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Wireless computers in classrooms: Enhancing interactive physics instruction with Tablet PCs and DyKnow software

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Abstract

Networked one-on-one computing in educational setting opens a wide array of possibilities for more interactive and more dynamic instructional methodologies. We explore and analyze options offered toward that end by pen-enabled computers associated with DyKnow software. Pedagogies supported and driven by this technology include collaborative note taking, group problem solving, multiple channels of real-time feedback, classroom-wide interaction/content sharing and options for after-class activities etc.. DyKnow software (www.dyknow.com) is primarily designed for face-to-face instruction and pen enabled computers such as Tablet PCs but can be also used with laptops and desktops - with or without external pen input such as the Bamboo Tablet (www.wacom.com/bamboo). This web-based computer interaction also opens distance learning opportunities. We survey research results associated with implementations of this technology in several introductory physics settings.

Keywords: Physics Education, Tablet PCs, DyKnow.

Resumen

En red uno-a-uno computación en el establecimiento educativo se abre una amplia gama de posibilidades para las metodologías de enseñanza más interactivo y dinámico. Se exploran y analizan las opciones que ofrece a tal fin por la pluma equipos habilitados asociados con el software DyKnow. Pedagogías apoyado e impulsado por esta tecnología incluyen la colaboración teniendo en cuenta, la solución de problemas en grupo, múltiples canales de información en tiempo real, interacción en el aula en todo el / intercambio de contenidos y opciones para etc. actividades después de clase. Software DyKnow (www.dyknow.com) está diseñado principalmente para la instrucción cara a cara y pluma equipos habilitados como Tablet PC, pero puede también ser utilizado con ordenadores portátiles y de escritorio - con o sin entrada de la pluma externos, tales como bambú Tablet (www.wacom.com/bamboo). La interacción de la computadora basada en la web abre también oportunidades de aprendizaje a distancia. Nosotros resultados de la encuesta de investigación asociados con las implementaciones de esta tecnología en varios entornos introducción a la física.

Palabras clave: Educación en Física, Tablet PC, DyKnow.

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I. INTRODUCTION

Traditional lectures, even when presented by good lecturers, have a limited success in helping students learn physics. [1, 2] Hrepic *et al.* [3] identified a variety of venues in which students can misunderstand the content delivered in a lecture type setting. These include recording stated facts incorrectly, hearing "what makes sense" while overlooking what was actually stated, concentrating on particularities and details in the instructor's statements at the expense of general concepts, using the same terminology that experts use but with very different meaning attached to it and so on.

Also, 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. [4] One of the widespread problems with the typical expository lecture is a fast delivery of complex information and the associated difficulty in taking effective notes while listening to such instruction. Knight [5] summarized the current findings related to expository lectures 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". [5, p.46]

However, the lecture is by far the most widely used format of introductory physics instruction in general and is likely here to stay. The first reason is the ease (if not necessarily efficiency) of simultaneous addressing large numbers of students through frontal delivery. The second reason is probably the fact that a large majority of the current physics and science instructors were educated through dominantly lecture-oriented instruction. Those instructors represented the small fraction of students for whom this approach worked well, which makes it more difficult for them to recognize deficiencies of this type of instruction or to adopt alternative approaches.

Moreover, supported by a body of knowledge related to human learning and current research into science teaching, Donovan *et al.* [6] claim lectures, just as books, can be very efficient in transmitting new information, exciting imagination and honing students' critical thinking skills. The lecture is a tool and its utility, just like that of any other tool (a drill, hammer …) depends on the task at hand and the material one is working with.

Therefore, the issue is probably not whether we should (or can) eliminate the lecture, but rather - how to build on the advantages of a lecture setting while bypassing its limitations. Based on the research into effective teaching methods in physics [5, 7] and sciences in general [8], we propose that the answer is in interactive engagement, sometimes referred to as active learning [5]. The purpose of this paper is to explore whether pen-based computing technology can facilitate active learning in a lecture-oriented instructional setting by examining the characteristics of this technology and by analyzing results of the reported deployments.

Before we explore this question, we disclose that our theoretical pedagogical stance is based in social constructivism according to which knowledge is constructed gradually, in complex processes [9] and learning is mediated by social interactions. [10] Interactive engagement teaching strategies naturally fit this theoretical framework.

II. CHANGING THE NATURE OF THE LECTURING GAME – USING TECHNOLOGY AS A LEVER

Computing technologies are ubiquitous in higher education, and rightfully so. This development recently reached two separate milestones: (1) campus wide wireless coverage and (2) wide commercial availability of pen-input devices. Of these, the most versatile are Tablet PCs *i.e*. notebook-type computers that can be operated with an electronic pen (optionally by touch) in addition to the keyboard and the mouse/pad [11]. Tablet PCs (unlike newly launched pen and/or touch slate devices) also support high-end personal computing processing.

