/10

It is worth mentioning that when compared to F05, the Teacher Evaluation Survey (TEVAL) results in F06 for this course showed improvement for this instructor in all three measured categories (Instructional styles, Facilitating learning, and Overall evaluation) (Hrepic, 2007). This perhaps could also, be partially attributed to the consistent usage of this technology throughout the semester. However, the difference was not statistically significant.

Here we finally summarize students' open-ended answers to questions related to advantages and disadvantages of using DyKnow software. For this purpose we present composite results for both Physical science and Modern physics course. Out of possible 76 students enrolled in these two courses between U06 and F07 semesters, 61 took the survey. Of those, 51 gave a written answer to question "What have been the biggest advantages, if any, of using DyKnow?" Three distinct themes emerged here: Increased interactivity (mentioned by 56.9% of those who gave input), facilitated note taking (41.2%) and ease of following the instructor (9.8%). The question "What have been the biggest disadvantages, if any, of using DyKnow?" was answered by 50 students but only one prominent theme emerged 32% of respondents mentioned hardware issues here (individual tablets out of order, stylus not writing, wireless network drops, slow connection, battery life etc.). 14% stated nothing was the disadvantage. 12% mentioned distractions such as Internet in context of this question. 10% stated they initially had problems with learning the software itself and further 6% thought they did not take as many notes with the DyKnow as they would traditionally on paper.
In response to the question "What problems did you have when using DyKnow?" 30 students, or 58.8% of those who responded (51) stated they did not have any. All other three categories that emerged (remembering DyKnow functions, softer freezing up and slow connection) together accounted for 19.6% of inputs and were nearly equally divided in percentages.

Effect of tablet PCs and DyKnow software on students' attitudes – other deployments

High levels of students satisfaction with DyKnow software and Tablet PCs are commonly reported in other studies related to the topic (Mutchler *et al.*, 2006; Scott *et al.*, 2006; Wang *et al.*, 2007). As an example, at DePauw University, where DyKnow is deployed in a variety of courses, computer science majors and minors were invited to participate in a survey related to the software. 81 student who took the survey (out of 120 invited students) collectively took 431 courses in which pen-based computers and DyKnow software were used (more than five such courses per students on average). In response to the statement "Overall, DyKnow has had a positive impact on what I have learned as a computer science major or minor" - 73% of respondents strongly agreed, 25% agreed somewhat, and less than 1% either was neutral (1 student) or disagreed somewhat (1 student). No students strongly disagreed. (Berque, 2006) At the same time 100% of instructors who responded to similar survey (N=10) either agreed or strongly agreed with the statement "DyKnow has had a positive impact on student learning in my classes". (Berque, 2006) Very positive instructor's inputs are reported in other studies as well (e.g. Tront & Scales, 2007). Positive feedback from students is typical also for usage of tablet

PCs with other software packages similar to DyKnow such as Ubiquitous Presenter. (Huettel *et al.*, 2007)

But there are also examples of the opposite sentiment obtained from students during DyKnow/Tablet PC deployment. In a study reported by Chidanandan *et al.* (2007), old computers (which might have translated into slow and/or unreliable) seem to have substantially decreased students' satisfaction with this technology. Other authors (DiStasi *et al.*, 2007) report dramatic differences in students feedback obtained in classes taught by different professors who used the same technology (tablet PCs and DyKnow software) at the same college. DiStasi *et al.* (2007) identified several variables that contribute to these differences. The class where DyKnow was received most favorably was one where DyKnow use was voluntary and not required. Students, who reported greater use of the stylus where significantly more satisfied with the DyKnow than students who reported lesser use of the stylus. Finally, students who saw their professors as more proficient, rated DyKnow higher. (DiStasi *et al.*, 2007) So the unfavorable results seem to have been caused by insufficient reliability of the hardware, instructors' opposition to using this technology or their inadequate proficiency in using it.

