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Hands-on Computer Use in Science Classrooms: The Skeptics Are Still Waiting[1]

Alan Runge,[2] Amy Spiegel,[3] Lisa M. Pytlik Z.,[3] Steven Dunbar,[4] Robert Fuller,[5] Glenn Sowell,[5] and David Brooks[6,7]

INTRODUCTION

Frank Collea was a friend of Robert Fuller and David Brooks, and a mentor to Brooks. We miss him for his energy, his enthusiasm for teaching science, and his perception about how to improve science education.

Frank Collea was not a big fan of using computers in instruction. Frank was neither an advocate of using computers to deliver instruction, nor an advocate of teaching their use as professional tools. Indeed, he thought that most of those of us who advocate computer use make assertions that are unwarranted.

A decade ago, desktop computers were beginning to appear in colleges and universities in small numbers, and we began to explore their use (Sowell and Fuller, 1990). Since then, our thinking has changed substantially, moving away from having computers serve as patient teachers of the classical curriculum, and toward using them as professional tools—to extend, to magnify, to expand, and to enhance human reasoning. This article deals with the issues related to students learning to use computers as such professional tools. Two qualitative data sources inform this paper. The first is a recent doctoral dissertation consisting of a case study of a 'mathematical methods in physics' course that incorporated the use of *Maple*™* software (Runge, 1997). The other is an evaluation of a new undergraduate course, 'multimedia physics,' that sought to integrate mathematics and physics content, and involved the use of many media forms (Pytlik Z. and Spiegel, 1997).

Mathematical Methods Course

A traditional undergraduate physics course on mathematical methods was redesigned to incorporate the use of a computerized algebra program (*Maple*™) during all aspects of the course. One goal of the revised course was to expose beginning students to professional tools in order that they might incorporate them into their mental models and problem solving methods. Thus, though several options were available, *Maple* was chosen in part because it is a powerful tool currently used by professional mathematicians and physicists.

Topics covered included: complex number theory, series approximations, matrix theory, partial differentiation, vector algebra, and vector calculus. Only minor deviations were made from the list of topics covered previously in this course without the use of *Maple*. Five undergraduate students were enrolled, two mathematics majors and three physics majors. A qualitative case study methodology was used to describe the course and develop an understanding of how *Maple* effected the instruction and learning in

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* *Maple* is a registered trademark of Waterloo *Maple* Software Inc.

this course. The impact of using *Maple* on the number and types of interactions was examined. The entire se mester-long course and all six participants (one faculty plus five students) were included in this study. All class sessions were observed and recorded.

The instructor allowed the use of the *Maple* program on all homework and exams with each student having his own computer during class. Constraints, such as restricting the use of single command shortcuts or requiring the demonstration of all steps in a solution method, were made so that the assessment emphasis remained on the mathematics and the conceptual understanding of the problem solving methods. All of the students demonstrated some level of proficiency in using *Maple* to solve the assigned problems. Strategies for using *Maple* effectively were presented by the instructor and then were individualized by the students.

Instructional methods used in this course included the following: (1) various lecture techniques without *Maple* assistance, (2) lectures and demonstrations using only *Maple*, and (3) student tasks assigned in class worked with the aid of *Maple*. *Maple* was used in all but 3 out of 45 class periods, and the use of *Maple* constituted about half of the overall class time.

The main thrust of this course, in terms of using symbolic mathematical computer tools, was expressed by the teacher:

> You cannot be a physicist today without using computers. Now, I know that there are still some physicists, famous physicists, who don't use computers. And there are a few rare individuals who can make great contributions without even having to touch a computer. On average though, it appears [to be] a fundamental change in the way we do physics.

Two environmental difficulties immediately became apparent: (1) the classroom lighting setup, and (2) dimness of the projection display were problematic. Adjustments were made, and the environment became more satisfactory. Although the teacher had hoped to use e-mail as a medium of communications with students, this medium proved unsatisfactory and remained largely unutilized. On his campus, e-mail services would support text-based messages only. Although some e-mail programs allowed a student to copy and paste input commands directly from *Maple*, the e-mail software provided with student accounts did not enable these cut-and-paste operations. Instead, the software permitted *Maple* output to be transferred only in its ASCII text form as an attachment to an e-mail document. Since most of the students used this type of terminal access to their e-mail accounts, they could only attach files that had first been transferred to the mainframe computer system. Thus, such sharing of files was not done.

The students were encouraged to find a way to use *Maple* outside of class time. One possibility was to use a student computer laboratory that had *Maple* available on both Macintosh and PC/Windows computers. They would be using Release 4 in the classroom and in the student computer laboratory. Students who had a computer at home were encouraged to purchase the student edition of *Maple*. Although the student version (which was only available in the previous version, *Maple* V Release 3, at the beginning of the course) would do everything needed for the course, there were important differences between the releases.