Nobel Prize winner Carl Wieman suggests that technology in general can serve as a lever in implementing effective teaching strategies to create lecture more interactive and engaging. [4] In addition to online simulations, Wieman and his colleagues, also strongly advocate advantages of electronic personal response systems often referred to as "clickers".

In this paper we examine a relatively novel technology that combines wirelessly networked pen-input computers and accompanying software that enables real-time exchange of information among all participants in the learning process. This technology appears, at least in principle, to facilitate the integration of vast number of effective learning strategies incorporated in successful teaching methods described above. And, in terms of their interactive options they are much more versatile than standalone clickers devices.

Hrepic *et al.* [12] proposed the following three aims as guiding principles for implementation of this technology to benefit expository teaching: This technology should 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 define some novel teaching strategies applicable to the lecture-type setting. For example, students can work in groups so that individual students simultaneously annotate the common slide *i.e.* writing space by annotating and erasing the content from their respective tablet PC screens. The instructor monitors the progress of all groups simultaneously from his/her own tablet screen and is able to accordingly intervene, provide scaffolding, draw attention to possible mistakes or assign follow-up work as necessary. At the end of the session, groups can exchange the annotated files.

III. UTILIZING TABLET PCs ACCOMPANIED WITH DYKNOW SOFTWARE

There are several software packages that were designed to promote the interactive classroom instruction such as the one described above. The most popular of the freely available packages are "Classroom Presenter" [13, 14] and its web-platform oriented derivative "Ubiquitous Presenter" [15, 16]. Although free for users, those two programs feature similar principal functionalities like their more robust, commercially available counterpart called DyKnow Vision [12, 17]. Compared to Classroom Presenter and Ubiquitous Presenter, DyKnow is more versatile, more user-friendly and comes with technical and user logistics support, but it is not free.

All of these three software packages are primarily oriented toward a pen-based, wirelessly networked computing environment in a face-to-face setting. However, their features are also fully functional with laptops and stationary computers, which can be easily equipped with external (USB) pen-input devices for a fully operational handwriting/tablet experience.

This paper will concentrate on deployment results associated with the DyKnow software. While elaborating the software's features, Hrepic *et al.* [12] clusters its functionalities into three major categories, or feature sets, summarized below.

A. Feature set 1: A new dynamics of the note taking

The software transfers instructors' and prepared slides annotations wirelessly and in real time to the students' computer screens. This way each student can take notes and write customized annotations on top of and in addition to the material prepared and annotated by instructor. The instructor annotations are typically associated with formula derivations (Fig 1) and problem solutions (Fig 2).

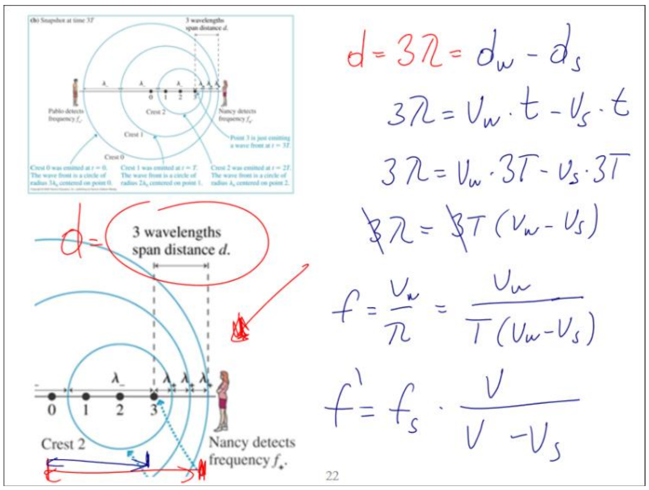

FIGURE 1. Example of instructor annotated slides – derivation of a formula.

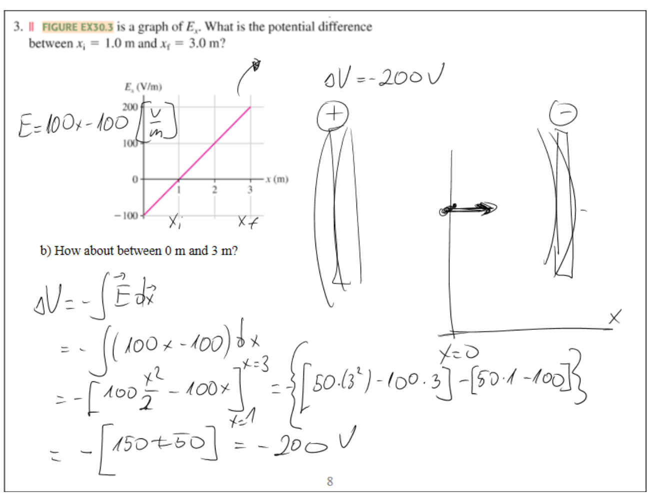

FIGURE 2. Example of instructor annotated slides – problem solution.