Cumulatively, our studies and most of other studies mentioned before show that from both students' and the teacher's perspective, DyKnow in most cases substantially and positively changes the typical classroom dynamics. Through a variety of communication channels described before, this technology greatly facilitates the interaction between students and the teacher as well as among students themselves. It facilitates their note taking and learning, increases their motivation and attention and is by a large majority of students perceived as enjoyable. This is an excellent basis on which instructor can build the active learning experiences adaptable to lecture environment that research has proven effective.

Effective teaching with pen-based technology

However, as Tront & Scales (2007, p.9) observed: "while the use of technology in higher education is commonplace, the use of tablet PC technology in the classroom is innovative". The research on effective learning strategies in this environment is very scarce and there are many open questions related to effective teaching in this environment. For example (1) what are the optimal teaching strategies in highly interactive, pen-based learning environment? (2) which knowledge domains benefit most from the use of pen-based technology, (3) what the barriers to using tablet PCs in the classroom exist and how to overcome them. (Huettel et al., 2007)

While deploying tablet PCs and DyKnow software in modern physics course (Hrepic, 2007), in the second half of the semester, when students were well familiar with variety of instructional modes with and without this technology we administered a survey aiming to answer the following question: Given the choice of utilizing different levels of technology involvement in instruction (a) what is the students' preference in terms of the instruction/presentation mode and (b) what is their preference with respect to the problem solving mode. These two aspects are both crucial in this course.

Not all DyKnow instruction is created equal:

Students expressed their preferences for different modes of instruction, so they independently rated each mode on the scale between 1 and 10 (with 10 representing the best alignment with their preference). Four major instructional modes were offered in the survey, two which utilized DyKnow software and another two which did not:

- "Chalkboard" - Instructor writes on chalkboard, and students take notes on paper. (Note: This is the traditional presentation mode, and does not involve any technology)
- "Blackboard" - Instructor writes on tablet PC screen, and students take notes on paper. At the end of instruction instructor posts his notes on Blackboard. (Note: Blackboard refers to The Blackboard Academic Suite™ - an online course management system).
- "In class writing with DyKnow"- Instructor writes derivations on DyKnow slides so writing appears also on students screen - as it is written. (Note: This mode fully utilizes opportunities of both DyKnow software and tablet PCs.).
- "Pre-prepared slides with DyKnow" - For the most part instructor pre-prepares the slide content and sends a whole slide at one time and follows up with explanation. (Note: this mode differs from the previous one in that derivation is not done in the class. Rather, it is prepared in advance and only explained in the class.).

The results obtained in this survey are shown in the Table 4. All 10 students took the survey.

Table 4: Students' preferences for different instructional modes, each rated on 1-10 scale

Rate instruction modes individually (Scale 1-10):	1&2	3&4	5&6	7&8	9&10	Average	SD	Mode	Median	Rank per Average	Facilitated by DyKnow
1. "Chalkboard"	3	1	3	2	1	4.6	2.9	1	5.5	3 / 4	No
2. "The Blackboard"	4	0	2	4	0	4.6	3.0	1	5.5	3 / 4	No
3. In class writing with DyKnow	0	0	2	4	4	8	1.5	7	8	1	Yes
4. Pre-prepared slides with DyKnow	1	2	0	3	4	6.9	2.9	9	7.5	2	Yes

In this comparison students on average rated both of the DyKnow-based modes of teaching higher then the other two options. Ratings for DyKnow-based teaching modes also had smaller standard deviations and much higher modes. Of the two DyKnow based modes the dynamic usage of the software was rated higher than the in class writing of the course material.

Six out of ten students wrote a comment as a follow-up on numerical input related to their ratings. Two themes surfaced up in comments: (1) Pre-written slides are OK but writing them in class is better - expressed in 5 comments. (2) Physical movement of the instructor, pointing on different parts of the screen rather than with pointer on the tablet helps to follow the content – expressed in 2 comments. The following thoughtful comment nicely summarizes both themes that surfaced in written comments.