The teacher's dominant instructional style, whether in a traditional lecture mode or in a *Maple* demonstration or presentation session, was to use a stream-of-consciousness, thinking-out-loud approach. When he taught using this style, he most often was also working problems from scratch without a prepared worksheet or notes. He would speak out the mental questions he asked himself as he worked each problem. This teaching strategy was very freely flowing; the pace that he mentally worked through the steps and explained his thoughts to students generally was fast.

Qualitative Data from this Course

How did the course work out? All of the students satisfactorily completed the course requirements, receiving final course grades from B to A+. All of them continued voluntarily to use *Maple* during the following semester for other professional and school work. For the purpose of this article, we have selected quotes from the five participating students to bring the key issues to light.

Brad was a 31 year-old physics major with a small amount of prior computer experience.

> . . . show us some simple examples by hand so we all can [learn] the techniques, and then show us the messy, real world problems. And that way, you get a better understanding of when *Maple* is appropriate.
>
> I ended up wasting a lot of my time on *Maple* because I was trying to punch [all of the problems] through on the [computer]. A few of the other stu-

> dents told me that they didn't realize we had the option of not using the *Maple*, and they were trying to force it through *Maple*, when sometimes it wasn't the appropriate tool. But, like I said, just the slight indoctrination of when *Maple* was the more appropriate tool would have just saved us wasted time and made us appreciate that *Maple* was a powerful tool. If the computer just died on me, [for instance], the last few weeks of the class I've not used *Maple* as much, so I feel more comfortable by doing it by hand, which makes me more comfortable with the *Maple* . . . . I think what happens is we get the cart before the horse, we used the *Maple* before we did it by hand, and I'm just saying to reverse the order a little and it would come together a little bit.

John was a 26 year-old physics major with an older computer at home. He installed *Maple* on that machine, but it ran very slowly. He felt that he could do much of the work by hand in a matter of minutes, and that these problems took him much longer when he used *Maple*. He mentioned that he was on the learning curve for *Maple*, and that was what was consuming most of his time when working on the homework problems. During his final interview, John commented that he would have rather had a traditional style course, with the *Maple* tasks included in a separate course or lab section.

> I would prefer that they had a separate course for *Maple*, maybe a one credit hour, and required it like they do the two general labs.

Eric was a 34 year-old senior math major with a small amount of prior computer experience. Eric had sold his home computer to help pay for school, and he felt that he needed to learn a lot more about using computers to help with his school work. *Maple* assignments had been required in several of his math courses, such as numerical analysis, linear algebra, and calculus II. He also had been required to learn a statistical software program for certain math courses. He commented that he had used *Maple* fairly extensively, rarely working problems only on paper. The only weakness about the *Maple* program that he shared was that it did not always simplify its results into a simple, easily recognizable form. Eric hoped that the developers of the *Maple* program would add more simplification commands to assist the user with this task. He commented that the greatest strength of *Maple*, aside from its strong mathematical capabilities, was in its plotting and graphing capabilities for visually inspecting functions as well as the solutions generated in *Maple*.

When asked whether he still would have enrolled in the course if he had been told everything about it, Eric decided that he probably would not have done so.

> Well, when I came into the class, I hadn't anticipated the *Maple* component as an integral part of the course and, just the *Maple* assignments, they were just consuming huge amounts of my time. I was spending 60% of my time for this one class and I have five others to contend with. But, I feel that maybe if they had, like a *Maple* lab, like a lot of universities have a separate one-hour *Maple* lab, I think that that would be of more benefit to the students.

Todd was a 19 year-old. The teacher described this course as being intended for the sophomore level student who had just completed the introductory physics course series and the first two calculus courses. Todd was the only student who fit this description, with the other four being further along in their programs of study. Todd indicated that he did not feel highly proficient with computers. He had owned a Windows based computer for about a year, and was still becoming comfortable using it. It did not appear that he was anxious about using computers, however.

As Todd became more comfortable working with the *Maple* program, he used it more frequently in various aspects of his work. Todd indicated that, most of the time, he first used *Maple* to generate solutions to the assigned tasks. He would then also work problems by hand.

> I'd usually try it all in *Maple* first and then, so it's not that I would start on paper and it would get hard, and go to *Maple*. I would go to *Maple*, and when that got hard I would go to paper. Sometimes it's just that have to do it on paper to understand. And that is probably a learning style more than anything.