Note the parts of Figure 1 and Figure 2 on the left side that have been prepared ahead of the class based on the adopted textbook images. Preparing these ahead of time provides a ready to go situation for explanation without copying of material either by the instructor on the chalkboard or by students - into their notebooks. The time saved on copying can instead be spent on analysis, discussion and reflection of the content, or on additional problem solving. The software also records the pen strokes so students can later view annotations appearing in the same order in which they were written.

B. 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. They include:

a) Students' "status" - through which students indicate their level of understanding as high, medium and low continuously during the lecture [18].

b) Chat feature - which opens a venue for students to submit a written message to the instructor (or to the rest of the class).

c) Pooling option - to elicit multiple-choice answer distributions from the classroom (equivalent to classroom response systems (or clickers) with the option to record the voted distributions on slides (Fig 3).

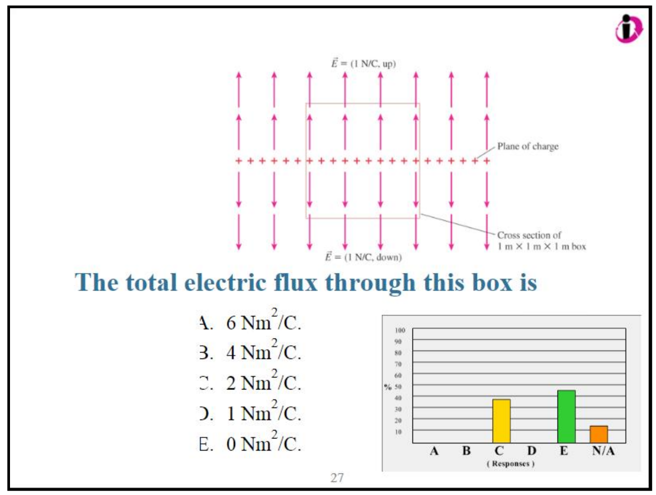

FIGURE 3. A multiple-choice question and obtained distribution of students' answers incorporated into the panel.

d) slide submissions - with hand written solutions to numerical problems (Fig 4), annotated responses to open ended questions, graphical or vector solutions etc.

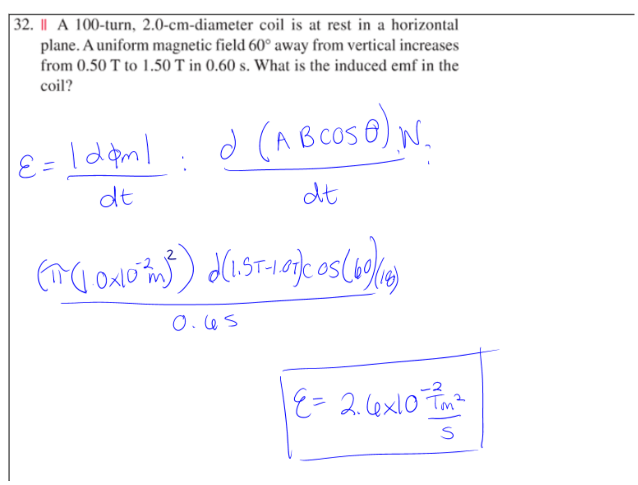

FIGURE 4. An example of a students' slide submitted with numerically solved problem.

These four feedback channels together make it possible for students to be heard by the instructor without necessarily speaking up in classroom (which is an option that stays as viable as ever). To the instructor, these channels offer all the benefits of formative assessment, which include student engagement, immediate feedback, adjusting of teaching well before the exam and according to the specific needs of your students.

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

In this mode of learning, groups 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. 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, the instructor can monitor progress of each group from his own screen and intervene in order to scaffold as necessary or appropriate [12].

D. Using DyKnow features to enhance physics lecture

All research-based teaching methods are student centered [5]. They rely on cognitive principles that students learn more effectively if they are intellectually engaged, and they obviously require changes in a typical traditional, non-interactive lecture format with one-way information flow.