> "At times I think it is appropriate to have some slides pre-written out. But for the most part I would like to see the slides written out in class. It's as if you would be using DyKnow as the chalkboard. It just makes it easier to "see" how ideas are developed, when they are actually written out step-by-step in class. Having the slides pre-written isn't much different than reading out of the book, and I can do that on my own. It also helped when you stood up at the screen in class and pointed to parts of the slide as you were explaining it. Just having you move around helps keep our level our of interest. I guess, it is always helpful in any class if each class period is not exactly like all the other class periods. In other words, mix it up! :-) "

This was a nontraditional student so the part referring to book reading by students might not be as widely generalizable as we would like it to be. In the same mid-semester survey, students also rated problem solving modes according to their preferences. Each mode was again individually rated on the scale from 1 to 10 with the score 10 representing the highest preference). The choices offered in the survey and corresponding results are shown in the Table 5.

Table 5: Students' preferences for different problem-solving modes, each rated on 1-10 scale

Rate problem solving modes individually. I prefer problems solved by… (Scale 1-10):	1&2	3&4	5&6	7&8	9&10	Average	SD	Mode	Median	Rank per Average	Facilitated by DyKnow
1. Instructor on the chalkboard	4	1	1	3	1	4.5	3.3	1	5	6	No
2. Instructor on screen and posts them later on Blackboard	2	0	2	3	3	6.5	3.3	1	7.5	3 /4	No
3. Instructor on DyKnow so they appear on students slides as solved	2	1	2	2	3	5.9	3.3	1	6.5	5	Yes
4. Instructor in advance, sends solution through DyKnow and explains the solution	3	3	4	0	0	3.5	1.9	3	3	7	Yes
5. Students individually	1	2	2	1	4	6.5	3.3	10	6.5	3 /4	Yes
6. Students collaboratively, in groups	0	2	3	3	2	6.6	2.3	6	6.5	1 / 2	Yes
7. Instructor and students by working on the same problem at the same time and on the same slide.	0	1	4	4	1	6.6	1.8	8	6.5	1 / 2	Yes

Two of the students' top choices for problem-solving modes (averages 6.6) were both DyKnow-based. These modes were collaborative problem-solving in groups (#6) and class-wide problem-solving together with the instructor on the same slide (#7).

The average score (averages 6.5) for two other choices closely followed - individual problem-solving (mode 5) and the problem-solving mode, in which the instructor solves problems on his/her own and posts the solution on the Blackboard (mode 2). The individual problem-solving was done in DyKnow mode throughout the course. The advantage of using DyKnow for individual problem-solving (as opposed to individual solving on paper) is the teacher's ability to share and/or discuss a particular student's solution with the whole class as well as monitor their individual progress as they work on the problem. The high score for the problem solving by instructor accompanied by later posting on the Blackboard is somewhat surprising because the equivalent instructional mode in the first survey question was not highly rated. In order to interpret this result, the instructor followed up by informally asking this question in the class and found out that some students particularly liked when an additional (not shown in class) set of problems was solved by instructor and posted online as additional resource and for test review. These sets were more neatly written and better organized than typical problems solved during class time which made them additionally appealing.
Somewhat lower average score (5.9) than scores obtained for top choices (averages 6.5-6.6) was obtained for option when the instructor solves problems alone in real-time, using DyKnow, so the write-up appears on students slides (mode 3). The chalkboard mode score (mode 1) came yet lower (average 4.5). But the least popular of all choices was a DyKnow-based mode, in which the instructor solves the problem in advance, during class time sends the solution to whole class as a ready-made slide and then follows up with an explanation (mode 4).
Thus, while most of the DyKnow-based instructional and problem-solving modes were students' top choices, certain ways of using DyKnow came out as the least appreciated modes, with ratings lower than those of the traditional, "technology-free" instructional mode. This clearly shows that technology itself is not an educational panacea; however, particular ways of using it may secure significant progress. . And in our view the very wide range of options and possibilities that this technology offers is what makes it so promising as well as obviously appealing to both students and instructors. Along those lines, it is informative to note that, while pre-prepared slides with solved problems were students' least appreciated choice, the equivalent instructional mode received above average ratings.

Three students wrote an additional comment in response to this question. One of them expressed he or she enjoys working the problems either individually or in groups. One suggested working (or thoroughly thinking through) problems individually first and then solving them together as the class together with the instructor.