Aaron was a 25 year-old junior majoring in mathematics. He had never taken a course that integrated the use of computers into the classroom. This course was his first exposure to the *Maple* software program. By the end of the course, he felt fairly comfortable with his ability to use *Maple*. Aaron consistently performed at the top of the class academically. At the end of the semester, he said:

> I am kind of divided. Learning all the *Maple* commands and seeing how it works, and especially

> like the 3D graphs, I thought was very helpful. But, I'm a math major so I like to see more rigorous proofs, you know, exactly why this is. [Putting the *Maple* and traditional course material] together is fine. It's just that, it seems like maybe make it a four credit course so that maybe you could go, you wouldn't, the *Maple* time wouldn't be eating into the time of showing exactly why something was this way.

Aaron did not feel dependent on *Maple*'s capabilities, however. In contrast to his positive view of the usefulness of the *Maple* program, he wrote the following remark near the middle of the course about his perceptions of the strengths and weaknesses of using *Maple* to learn problem solving skills in physics:

> So far, I only find *Maple* useful and efficient for solving problems that would take much time to do by hand. I don't find *Maple* useful to learn problem-solving skills, but in some cases, I find it to be a great time saver.

One test of whether the students had integrated the use of *Maple* into their personal problem solving methods was whether they continued to use it after this course. When contacted at the end of the following semester, or approximately four months after the final exam, following this course, all of the students reported that they had used *Maple* to some extent in their courses. Three of the five students were using *Maple* at home on their own computers so that they had more ready access to it when they were doing homework.

The most positive outcome observed in this study was that the students each did achieve at least a minimal level of ability in applying *Maple* to solve physics problems. After the semester, the teacher commented that the task of getting the students to be able to use *Maple* in a meaningful way in doing physics was still a goal he was working towards, and had not yet fully attained.

> But to look at an abstract math problem, a physics problem, and to try to talk about it; it's tough. And so I've [got] to help them learn how to do that, I've got to design activities that are doable in a reasonable amount of time, where they are not going to get hung up on really rough issues either in terms of the computer or in terms of the math itself, and so that's a real challenge. I mean, it's almost like I'm trying to do two things that are both difficult. One is more active learning in the upper division courses, and then more active learning with the computer there to assist them.

These comments were especially noteworthy. Indeed, the crux of the problem is that there now are two major learning goals in sight where before there had been only one—learning physics.

There were concerns. Each of the students raised concerns at least once during the semester about the problems that they regularly faced in understanding the output generated by *Maple*. Most of the time, they were using *Maple* to verify or assist with the by-hand methods for solving problems. It was often difficult to get *Maple* to simplify its output expressions and to convert them into the form that could be compared to what they had generated on paper. The students felt that *Maple* was not consistent in the way that it responded to the commands that were intended to perform this task, such as simplify() and expand(). When they could not verify that the *Maple* result was correct, either because they could not easily determine if they had entered the input correctly or they could not evaluate if *Maple* had properly performed the mathematics, they lost confidence in its capabilities and usefulness.

Another area of concern, mentioned by several students, was that during some of the topics the teacher began demonstrating the methods in *Maple* too soon. They were required to learn the by-hand methods for solving the types of problems covered in class. This was true whether they would choose to use *Maple* to accomplish the solution or work it out by hand for the homework and exams. When *Maple* was used to introduce the by-hand methods, their focus was split between learning the *Maple* techniques to work each step and the mathematics that they needed to understand to use the method.

Paperless Physics

In this course, every transaction involved electronic communication. The computer was the tool delivering instruction as well as the tool for professional analysis of data. This course, then, involved even more drastic change than did the math methods course.

A goal of the 'Multimedia Math Across the Curriculum' (MMATC) project is to "facilitate integrated student learning of mathematics and science by developing multimedia 'modules' that bring concepts to life and draw explicit connections between mathematics and science concepts." The 'Paperless Physics' class, a 5-credit course, was based almost entirely upon such multimedia modules. In contrast with the math methods course, there was essentially no traditional lecturing in Paperless Physics. Instead, some form of electronic medium provided students with all necessary information and tools.

Just how is it different to be a student in an interactive, high tech class? The differences include adjusting both to new technology and to a new learning paradigm that requires different study skills and time requirements.

Inconvenient access was a problem. One student (the only interviewee who did not have his own computer) suggested that students ought to be told that the course will be substantially more difficult if they do not have a computer of their own at home. He also said,

> I don't have very good access to all of the course materials because . . . it is difficult to find a machine on campus that has all of the abilities [software] required for this course . . . [The instructor] said there were some in dormitories, but those places are always packed when you go in there, and the computers aren't marked which ones have [proper software] on them, so it's kind of hard to find.

As already noted, a very similar access issue arose during the math methods course.

To the extent that students' prior experiences with computers vary within a class, it becomes difficult to provide the less experienced students with the additional instruction that they require while simultaneously challenging the more experienced students. Is a goal of the course to challenge students in the area of technology, or is the technology simply a tool—implying that all students need a certain mastery level but no more? The students level of prior technology experience in the Paperless Physics class varied greatly, even more greatly than their prior mathematics experience.