Redish [7] calls for more interactive approaches to traditional lecture and suggests a 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. In a student-centered lecture, students take primary responsibility for their knowledge, they participate in activities, study the text and complete the assignments and receive immediate feedback on their work [5].

The three above described sets of DyKnow software features, when working together and in synergy can easily promote many of these suggestions and work toward the three goals of instruction with this technology earlier set forward: engagement, collaboration and in class learning.

IV. TABLET PCS AND DYKNOW SOFTWARE IN TEACHING INTRODUCTORY PHYSICS - DOES IT WORK?

Tablet computers and DyKnow Vision have been utilized at all educational levels. The advantage of hand-written input that pen-based technology provides is critical in fields where formula writing, graphing, schema sketching or free drawing play a vital role. These fields include mathematics, sciences at large, engineering and art [e.g. 19, 20, 21]. But Tablets have found extensive applications also in teaching of a variety of possibly unlikely academic fields ranging from Japanese language [22] and music [23, 24] to special education [25] and medical imaging [26]. The observed benefits have included improved learning of concepts, higher levels of student engagement, higher rates of homework completion, fewer absences [27] improved grade distributions and higher retention [28]. Physics Education Researchers at California State University in San Marcos have been exploring the utility of using Tablet PCs combined with Ubiquitous Presenter and found a variety of benefits such as improved note organization and archiving [29] and dramatic increase of productive multiple representations in physics lab report writing [30] when they compared Tablet PC users with laptop users.

There is however, a limited number of studies that in addition to qualitative analysis and survey results investigated the differences in (a) student learning in terms of their test success and (b) retention - with and without application of DyKnow software and (typically) Tablet PCs. This paper analyses four reported studies of that kind. [31, 34] Described are experimental setups that were staged in four sets of introductory physics courses, offered at three different US universities between 2005 and 2010.

A. Implementation at Louisiana State University at Shreveport in a Calculus and Algebra-based, Lecture-oriented Intro Physics Courses [34, 35]

Cynthia Sisson of Louisiana State University at Shreveport (LSUS) carried out one of the most successful deployments of this technology in her teaching of introductory physics [34, 35]. Algebra-based and calculus-based introductory physics courses are offered at LSUS as three-hour per week lectures with no recitations. Compared to other US universities, this is the lower end of hourly exposure for students in these courses (with the typical range between 3 and 5 hours). Within this limited timing, Sisson considered the lack of exposure to problem-solving a critical issue impeding student success. With no opportunity to incorporate recitations into the course offering, she dedicated one of the three lecture hours exclusively to problem solving. The key venue for communication and exchange between students and instructor - as well as for the collaborative work among students - in this experimental session were Tablet PCs (typically with two students on one computer) accompanied by DyKnow software.

Sisson compared student performance in the experimental section of the algebra-based course (that used Tablet PCs in the recitation-reserved lecture hour) with the performance of her students in sections she taught traditionally since Fall of 2003. This included 13 sections of algebra-based physics (including one taught traditionally in parallel to the experimental section in Fall 2007) totaling 437 students.

The study used three metrics for student success comparison: (1) Conceptual understanding as measured by

FCI post-instruction results (2) Problem solving ability as measured by results on final exams and (3) course success as measured by the percent of passing grades (A, B and C).

Compared to the five-year average, in algebra-based experimental courses (Fall 2007, N=39); Sisson saw (1) a 7% increase of FCI results (p=0.14), (2) a 2% improvement in final exam scores (p=0.64), and (3) a 22% increase in successful course completion (from 57% to 79%). This success rate in the experimental section of the algebra-based course was more than two standard deviations larger than the historical average and was statistically significant.

She repeated the experimental strategy in the calculus-based course (Fall 2008, N=26) and compared it to the 5 year average involving five sections of calculus-based physics totaling 83 students. The experimental section showed (1) a 3% increase in FCI results of (p=0.99), (2) an 11% improvement in final exam scores (p=0.05), and (3) a 10% increase in successful course completion (from 56% to 67%). This success rate in the calculus-based course was more than one standard deviation larger than the historical average and, like the retention increase in the algebra-based section, was also statistically significant.

The magnitude of the increased student success puts additional weight on the observed increase of conceptual understanding and problem solving ability in these classes because the final scores in experimental sections were based on larger number of students, a chunk of whom would have most likely failed in previous semesters.

These results are highly encouraging and show that with appropriate strategies, this technology can substantially improve student learning in introductory physics courses even under severe time limitations.