The third comment came from the same students quoted above, and was again detailed and thoughtful.

> "Okay, I am really glad you asked these questions. I think the ideal situation would be if you were to write out the solutions to problems on DyKnow in class (NOT solved in advance). But then you could have the same problems pre-written out and put up on Blackboard. I suggest this situation because there are times in class when we don't need to

completely solve it to completion (or run out of time). However, when we are studying for a test it is VERY helpful to have the completed solution so when we work out the problem on our own we can check to see if we arrived at the same result. And in regards to the individual/group situation: Ideally I would like to have you give us about 1 minute to individually think about how we would go about solving the problem before you solve it on DyKnow (that is writing out the solution in class). Also, use a timer if you need to in order to keep us on track. But it is also nice to have you mix it up every once in a while. Maybe ONCE a week have us try and solve ONE problem in groups before discussing it as a class. And of course, as you are explaining how to solve a problem I think it is always good to get our input. However, please be careful that the same person is not always answering the questions. And finally, I really do not like having the 'timed' problem solving sessions [with extra credit offered to group who solves the problem first]. It just makes me shut down because I know 90%+ of the time [name] will be the first to solve the problem. Thank you for taking the time to get our input. It really shows you care and want us to succeed. Have a good break. :-)"

Effect of tablet PCs and DyKnow software on students' learning – deployment in Modern Physics course at FHSU

The final question we wanted to answer in F06 deployment of tablet PCs and DyKnow software in modern physics course, was whether usage of tablet PCs combined with DyKnow software effects students' test scores

To answer this question we compared the course test results when DyKnow and tablet PCs were used in the course (F06) with results in the previous offering of this course when this technology was not used (F05). The same instructor taught the course both times, used the same textbook and covered the same content. The scope and complexity of test questions were the same although administered problems were different. Three tests were administered in both semesters and in each of the semesters one of the tests was repeated due to the low initial scores in order to encourage further learning and deeper understanding. The Table 6. shows the test results obtained in F05 and F06.

Table 6: comparison of test results in Modern Physics course in F05 (without DyKnow) and F06 (with DyKnow)

	F05 (N=13)		**F06 (N=10)**		
	Average (%)	**SD (%)**	**Average (%)**	**SD (%)**	**P(T<=t) one-tail**
Initial test results	71.31	13.04	80.70	16.51	0.1035
Repeated test results	75.78	10.54	82.53	15.92	0.1635

As presented in the Table 6, when compared to F05, the average test results were in F06 almost a full grade (9.39%) better for the initial test and were 6.75% better for the repeated test. However, the difference was not statistically significant at 0.05 level, which, with this difference in averages can be attributed to the small sample sizes. The statistical significance was determined with independent samples t-Test, assuming equal variances. The equality of the variances was established with Levene's test.

Available background information related to students high school GPA and their college entrance ACT scores showed that the F05 semester population had somewhat better HS GPA and ACT composite score while F06 semester population had slightly better ACT science score. However none of these differences were statistically significant. This data was available for five (HS GPA) and six students (ACT) out of 10 total.

Effect of tablet PCs and DyKnow software on students' learning – other deployments

Studies reporting impact of tablet PC/DyKnow technology on students learning gains are emerging but are not abundant and results are frequently not robust. Most of the reported studies involve quazi-experimental research designs with limited number of subjects. However, as in our study described above, the results are consistently positive (Berque *et al.*, 2007; Berque et al., 2008; Dixon et al., 2007; James *et al.*, 2006; Schroeder, 2004). These studies demonstrate greater learning gains in experimental groups using this technology but only one (Dixon et al., 2007) has shown statistically significant difference.

Dixon et al. (2007) investigated whether this pen-based hardware/software educational technology assists students in learning graphical analysis introductory college economics. The control group received the same material as the experimental one but in a traditional manner (instructor writing with pens on a wall Whiteboard at the front of the classroom. In a test given after two weeks of instruction, students in the pen-based computing section scored 10 percentage points higher than students in the control group (82% versus 72%), which was statistically significant 5% level. In addition, the variance of the scores was substantially lower for DyKnow vision group than four the traditional group. Dixon et al. (2007) suggested that it is possible that the pen-based technology helps reduce the inequality of outcomes that stem from the variable note taking ability of college students.