Even students who had their own computers noted that they sometimes found accessing the necessary technology difficult or inconvenient. One student noted that, since his grade was dependent upon work outside of class, he really wished that he could have an Internet connection in his dorm room. Another student said,

> You can't just do this [the work for this class] anywhere, you can't take it with you and do it on the bus, or do it sitting in front of the Union, you have to allot time to work on this . . . Even at home, you have to have your computer free [i.e., not in use by someone else].

Thus, appropriate access to materials, which in this course meant having technology access, is an important feature to consider when implementing computer-based materials with students. Problems outside of class included difficulties gaining Internet access, problems transferring files, and problems for individuals whose computers would "freeze up" or stop responding in the middle of an assignment. During the first month of the semester, one student reported spending over half of his physics study time on "computer problems" that included reinstalling software and finding access to computers during study hours.

One of the Paperless Physics staff noted that some problems occurred because students lacked adequate technical knowledge, especially with regard to accessing the Internet. This staff member noted that UNL had recently required students to have their own Internet provider for Internet access at home (on-campus Internet access was still available, however) and most students had little or no idea about how get such access. This staff member also noted that students varied in how they adapted to technical problems. For example, with regard to file transfer protocol (FTP) problems, some students adapted by "getting homework from the web, submitting it directly by attaching a file in e-mail, or simply bringing in a disk (to class)." (The same problem was noted for the mathematics methods course.)

Despite the frequent mention of technical problems by both students and staff, those who commented agreed that the problems substantially decreased over the course of the semester. Perhaps related to this was the early higher-than-expected dropout rate in the course. Even though this was a small class with several well-regarded instructors, about one-third of the students dropped—a rate nearly twice that anticipated for a similar traditionally-taught course. This may indicate that, to the extent that both students and instructors are familiar with the software and equipped with adequate computer skills and experience, they may also experience fewer technical problems. Nonetheless, technical problems continued throughout the semester. For example, during the mid-semester week long class observation by the evaluators, there was a problem with the server that prevented student access of one of the in-class assignments to be completed that day. A second time, near the end of the semester, students again were prevented from accessing some of their assignments due to another unforeseen problem that led to a loss of access privileges.

Qualitative Data from this Course

Evidence from the student e-mails, student interviews, staff comments, and class observations all seemed to indicate that the Paperless Physics class was more demanding than other classes at a similar level. Of the students who reported the amount of time that they spent on the Paperless Physics class outside of actual class meetings (which typically took 6.5 hours per week), the maximum time spent was 10 to 15 hours per week, and the minimum was 1 hour per week. Most students claimed to spend between 6 and 10 hours per week, outside of class, on various requirements. One student claimed,

> At first, one of my other classes didn't demand much, [and] I could keep up with this class pretty well. But the last . . . 6–8 weeks, it's really been tough to keep up on . . . It [has] required probably twice as much work for this class as it did for calculus, and they are both 5 hour classes.

It is important to note that the student offering this quote reported being "above average" (with an overall grade point average over 3.5) and was not someone faced with the extra difficulties of lack of computer access and lack of computer experience. He reported having his own computer at home, and having had a great deal of computer experience prior to taking the Paperless Physics course.

There was also evidence that the use of the modules increased demands on instructors. Consistent with this, one member of the Paperless Physics staff noted that the assignments take longer to grade than he had expected, while another of the Paperless Physics staff suggested,

> My guess is that usually, when grading physics problems, you look at the answer. If not correct, you go back and quickly try and make sense of the work they did. In this paperless course, not only is the screen a restriction (hard to read, cannot page quickly back and forth) but they write down what their thinking was in solving a problem. If their thinking is incorrect, it is hard not to want to write a response. This takes time and energy.

Students and staff alike commented upon the fact that students rarely completed their in-class assignments. One student said,

> We tend to run over in labs, so sometimes we wouldn't even have a discussion about what happened at the end of the day. We'd just kind of wrap up with the lab . . . and we'd be handing stuff in that maybe we didn't know exactly what was going on [i.e., assignments we didn't fully understand].

Thus, while the staff was challenged to create and implement the modules within a certain time frame, students were challenged to fully employ the modules that were often too long to complete during one class period. Furthermore, in a traditional "lecture" class, if an instructor writes a lecture that is too long, students typically expect that the lecture will be finished during the next class period. However, when modules took longer than one class period, if the Paperless Physics students were to learn everything the modules were intended to teach, they often needed to find time to finish them outside of class. While some of the student interviewees did indicate trying to complete the in-class assignments outside of class, the staff seemed astonished with how few students actually did so. One staff member commented,

> . . . I have noticed that the students rarely come to closure on the lab activities in class. I get the impression that they never go back to look at those activities once they leave the room for that day. Never. Most of the activities ended with very important summary questions which the students could have answered even outside class based on the data they had already put into their report files. I get the impression that they submit something at the end of the day and that means it is done. Perhaps we should require them to answer summary questions as homework so that they have to go back and review their work in the files.