B. Implementation at Fort Hays State University in a Calculus-based, Lecture-oriented Modern Physics Course [33]

DyKnow software was first deployed at Fort Hays State University (FHSU) in the summer of 2006 as part of an ongoing campus-wide mobile computing program. The purpose of the program was promoting and investigating effective ways of using Tablet PCs (among other mobile devices) in teaching and learning. Physics was one of the departments that piloted using a cart with a set of Tablet PCs so students would check the computers out during the class time and return them at the end. The checkout process worked similarly as that at LSUS in the earlier described study [34, 35].

The author taught a sophomore level calculus-based modern physics course at FHSU for one semester (Fall 05) before the DyKnow software was implemented. This course is a 3rd semester core course for physics majors covering relativity, atomic and nuclear physics. The course had three 50-min. sections of lecture per week and did not have associated recitations or an associated lab. In this first deployment, the lecture was organized in a typical frontal manner but since the class was small (13 students) it was easy and natural to use a lot of discussion and Socratic dialogue during the instruction. Although DyKnow software was not deployed in Fall05, the instructor was making annotations on his tablet PC screen thus still capitalizing on half-prepared slides that would have been arranged in advance. Without DyKnow, these annotations were not automatically transmitted to students. Similarly, options for real-time feedback, computer facilitated collaborative problem-solving and solution exchanges were not utilized.

DyKnow was deployed in the offering of this course in Fall of 2006. All three major interactive feature sets described in the introduction were used. Lecturing and problem solving (mostly collaboratively among students) were intermixed during the same class periods and students' solution submissions were regularly projected out and discussed with the whole class. The content covered in the course as well as the textbook used in the two subsequent offerings (Fall05 and Fall06) were the same. Three tests were administered in each semester. The problems were different in the subsequent semester but had the same level of difficulty.

In the experimental course offering with DyKnow deployed in Fall 2006 (N=10), students' average test results improved to 82.5% compared to the average of 75.8% in Fall 2005 (N=13). This is a substantial improvement but because of the small samples, the difference was not statistically significant (p=0.164; independent samples t-Test).

It might be worth noting that the experimental section of Fall06 had on average slightly *lower* HS GPA scores and *lower* ACT scores than the control group. These differences were not significant but give some confidence that the initial preparation did not factor favorably for better scores during the technology deployment.

C. Implementation at Fort Hays State University in a Concept-based, Inquiry-oriented Physical Science Course [32]

Another course that the author was teaching at FHSU before and after the Tablet PCs deployment was a concept-based physical science course for elementary education majors. This course taught entirely in an inquiry manner following a variation of 5E methodology with constant student experimentations with group and classroom discussions. This course was developed in 2004 and 2005 through an NSF funded research effort [36]. As part of this initial research, student learning in the course was monitored closely in the period between Fall04 and Fall05 when the course was taught without TabletPC/DyKnow technology. Between Fall07 and Fall08, the instructor used DyKnow/TabletPC technology in teaching this course, while using the same inquiry materials and the same accompanying textbook as before.

At the very beginning of the DyKnow deployment in this course it was evident that the program readily helps encourage students to participate in classroom discussions. As part of the course methodology, the instructor would present an intriguing demonstration or situation to students at the beginning of a new topic and students would have to suggest ideas that might explain the phenomenon as well as suggest testable questions for their own experimentation.

In semesters when DyKnow was not used this process could have been described as quite abrasive. Students typically did not have well formulated ideas to suggest and also had a difficult time coming up with explorable experimental questions associated with the topic. The instructor would spend part of the time trying to clarify a few typically ill-defined contributions before writing them down on the classroom white board for later reference. Students were engaged one at a time during this process with frequent pauses between contributions.

DyKnow changed this in a quite remarkable way. With the technology available, the instructor would create a slide with pre-defined spaces for ideas and questions for each group. He would give all students access to write on the slide so their annotations would appear on everybody's screen. This quickly and effortlessly resulted in a fully annotated slide with a set of ideas and questions from all groups - in the best venue of the “All in control” interactive feature set (students in charge of the teaching/learning game as described in the section IIIC). Rather than being requested to comment individually, students were now discussing the topic within their groups and writing their contributions on the allocated slide portions. The process was simultaneous for the entire class. Once the inputs were completed and projected out, it was only natural for students to follow up and elaborate on their thoughts. Figure 5 shows one example of such annotated slide.