Dave Berque et al. (2007) investigated effectiveness of DyKnow software in facilitating learning through group problem solving. In this mode the teacher transmits a problem to students' tablets, students solve the problem in small groups, share the solution and participate in group discussion. 20 students participating in study were divided into an experimental group (working with tablet PCs and DyKnow) and the control group (using lower-tech solution with transparencies and markers). As a result, the Tablet PC group had a greater mean gain in the correctness of the problem solutions in pre- and post-instruction tests, but this difference was not statistically significant for the two options of shared writing surfaces (Berque et al., 2007). The study did however found significantly higher level of student satisfaction with the tablet PC shared writing surface when compared to transparencies and markers. The study also found that students who used tablet PCs were making discriminating choices related to the optimal input venue (ink vs. keyboard) for different problems at hand. Thus, they used digital ink without exception to enter the solutions related to the prediction of the output of the software command. However, in order to write program lines, 62% used exclusively keyboard (Berque et al., 2007).

David Schroeder, a Mathematics teacher at Cabrillo High School in Lompoc, California used DyKnow software combined with tablet PCs in his Math II class for the first time during the 2003-2004 academic year. The Math II is a two-semester mathematics course, mainly geared toward sophomores. Schroeder (2004) reports that the course becomes progressively harder by the second semester as more abstract topics are introduced. While using DyKnow in Math II, second-semester final exam averages improved from 72% to 82% between the 2002-2003 and 2003-2004 academic years (Schroeder, 2004)

James et. al., (2006) evaluated DyKnow deployment at the University of Central Arkansas by conducting a study of a multi-section general psychology course and a multi-section kinesiology/health education course. Within each study the same instructor taught at least one control section of the course and at least one experimental section that used DyKnow software on a pilot basis (James, 2006). The authors found that: "In general psychology, 87 percent of the students in the pilot [DyKnow] section earned a C grade or better compared with 73 percent in the control sections; 13.3 percent of the students in the pilot [DyKnow] section withdrew compared with 23.7 percent in the control sections" (James, 2006). Similar results were obtained in the kinesiology/health education courses: "91 percent of students in the pilot [DyKnow] section earned a C grade or better compared to 84.8 percent in the control sections; no students in the pilot sections withdrew compared to 4.85 percent of students in the control sections" (James, 2006).

Other reports on DyKnow implementation include Joliet Junior College in Illinois, described in March 2006 issue of Campus Technology (Briggs, 2006). One of the challenges in teaching at this institution is extremely wide range of student ages (from 18 to 65) and wide range of learning experiences and styles. Although older students may not be used to computers in classrooms, professor McNeil, who pioneers DyKnow implementation in this institution, says quiz scores improved with Dyknow, grades are higher, student confusion has decreased, and questions are more on track. In McNeil's opinion, the success is result of the way DyKnow helps focus and engage students during the class time. Also the way it provides for a variety of learning styles thus decreasing the differences between a range of ages and backgrounds (Briggs, 2006)

Widely positive experiences and frequently improved learning are in view of the authors of this chapter the most promising characteristics of current deployments of the pen-based computing accompanied by interactive software. However, just as promising may be the large number of different options that this technology provides which may further improve venues for more successful teaching methodologies. While we all still learn fast track how to make advantage of these options, the simple fact of having options gives us a great advantage with respect to earlier educational technologies.

CONCLUSION

We began this chapter by summarizing the shortcomings of expository lectures in context of physics and physical science teaching. A large body of literature accumulated in 1990s demonstrating inadequate learning of students going through traditional lecture based physics instruction. At the same time, the research showed superior learning results in more interactive and more student-oriented instructional settings.