Students suggested several reasons for not finishing (in- or out-of-class) the in-class module activities. These reasons included that modules were too long, possibly because of their 'discovery' orientation, and there were too few staff to help during class.

> Sometimes we'll be doing a lab and we'll be trying to figure out what's supposed to be going on, and then with like five minutes left of class, the professor will say, 'Well, you should be trying to do this.' And then it is like, 'Oh. Well, thank you, but we only have five minutes left.'

Another student said that he had trouble finishing the in-class modules outside of class because the Paperless Physics class required so many other assignments outside of class. Yet another student seemed somewhat confused about whether or not he should try to finish the assignment after class, since most of the assignments ended with the instruction to submit the assignment, presumably finished or unfinished, at the end of the day.

Learning from the modules apparently required three adaptations by students. First, the use of modules made attendance very important. One student said,

> I think a lot of students are used to being able to miss class, but in this class you can't.

Second, some students may have needed to adjust their expectations. One staff member, recognizing that the Paperless Physics class may not match the expectations of the "typical" student said,

> [Students] are used to being spoon-fed everything. Certainly in a traditional course, everything is set out and they are told exactly what is going to happen. In this course, on top of not using paper to communicate, we expect students to think on their own, a tough proposition if one is not used to it.

A student indicated that he knew that the "discovery" aspect of the modules was an intentional aspect of the module design, intended to increase learning. He simply disagreed that his learning was facilitated, and he felt that "discovering" concepts was too much to expect of students who had not had a lecture or other introduction prior to the experiments. He said,

> I know he [the instructor] said before that students learn better when they see it happen rather than just learning an equation, but I don't think that's always the case, because . . . to just not have any [knowledge] prior to that [the module], to not have any awareness of it, why should you 'be able to see it?' . . . . The days where it clicks . . . [are when] we are introduced to the math before we do the lab, then it seems like [you can say], 'Oh yeah, that's why it works that way.'

Students may not have expected to be as responsible for keeping records as they were. This was apparent in a comment by a student who complained,

> We don't know what ideas we cover when, exactly, unless we keep track of by our own records or methods . . . unless you write down something, you have nothing to fall back on or review with, like for exams and tests.

The modules themselves may have conflicted with student expectations (e.g., expectations about attendance, the desire for lectures, and a more traditional text). The class itself also sometimes violated student expectations in ways that may have made them feel the class was too demanding. First, at least one interviewee said that he expected more "class structure," and felt burdened by the perceived lack thereof. This student indicated that he had a typical learning strategy that included reading before class, going to class, and reviewing after class. This strategy, he said, helped him to get the ideas "fully."

It is clear that the students had difficulty in accepting responsibility for their own learning. The degree to which this turned out to be true was not fully anticipated by the staff.

WORKS IN PROGRESS

The teacher of the mathematics methods course retreated considerably in setting goals for computer use after the first attempt described here. That is, his subsequent teaching of the course involved much less computer use than did his first effort at systematic introduction of *Maple*.

Using the information obtained during the first offering, the instructors of 'Paperless Physics' made many rather substantial changes in their course. There was an explicit decision to keep the number of *Maple* commands down to a bare minimum. In the first version of the course, the mathematics required to solve to a physics problem was demonstrated in the most mathematically direct way. While efficient, and intellectually satisfying to the instructors, the *Maple* commands were overwhelming to the students. In the second pass through the course, only the simplest *Maple* commands that were absolutely essential for solving the physics problem were taught. About 15 *Maple* commands were introduced over the span of a semester. Although this occasionally led to inefficient, round-about ways to solve a physics problem, it had several beneficial effects. Students became familiar with the function, output, and syntax of commands, since students saw the same command used repeatedly in a variety of contexts. The commands generally corresponded directly with mathematical operations that the students already were familiar with, rather than compound commands that combined several operations into a whole. This meant that the mathematical operations on the computer corresponded better with the students' understanding of the mathematical operations. The stress associated with constantly learning new commands and trying to remember many commands was lowered.

An associated decision was the inclusion of a short instructional interlude on the commands and syntax of *Maple* itself, called "10-minute *Maple*." This was a quick, bite-sized chunk of knowledge that could be easily digested. Most of the interludes lasted about 5 minutes, since it just gave the syntax of a new command or two, and gave a couple of isolated mathematical (only) examples.

Each of these lessons introduced the one or two new commands that might be used that day in the physics lessons. As the semester went on, commands were revisited to add some parameters and variations on already well-known commands.