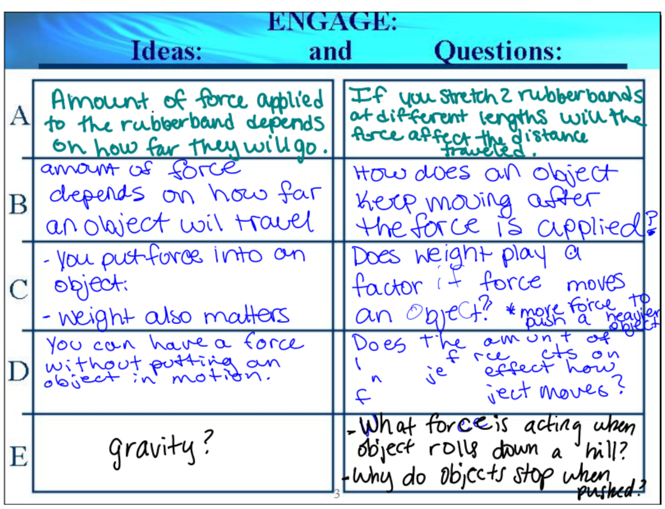

FIGURE 5. An example of a class-wide annotated slide in “all in control” fashion - in the inquiry-oriented course.

By using DyKnow the instructor was also able to manage the students collaborative activities in the described inquiry-based course [32] more effortlessly and more efficiently than previously possible with two student teaching assistants helping during the class time.

In order to gauge student learning during the technology implementation, we deployed the same, externally developed tests [37] that were used during the Fall04-Fall05 course offerings but were never given back to students except during the feedback sessions given in class. In the physical science course, we were administering the deployed summative tests both before and after instruction. Therefore, student learning gains were also measured - defined as [(post-test% - pre-test%) / (100% - pre-test%)] [38].

Table II below summarizes the results of three semesters when technology was not used (F04,S05,F05) and three semesters when technology was used (F07,S08,F08) and displays them together with the previously described results obtained in the Modern Physics course also taught at FHSU.

Cumulative learning gains in the Physical Science course were highly significant ($p<<0.01$) for both sets of the course offerings – experimental (TabletPC/DyKnow) and control. However, comparison between F07-F08 (experimental) semesters and F04-F05 semesters show somewhat lower gains for the F07-F08 (experimental) group. This difference was not statistically significant ($p=0.13$) but its direction is inconsistent with results presented earlier (as well as with the results of the study presented next).

This particular study did not clearly isolate possible detrimental factors that technology deployment may have in the teaching of an inquiry-oriented course. However during the experimentation with various teaching strategies in this context from semester to semester, the importance of several factors affecting students learning became clear:

(i) the paper textbook may be beneficial as the reading and review source although technology may easily support exclusive use of online textbooks,

(ii) when free electronic sources (which may only loosely correspond with the course content) are suggested or used - it is necessary that instructor specifically outline the match/correlation between the topics covered in electronic sources with pertaining course topics,

(iii) the number of note sources should be minimized as a variety of sources (printed inquiry worksheets, electronic worksheets, paper notebooks, textbook notes) may detrimentally affect student organization and thus their learning,

(iv) the increased class activity does not replace the need for homework activities,

These guidelines would be a good starting point in further experimentation with Tablet PC/DyKnow deployments in inquiry based courses.

D. Implementation at Columbus State University in an Algebra-based, Lecture-oriented Introductory Physics Course [31]

In 2009, the author started teaching at Columbus State University (CSU) and by the end of the Fall semester obtained a grant for a hundred DyKnow licenses. Although CSU does not have a laptop initiative like FHSU, courses that deploy DyKnow are using it as an optional benefit for students who bring their computers to classes. This optional usage strategy was first deployed in algebra-based physics course at CSU in the Spring of 2010. We invited and encouraged students to bring their wireless computers to class and deployed DyKnow to increase students’ active participation in the lecture as well as to facilitate productive note taking. Expecting mostly laptop computers, we were concerned with the limitations posed by the lack of the inking input *i.e*. with students possibly unable to take effective notes in this situation. We also did not know how many students might own and be willing to bring computers to class as there were no records of similar deployments in the past.

TABLE I. Students' Test Scores and Pre-Post Gains for Modern Physics and Physical Science courses taught at FHSU.

Course	Semesters	DyKnow used	N	Pre-Test Score Mean (+/- SD)	Post-Test Score Mean (+/- SD)	Normalized gain Mean (+/- SD)
Modern	F05	NO	10	NA	75.8% (+/- 10.5%)	NA
Physics	F06	YES	13	NA	82.5% (+/- 15.9%)	NA
Physical	F04,S05,F05	NO	103	38.8% (+/- 16.3%)	73.9% (+/- 13.1%)	56.8 (+/- 20.0)*
Science	F07,S08, F08	YES	80	37.8% (+/- 16.7%)	69.6% (+/- 18.3%)	51.5 (+/- 26.0)*

*p< 0.01;

On the first day of classes in Spring 2010, the instructor determined that 46 of 51 present students owned a wireless ready laptop. Shortly thereafter, the number of students who carried their laptop to classes stabilized at around 60% of attendees (the attendance number was typically in lower to mid 40-ies). This was sufficient to enable the majority of students to capitalize on productive software features and for the instructor to capitalize on a real-time feedback option. In the first half of the semester, four students purchased a Tablet PC and used them consistently in classes.