In the second part of this chapter we investigated features and usability of pen-based computing technology (typically tablet PCs) accompanied by software packages that enable real-time communication and data exchange between all devices (thus between the teacher and students in all directions). A typical software package of this kind are DyKnow (Vision and Monitor) (DyKnow, 2007) or Ubiquitous Presenter. (e.g. Price & Simon, 2007) Tablet PC pen input functionality provide extra value especially in fields like physics and other sciences, engineering, mathematics, art i.e. in which the handwritten input is invaluable. This input option together with the regular keyboard make tablet PCs extremely versatile devices applicable in any educational setting.

The classroom implementation of pen-based computers and associated learning software packages make a substantial change in classroom interaction (DiStasi *et al.*, 2007). This hardware and software combination offers a range of new opportunities in terms of visual presentation of the content, active learning and collaboration, shared note taking approaches, formative assessment etc. which are not possible in the common slide-based lectures. Commonly used slide lectures help represent the content in a neat and organized manner but they provide information in a way similar to the chalk/whiteboard lecture i.e. in a one-directional and non-interactive manner.

The range of additional input and communication options make tablet PCs and interactive learning software packages promising assets in overcoming deficiencies of the lecture-type instructional setting which by far the most common way of science instruction in universities across the United States and will likely continue being that in foreseeable future.

Applications of tablet PCs combined with interactive learning software packages started only several years ago and research related to effective teaching strategies and effectiveness of this technology for student learning is emerging. Due to this short implementation time, data available for evaluation is not abundant. However, the results that we have so far are very encouraging. Fort Hays state University (FHSU) is one of the universities which started University wide tablet PC implementation program in fall of 2007 after one year of deployment of this technology on pilot basis. We presented in this chapter results obtained in two of the introductory physics courses at FHSU. They show high levels of student satisfaction with this technology and improved learning (although without statistically significant differences due to small class sizes).

In conclusion, pen-based computing technologies together with accompanying interactive learning software packages offer an unprecedented range of options that enable or facilitate variety of channels for interactive learning and communication between all participants in the learning process. This set of features can be particularly beneficial in a lecture-type classroom, because that setting is least interactive, yet most widely used instructional setting.

The future research in this domain should more closely identify optimal teaching strategies with this technology in variety of knowledge domains.

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REFERENCES

Berque, D. (2006). Pushing Forty (Courses Per Semester): Pen-Computing and DyKnow Tools at Depauw University. In D. A. Berque, J. C. Prey & R. H. Reed (Eds.), *The*

Impact of Tablet PCs and Pen-Based Technology on Education: Vignettes, Evaluations and Future Directions. West Lafayette, IN: Purdue University Press.

Berque, D., Bonebright, T., Dart, J., Koch, Z., & O'Banion, S. (2007). Using DyKnow Software to Support Group Work: A Mixed-Method Evaluation. In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.

Berque, D., Bonebright, T., Dickinson, T., Smith, C., & Thede, S. (2008). Enhancing Introductory Computer Science, Psychology, and Education Studies Courses with Problem Solving, Graphing, and Feedback Enabled by Tablet PCs and DyKnow Software Tools. Retrieved March 05, 2008, from http://www.cfkeep.org/html/snapshot.php?id=82870413533291

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How People Learn: Brain, Mind, Experience, and School*. Washington, DC: National Academy Press.

Briggs, L. (2006). Interactivity in Class Engages Students, *Campus Technology, March 2006*: Retreived from: http://campustechnology.com/articles/39126/.

Chidanandan, A., DeVasher, R., Ferro, P., Fisher, D., Mitra-Kirtley, S., Merkle, L. D., et al. (2007). Evaluating the Symbiosis of DyKnow Software and Pen-Based Computing in the Rose-Hulman Classroom. In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.

DiStasi, V. F., Ayers, D. J., Birmingham, W. P., Gunawardena, A., & Welton, G. L. (2007). Evaluating Learning Software into the Classroom: A Preliminary Study. In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.

Dixon, M. P., Pannell, K., & Villinsky, M. T. (2007). Can Pen-Based Computing Enhance Graph Construction and Comprehension in the Introductory Economics Classroom? In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.

Donovan, S. M., Bransford, J. D., & Pellegrino, J. W. (Eds.). (1999). *How People Learn: Bridging Research and Practice*. Washington, DC: National Academy Press.