Classroom architecture nearly always emerges as an issue when technology-rich instruction is employed. As with the math methods course, the instructors struggled with the classroom arrangement. During the second year of this course, even brief orientation lectures were dropped entirely—with inadequate classroom architecture being the main driving force for this decision. Paperless Physics became *PaperLite Physics.* The projecting device was removed from the laboratory, thereby reducing the amount of lecture material to an absolute minimum. Structured worksheets were developed. These worksheets began with a very short explanation of the physics concepts, provided a short mathematical explanation, and progressed with the problem solving process. As the semester went on, there were fewer and fewer prompts or explanations (a technique sometimes called scaffolding). The instructors circled the classroom, talking through the worksheets at the beginning, but ultimately releasing students to work through the remainder of each lesson in teams of two. The instructors were available to answer questions, provide prompts and hints as necessary, or occasionally to interrupt the class and inject a short "chalk talk" to get the class on the right track. While not solving every problem, these certainly went a long way toward reinforcing student comfort with the computer algebra system used for the class. Students demonstrated confidence with the hardware and software at the end of the semester the second time through the class.

Transmitting information in both courses was problematic. Neither e-mail attachments nor ftp's proved satisfactory. During *PaperLite Physics*, the use of the World Wide Web was introduced. This had the effect of lowering but not removing access barriers.

The faculty were a great deal more satisfied with the course the second time through, and they perceived greater student satisfaction as well. However, although a detailed analysis of the second effort was beginning at the time this paper went to press, an evaluator offered the following comment:

> . . . there remain several pertinent and nontrivial issues related to technology which hamper the students' success in the course.
>
> The inclusion of so much technology on top of learning the physics itself is still difficult for students . . . they feel that the burden is too great. By including so much additional material, it makes the course much more than physics, and they feel this is not reflected in a comparable reduction in other areas of requirements. In other words, the requirements for success in the course are substantially greater than a comparable course without so much technology. If students need to learn that much technology, they don't have as much time to learn other stuff. This needs to be taken into account in the course as a whole. While this has been addressed to some degree [by the faculty], it remains a difficult issue for students. This seems to me to be a fundamental difficulty of teaching with more technology . . . there's so much more to learn, but no additional time to learn it.
>
> . . . but I wanted to emphasize that although [the faculty] have made a lot of changes, it's still difficult for the students to handle all that is asked of them in these "paperlite" (technology-heavy) courses.

Finally, we have preliminary data about attitudes for the second offering of the multimedia physics course. In the conventional physics course, students' favorable attitudes toward physics decline during the interval of one semester of instruction. The decline seems to be even greater for a semester of *PaperLite Physics*. Perhaps more important, there is a greater parallel diminution of favorable attitude toward technology use for *PaperLite Physics* students as compared with conventionally taught students.

Obviously, ours remain works in progress.

AN OVERVIEW OF ISSUES

When movable type was invented, and the first books were printed, there were no running headers, or indices, or tables of contents, or, for that matter, page numbers. Today, the technology of the book is standardized. We have come to expect these standards, and students are very familiar with them. When we teach a course from a book, all parties know what to expect and what to do. Even though dissemination improved during the second effort, the technology of the World Wide Web certainly has not yet standardized and dissemination problems were not eliminated.

Traditional college education was once very content oriented, but it has shifted systematically toward a process orientation. Today the "balance of power," if that term expresses the essence of this issue, is more and more toward the process end. Computers exacerbate this shift. When the senior authors of this paper learned to create graphs, one never had a graph where there was no conscious decision about what the x and y meant. Each point, after all, was plotted by hand. Today a computer will graph something that can very well be meaningless or inappropriate. In earlier times, there was too much human time and labor for such instances to be tolerated more than once or twice. Both what we know about a routine but important task like graphing, and how we come to know it, have changed.

When one changes the method of communication, this vast reservoir of comforting experience vanishes. For example, one student made the following comment about improving the course:

> Definitely a syllabus . . . just having an organization—even just a syllabus. [Having to do] Too much [organizing] on my own, led to frustration and procrastination. And so, and then, I don't know, I wasn't as willing to learn.

This comment comes in the face of the fact that, if there is one major difference for faculty teaching these courses, it involves the vast amount of material that must be very carefully prepared and organized in advance! The advanced workload is enormous; the course is 'taught' vicariously several times before it ever is offered. In spite of that, the vast amount of advanced effort often goes unnoticed by students. To students, books represent the curriculum: no book, little student-perceived structure.