As the class proceeded, the instructor would write notes on the Tablet PC screen which was simultaneously projecting the annotations on the large classroom screen. So students had an option of copying the notes from the screen as they would from the chalkboard, but if they wanted to bring computers in, they could also capitalize on the fact that instructor notes were automatically transferred on their computer screens.

Formative assessment tools were used throughout the semester. Students with computers were regularly logging in to DyKnow and were consistently provided feedback through the "status of understanding" feature and answers through the pooling option. Students were also actively submitting slides in response to open-ended questions and problems. Because not all students had computers, it was also necessary to resort to traditional, verbal methods of eliciting questions and other feedback from students.

This study was different from those previously described because it allowed us to compare the success of students who used the technology and those who did not - within the same section. Therefore, everything that students were exposed to - in terms of both instruction and testing - was identical for all participants.

To compare the success of student groups that either differently used - or did not use - this technology, we combined student test scores with their reported computing activity expressed in the end of the semester survey [31]. Of 53 students enrolled in the class 14 days into the semester, 37 took the survey (69.8%). All survey respondents indicated they personally owned a computer, either a desktop (17) a laptop (29), a Tablet PC (3), or more than one of these types. Six students owned a desktop only. Compared in Table II are the patterns of computer usage determined through surveys with two of the average scores of tests taken (only taken tests were included so this indicator is not affected by missed tests).

TABLE II. Comparison of Frequency of Students' Computer Usage with their Success Level.

In Spring 2010, on average		Cate-gory	All and Each Category			Categories 5 vs 4,3,2,1 vs 0			Categories 5 vs 4,3,2,1		
I was bringing my computer to physics class:		**Code**	**N**	**Avg. %**	**SD**	**N**	**Avg. %**	**SD**	**N**	**Avg. %**	**SD**
Avg. Scores Of Taken Tests	All responses:		37	60.88	22.92						
	Three times per week (all)	**5**	21	67.49	18.20	21	67.49	18.20	21	67.49	18.20
	Two times per week	**4**	1	10.67	NA	8	45.03	25.80	8	45.03	25.80
	Once per week	**3**	3	49.44	15.67						
	Once or twice per month	**2**	3	48.08	37.13						
	Once or twice in semester	**1**	1	57.00	NA						
	Never	**0**	8	59.39	25.85	8	59.39	25.85			
	(1,2) Kruskal-Wallis and (3) Mann-Whitney U-test p-values			**p=0.365**			**p=0.121**			**p=0.040**	

We used Kruskal-Wallis 1-way ANOVA for comparing 3 and more groups and Mann-Whitney U-test p-values for the two group comparison. As shown in Table I, students who brought computers most frequently to classes performed the best. However, students who never brought computers performed better than those who brought them less frequently or occasionally. This might be an indication that students who did not bring computers to class consistently - either did not use them effectively or they used computers for activities not related to the course during the class time. While differences between respective scores across all categories are not significant, comparison of scores for students who always used computers (category 5) with those who used them less frequently or occasionally (categories 4,3,2,1) show significant difference (p=0.040). The difference strongly favors consistent computer users.

We also compared students according to their reported cumulative computing activity which combines a) bringing computers to classes, b) logging on to DyKnow and c) actively participating in DyKnow facilitated activities [31]. Among students that did use computers to some extent, we found a strong correlation between the frequency of usage and their course success in a way that again favored technology users. However, as shown in the previous table, consistent technology users performed on average about a grade better than those who never used technology, students who inconsistently used the technology performed about a grade worse than nonusers [31]. This is an unexpected, but possibly not surprising result. Checking email typically does not help learning physics. The technology (as earlier discussed with the lecture itself) is a tool and its efficiency depends on how we use it. The good news is that it can be used in extremely beneficial ways. The bad news is that if misused it can hurt more than if not used at all.

As in the case of the modern physics course, in the CSU algebra course we again found that the better performance of technology users cannot be explained by their background (neither by SAT math scores nor by HS GPA).

The advantages of this technology that students themselves brought up during the focus group with an external evaluator in the CSU study include increased student-student and student-teacher interaction for the whole class, easy reviewing and the ability to seek content-related input without personal identification if help is needed. Students also found the software helpful for organizing notes and helpful in focusing on content instead of on note taking.