DyKnow. (2007). Company. Retrieved Sept. 03, 2007, from http://www.dyknow.com/company/

Exter, M. E., & Ochoa, T. A. (2006). Interactive Assistive Technology: A Preliminary Analysis of the Use of DyKnow Vision and Wacom Graphire3 4x5 USB Tablets in a Special Education Teacher Preparation Course. In D. A. Berque, J. C. Prey & R. H. Reed (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education: Vignettes, Evaluations and Future Directions*. West Lafayette, IN: Purdue University Press.

Hake, R. R. (1992). Socratic Pedagogy in the Introductory Physics Lab. *The Physics Teacher, 30*, 546 - 552.

Hake, R. R. (1997). Interactive-Engagement Vs Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses. *Am. J. Phys, 66*, 64-74.

Hake, R. R. (2002). Lessons from the Physics Education Reform Effort. *Conservation Ecology, 5*(2), 28; online at <http://www.consecol.org/vol25/iss22/art28>.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., et al. (2004). Scientific Teaching. *Science, 304*, 521-522.

Heller, P., & Heller, K. (1999). *Cooperative Group Problem Solving in Physics*: University of Minnesota preprint.

Hewitt, P. G. (1991). Vibrations and Sound Ii. On *Conceptual Physics Alive!* [Video tape]: Addison-Wesley.

Hrepic, Z. (2007). Utilizing DyKnow Software and Pen-Based, Wireless Computing in Teaching Introductory Modern Physics. In *Proceedings of 30th Jubilee International Convention MIPRO, Conference on Computers in Education (2007)*. Opatija, Croatia.

Hrepic, Z. (2008). Exploring the Role of Pen-Based Computing in Advancing Knowledge Society. In J. Langer, N. J. Alfirevic & Pavicic (Eds.), *Proceedings from the International Symposium "Alpe-Adria: Knowledge Region" (2007)*. Frankfurt am Main, Germany: Peter Lang.

Hrepic, Z., Zollman, D., & Rebello, S. (2007). Comparing Students' and Experts' Understanding of the Content of a Lecture. *Journal of Science Education and Technology, 16*(3), 213-224.

Hubbard, J. (2006). Use of Pen-Based Technology in Calculus Courses. In D. A. Berque, J. C. Prey & R. H. Reed (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education: Vignettes, Evaluations and Future Directions*. West Lafayette, IN: Purdue University Press.

Huettel, L. G., Forbes, J., Franzoni, L., Malkin, R., Nedeau, J., & Ybarra, G. (2007). Using Tablet PCs to Enhance Engineering and Computer Science Education. In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.

Itoh, R. (2006). Use of Handwriting Input in Writing Instruction for Japanese Language. In D. A. Berque, J. C. Prey & R. H. Reed (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education: Vignettes, Evaluations and Future Directions*. West Lafayette, IN: Purdue University Press.

James, T., Hill, J., Cone, C., & Latimer, S. (2006). The Calf-Path: One University's Experience with Pen-Enabled Technologies. In D. A. Berque, J. C. Prey & R. H. Reed (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education: Vignettes, Evaluations and Future Directions*. West Lafayette, IN: Purdue University Press.

Karatsolsis, A., & Mills, G. (2007). Tablets as Writing Canvases and Construction Sites. In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.

Knight, R. D. (2004). *Five Easy Lessons: Strategies for Successful Physics Teaching*. San Francisco, CA: Addison Wesley.

Lindroth, L. (2006). Blue Ribbon Reviews. *Teaching Pre K - 8, 36*(5), 25.

Mazur, E. (1997). *Peer Instruction: A User's Manual*. Upper Saddle River, NJ: Prentice Hall.