In an attempt to get some direct measures of cognition, faculty in 'control classes' were asked to share exam items with the *PaperLite Physics* course. On the "standard" items, PaperLite students did less well than traditional students. This is not really terribly meaningful, however, because of the nature of the controls involved. The final exam questions used in the *PaperLite Physics* course were deemed too difficult to use in the 'control' classes. Most PaperLite students did a very credible job on these items, and some did remarkably well—perhaps as well as one might expect a typical physics major to do on a graduating exam. While PaperLite students were not held to a higher grading standard, they certainly were held to a higher level of performance.

This points to still another issue. Much of what goes on in traditional courses involves students mastering some canned and rather simple algorithms. Indeed, *PaperLite Physics* is a course that lends itself to algorithmically-based instruction, and one graduate assistant in particular tended to deliver the course content in just that fashion.

Messages to Prospective High-Tech Teachers

In spite of all good intentions and advanced planning in both courses, problems arose that were only likely to be discovered the first time each course was offered. Indeed, it may not be possible to attempt courses like these without having one term for a 'shakedown voyage.' While various technologies offer unique affordances for instruction that make such an attempt worth the effort, be prepared to spend large amounts of development time. If possible, one might consider an evolutionary versus revolutionary approach to implementation into the curriculum.

Get your own technology act together. Understand your servers, how they work, and how they are accessed. Will server security present problems? Will passwords be required? What files can be served? Perhaps more importantly, which files can't be served? Are campus support personnel available? Are they up to speed regarding your course?

Work out the details of communication between teacher and students before the course begins. Can the teacher and students share appropriate information? Are special symbols involved? Will files be transferred? Will you establish a course listserv? In many situations, e-mail may be all that is needed.

Work out the means used for demonstrating technology. Will you project? If so, will screens be projected onto a large screen or monitor? Must accommodations be made to facilitate this projection? Though much easier said than done, it is wise to have a "Plan B" prepared at all times. Overheads? Handouts? Chalkboard? Alternate lecture or activity?

Revise attendance policies if necessary. Will demands for class attendance change as the result of using technology? Will attendance become more important rather than less important? In both of the courses described here, outside-of-class access to the instructional activities was different from that in a conventional course. For this reason, there was a big impact upon the importance of attendance. (In much conventional instruction, students can do very well, perhaps better, by getting 'the notes' from some other source.) Walk through access. Determine how easy it is to access materials at various campus sites. It may be helpful to warn students that they will need to set aside time outside of class to access the technology, if it is expected that they will not finish during class time. Choose tools that can be reasonably made available to the students out-of-class. For instance, use a version of the software that is available as shareware or in a student license version so that it is affordable and use this software in class.

Develop a procedure for students to follow when they encounter technical problems. This may involve contacting the instructor, but it also may require technical support personnel. Are there assistants? If so, how are they reached? Are there hotlines? In a course such as Paperless Physics, several quite different types of technical support for students may be required. Never underestimate the need for technical support for your students that may be specific to your course. Will your school provide these support resources, or will you be the primary contact for student support of this nature?

Both courses indicated substantial increases in time demands for students. Instructors who have learned how to use tools often forget that, while the tool shortens the time it takes for the instructor to accomplish a task, it takes much more time for their students.

Describe expectations explicitly and explain possible conflicting expectations. Since students often vary in their expectations, and since the expectations of both students and instructors often remain implicit or not well articulated, the best way to approach the problem of conflicting expectations may be to always explain explicitly how and why one is implementing the instruction. Similarly, whenever students seem to have strong learning preferences and styles, their expectations about how they "ought" to be taught may conflict with the design of some courses, and may need to be addressed directly. For example, if a course is designed such that it requires students to identify and organize information from several texts in lieu of a single text and a lecture (as was the case in the Paperless Physics modules), instructors may encounter somewhat less student resistance if they make that expectation explicit.

Students may benefit from gradual and explicit instruction in new technology-related study and learning skills, especially when these are required for successful completion of the course. For example, one of the Paperless Physics staff suggested,

> Whereas the students need to learn their own skills for recording and keeping track of what they have studied, it seems that we could provide a framework in the beginning to help require the development of these skills . . . It seems that they need some sort of overall organization of their own work whether-they do it on paper or electronically. Perhaps if we checked off that they were doing this overall view every five weeks or so it would be enough to keep them honest throughout the semester.

This strategy often is described using the term scaffolding—giving lots of support at first, but then withdrawing the support as more and more is put into place. Our experience shows that it is hard to do too much scaffolding.

These experiences suggest that the technology should be implemented progressively within a course beginning with basic instructions and simple applications. The instructor must monitor the cognitive load that the technology places on the students. In cases such as the two described the focus was to be kept mostly on the content, so care must be taken to introduce the technology in such a way that the students can keep most of their focus on the subject matter. One challenge is to provide guidance and examples using the technology without providing them with simple "templates" that do the students' homework with only minor editing. Each of the instructors in these cases somewhat underestimated the basic instruction needs of the students.