The disadvantages that were discussed included difficulty with classroom participation for students without computers, the temptation to check email and social networks during class time and occasional technical issues. Students also noted the difficulty of taking notes by hand alongside a laptop (due to the physical space limitations of the chair-desks used in the classroom). A possible way to overcome this obstacle is to use rooms with conventional desk spaces but there may be an additional, technological solution. A significant leap has been seen in the recent years in manufacturing and sales of USB pen and touch input devices such as Wacom’s Bamboo series [39]. Their writing resolution is not as good as resolution achieved on Tablet PC screens but the difference in the combined cost of a laptop and a USB tablet (when compared to cost of a Tablet PC) may make this resolution difference worth putting aside or ignoring.

V. SUMMARY OF STUDENT FEEDBACK ABOUT DYKNOW IN FHSU AND CSU STUDIES

One thing that students in all course sections taught by the author have in common is their strongly favorable attitudes about DyKnow usage as shown in the Table III.

TABLE III. Students’ Perceptions on Productivity of Using DyKnow Software in Teaching (FHSU and CSU Deployments).

Category of DyKnow Evaluation	***General Positive Aspects***		***General Negative Aspects***			***Cognition***			***Communication***		***Motivation***	
Students (%) who Agree and Strongly Agree 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
Modern Physics (Calculus-based, FHSU) Fall06 (N=9/10)	88.9	77.8	11.1	33.3	0.0	66.7	88.9	62.5	88.9	77.8	44.4	33.3
Physical Science (Concept-based, FHSU) Sum06–Fall08 (N=76/91)	92.1	90.8	10.5	5.3	3.9	61.8	89.3	82.9	77.6	86.7	69.7	70.7
General Physics (Algebra-based, CSU) Spring10 (N=37/53)	81.1	75.7	24.3	24.3	27.0	51.4	64.9	67.6	67.6	70.3	59.5	59.5
Weighted average across courses	**88.5**	**85.3**	**14.7**	**13.1**	**10.6**	**59.0**	**81.9**	**76.8**	**75.4**	**81.1**	**64.7**	**64.5**

Students also largely recommended that both DyKnow and Tablet PCs be kept and used in the introductory physics courses (Table IV) and this favorable feedback is another suggestion to consider in future deployments:

TABLE IV. Students' Recommendations for Future Usage of DyKnow Software and Tablet PCs in the Physics Courses They Took (FHSU and CSU Deployments).

Students (%) enrolled in	*Recommend to keep in the Physics course:*	*Definitely Yes*	*Yes*	*Neutral*	*No*	*Definitely No*
Modern Physics (Calculus-based, FHSU) Fall06 (N=9/10)	**DyKnow**	11.1	44.4	44.4	0.0	0.0
	Tablet PCs	22.2	66.7	11.1	0.0	0.0
Physical Science (Concept-based, FHSU) Sum06–Fall08 (N=76/91)	**DyKnow**	50.0	38.0	12.0	0.0	0.0
	Tablet PCs	50.0	41.7	6.3	2.1	0.0
General Physics (Algebra-based, CSU) Spring10 (N=37/53)	**DyKnow**	24.3	37.8	18.9	8.1	10.8
	Tablet PCs	24.3	27.0	29.7	13.5	5.4
Normalized average (to 100%) across courses	**DyKnow**	**28.5**	**40.1**	**25.1**	**2.7**	**3.6**
	Tablet PCs	**32.2**	**45.1**	**15.7**	**5.2**	**1.8**

Three of the four studies that were conducted by the author also showed largely positive student attitudes toward both the DyKnow software and Tablet PCs with a large majority of students recommending their continued usage in these classes. We elsewhere also reported that, instructor evaluations have been favorably affected in the semester when this technology was used [32, 33]

The combination of results of all four studies indicate a great potential for this technology in improving introductory physics lectures but they also show that there is a lot of room for investigation of the most efficient strategies for the technology deployment in specific course variances.

From an instructor's perspective, this technology brought into all courses an unprecedented ease in facilitating and supporting interactive classroom activities, student data collection, problem solving and exchange/communication in all directions. However, due to the lack of uniformity in test results, more data collection is needed for conclusive statements for this class. The results however indicate that while DyKnow can superbly facilitate traditional venues of content delivery, it cannot be used as a replacement for them (e.g. achieving rich discussions in classes with help of the technology is not a substitute for homework or textbook reading) and with the array of advantageous options that pen computing and interactive software packages offer, it is encouraging to know we are presently only at the beginning of exploration and understanding of the optimal venues on capitalizing on this technology.

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