McDermott, L. C. (1993). How We Teach and How Students Learn — a Mismatch? *American Journal of Physics, 61*(4), 295-298.
McDermott, L. C. (1996). *Physics by Inquiry* (Vol. I & II). New York: John Wiley & Sons.
Microsoft Corporation. (2005). What Is a Tablet PC? Retrieved Dec. 20, 2007, from http://www.microsoft.com/windowsxp/tabletpc/evaluation/about.mspx
Mutchler, D., Chambers, Z., Mitra-Kirtley, S., Sexton, S., Williams, J., & Zoetewey, M. (2006). Tablet or Laptop? Does the Pen Matter, and If So, in What Way? In D. A. Berque, J. C. Prey & R. H. Reed (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education: Vignettes, Evaluations and Future Directions*. West Lafayette, IN: Purdue University Press.
Novak, G. M., Patterson, E. T., & Garvin, A. D. (1999). *Just-in-Time Teaching: Blending Active Learning with Web Technology*. Upper Saddle River, NJ: Prentice-Hall.
Price, E., & Simon, B. (2007). Instructor Inking in Physics Classes with Ubiquitous Presenter. In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.
Redish, E. F. (2003a). *Teaching Physics with the Physics Suite*. Hoboken, NJ: John Wiley & Sons, Inc.
Redish, E. F. (2003b). *Teaching Physics with the Physics Suite, Wiley, Hoboken, Nj (2003)*. Hoboken, NJ: Wiley.
Rockman et al. (2005). A Case Study of DyKnow Vision: Conversations and Observations That Demonstrate Its Educational Potential. Retrieved Jan 20, 2007, from http://www.dyknow.com/products/more/North%20Daviess%20case%20study%20-%20FINAL.pdf
Roland, J. (2005). Reviews - DyKnow Vision and Monitor. *The ISTE (International Society for Technology in Education) journal of educational technology practice and policy, 33*(3), 38.
Schroeder, D. (2004). Tablet PCs and Collaboration Software Improve Classroom Engagement at Cabrillo High School, *T.H.E. Journal, November 2004, http://www.thejournal.com/articles/17040*.
Schulze, D. G., Struthers, R. R., Owens, P. R., & Scoyoc, G. E. V. (2007). Teaching Soil-Landscape Interactions Using Rugged Tablet PCs in the Field. In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.
Scott, C., Leigh-Mack, P., Ledeji-Oasis, J., Jackson, N., & Alao, S. (2006). Integrating Tablet PC Technology into the Dimensions of Learning Pedagogical Framework. In D. A. Berque, J. C. Prey & R. H. Reed (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education: Vignettes, Evaluations and Future Directions*. West Lafayette, IN: Purdue University Press.
Sokoloff, D. R., & Thornton, R. K. (2006). *Interactive Lecture Demonstrations, Active Learning in Introductory Physics*: John Wiley & Sons.
Thornton, R., & Sokoloff, D. (1990). Learning Motion Concepts Using Real-Time Microcomputer-Based Laboratory Tools. *Am. J. Phys., 58*, 858-867.

Toto, R., Lim, K. Y., & Wise, J. (2007). Supporting Innovation: The Diffusion and Adoption of Tablet PCs in the College of Engineering. In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.

Tront, J. G., & Scales, G. R. (2007). Implementing a Large-Scale Tablet PC Deployment. In J. C. Prey, R. H. Read & D. A. Berque (Eds.), *The Impact of Tablet PCs and Pen-Based Technology on Education*. West Lafayette, IN: Purdue University Press.

Ubiquitous Presenter. (2007). Retrieved Sept. 03, 2007, from http://up.ucsd.edu/

Vygotsky, L. S. (1986). *Thought and Language*. Cambridge, MA: MIT Press.

Wang, H., Gould, L., Hoopingarner, B., Weigel, C., Hrepic, Z., & Fulton, D. (2007). Exploring the Pen-Computing Learning Environment: Empower Students to Learn. In C. Crawford et al. (Ed.), *Proceedings of Society for Information Technology and Teacher Education International Conference 2007* (pp. 2128-2133). Chesapeake, VA: AACE.

White, B. Y., & Fredrickson, J. R. (1998). Inquiry, Modeling, and Metacognition: Making Science Accessible to All Students. *Cognition and Science, 16*, 90-91.

Wieman, C., & Perkins, K. (2005). Transforming Physics Education. *Physics Today, 58*(11).