Similarly, if the technology truly is a professional tool, then it makes sense that the students are asked to do realistic problems. The in-class instruction should model a real problem-solving mode. This means that the instructor should feel comfortable making mistakes and possibly bypassing the shortcomings of the technology in front of the students.

Are There Still Hidden Issues?

The faculty authors were trained before professional software was a reality. Yes, there were slide rules and books of logarithm tables. All of us used computers in our training. Access to powerful tools that allowed us to accomplish complex tasks was very different than it is today, however. Necessarily, then, our training has involved adding knowledge about tools on top of content knowledge developed with tools. Our current courses are very much developed on the basis of adding on to existing and previously successful notions about instruction. Perhaps we need to rethink the content of our curricula in more fundamental ways.

This is a new cognition afoot in this land: To know what to offload to a computer, and when to offload it. We're barely into this era, and certainly it is something we've not taught before. Clearly then, the time honored notion of teachers 'teach as they were taught' cannot apply in this situation.

Connected with this new cognition is a new metacognition—the rules about when to offload, what mental checks to make to decide how we are progressing, what clues to seek about when to persist and when to retreat from a particular attack on a problem. What we have learned as teachers is that there is much, much more to the introduction of computers as tools than knowing when to use a cut operation followed by a paste operation, however we might bring that about in a particular computer platform.

Other changes have taken place, too. When desktop computers first became commonplace, and colleges developed courses in computer literacy, there were some givens. One could more readily depend, for example, that a student was aware of the roles of various parts of a computer: cpu, input, output, memory, and storage. That knowledge is much less certain today. If one asks a student working at a computer 'where' information is at a given moment, there often is little understanding shown for how things work. As we offload operations once thought to be complex cognitive tasks requiring highly trained humans onto computers, this problem is likely to become ever more serious. In other words, a gap is developing between what students know and what they ought to know about using tools, a problem often referred to as the "black box syndrome."

Is this a transitional time as we await better-trained students to come to us from high schools (that make ever greater use of computer tools), or is this a time to rethink what we are about? So far, as we have struggled to revise our courses, we've treated this as a transitional problem. Perhaps it isn't. Perhaps we must rethink what 'knowledge in the head' is really necessary to be successful in our profession. For example, the replacement of the slide rule by the electronic calculator has gradually changed the emphasis on logarithms and estimation skills necessary to use slide rules adroitly. Perhaps it is necessary for us to revisit this very basic material in the courses we teach. If we are going to include these tools in our courses, inclusion of explicit material about how they work—at all levels, from the general architecture of the computer to the details of how the particular computer software is working, may be appropriate if not essential.

AUTHORS' EXPERIENCE FROM THIS MANUSCRIPT

Preparing this manuscript has been a rather remarkable experience for most of the authors. In the beginning, we thought we would be preparing a description of lessons learned. For example, it is quite remarkable that both of these very independent experiences encountered very similar pitfalls. What is much more remarkable for us, however, is how far we seem to be from where we want to be in terms of student learning and attitudes. In spite of the fact that each of us can point to anecdotal evidence (positive impressions about student ability on oral presentations; exciting student responses to very open-ended final examination questions) from the very experiences we report herein, the main body of data available to us is far less positive or encouraging than we would like it to be. As experienced teachers, as technology users, and as scientists who foresee drastic changes in the kinds of intellectual skills our students are likely to be expected to bring to complex physics problems, we see a long developmental road ahead.

EPILOGUE

Frank Collea's perspective regarding the use of computers was that of a skeptic. At the end of the twentieth century, advanced tool use by undergraduates is the exception rather than the rule at U. S. universities and colleges. Students come to courses with expectations about how things will be handled. The transition from high school to college most often involves substantial changes in expectations that account for many transitional problems students experience. Technology courses, especially ones where professional tool use will be a major factor, impose a similarly drastic transition. That is, the transition from traditional college instruction to tool-based college instruction is as dramatic and fraught with as much difficulty as is the transition from high school to college. We are certain that Frank would encourage us to continue our efforts. We are uncertain about how he would view our progress to date.

REFERENCES

Pytlik Z., L. M., and Spiegel, A. N. (1997). *Lessons from 'Paperless Physics': Using MMATC Modules in the Classroom,* a formative evaluation report.

Runge, A. (1997). Impact of *Maple*™ on the Design, Instruction and Performance in an Undergraduate Physics Mathematical Methods Course," Ph.D., University of Nebraska, [http:// www.cci.unl.edu/CVs/Dissertations/APR Diss/Diss Titl.html].

Sowell, G. A., and Fuller, R. G. (1990). Some 'do's' and 'don'ts' for using computers in science instruction, *J. College Science Teaching,* 19: 90–93.