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Computer Intensive Physics

Robert Fuller
rfuller@neb.rr.com

Computer Intensive Physics

an oral presentation by

Robert G. Fuller

Department of Physics and Astronomy
University of Nebraska - Lincoln
at the

National Conference on
Science in Education and in Life,

Lisboa, Portugal,
March 6, 1998

based on the

Multimedia Mathematics Across the Curriculum project
The story of a Paperless Physics Course
January - May, 1997
University of Nebraska - Lincoln

with
Steven R.Dunbar, Vicki L.Plano Clark, Christopher J. Moore

and Ph.D. students
Rebecca Lindell Adrian, Cecilia Hernandez, Thomas Koch

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(to be published in the Proceedings of the National Conference on Science in Education and in Life, Lisboa, Portugal, March 6, 1998.)

This is my first visit to Portugal. I want to thank the conference organizing committee for inviting me. When I left Nebraska last Saturday it was a zero degrees Celsius and it was snowing at the airport so to come to Lisbon at this time is a wonderful experience.

In the abstract packet for the conference is an article of references about ideas from cognitive studies that help us teach physics (Fuller, 1998). There is also a pamphlet of references to innovative physics teaching programs in the United States and many of those programs have world-wide web sites so you can access information about those programs from Portugal (O'Kuma, 1998).

I want to talk about my research project last year, which I now call "Computer Intensive Physics", but it really started out as paper-less physics.

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http://www-class.unl.edu/phys211/

Figure 1

I am going to discuss a physics course I taught from January to May 1997, which used no paper. I believe it is the first time since the invention of the printing press that a physicist has taught a physics course and used no paper. Here are the names of my collaborators (See Figure

1). If you want to see our present lessons you can get access to them on the www site for classes at the University of Nebraska, http://www-class.unl.edu/phys211/. 2

I am going to describe this course and then at the end I want to tell you why it failed and now instead of calling in "Paperless Physics" it is called "Computer Intensive Physics" or "Paper-Lite", L-I-T-E. It means, like low-fat food, a physics course with just a little bit of paper in it. In order for us to be honest to our idea of a completely electronic physics course we made a rule that no paper would be used to transmit the ideas or grades of this course (See Figure 2.)

Our paperless rule:

NO paper is transferred between instructional staff and students that contains course information or assignments for grading.

Figure 2

No textbook, no written homework, no paper, our examination , everything would be done electronically. Our vision was to see if that was possible and how that would change the way we taught physics and the way students learned physics.

I am going to describe this course for you. Fortunately it was part of a bigger project so we hired an educational psychologist to evaluate the course, to spy on what we were doing, to write down notes and to interview the students. I did not have to do the evaluation myself. I only had to try to figure out in this strange way, a way in which I could not write notes to the students, how could I teach them physics. First, I will give you a little bit of background of my own experience and then I will try to show you some photographs and describe what it was like for the students to do this physics course. There is now a long history of doing research in physics education.

Epistemological Roots:

- the Research in Physics Education community within physics
- Robert Karplus, U. Cal. Berkeley, 1960-70s based on Jean Piaget, 1930-60s
- Freed Reif, U. Cal. Berkeley, 1970s

Recent summary:
E.F. Redish, AJP 62(9), 796-803,1994
"Implications of cognitive studies for teaching physics"

Consequently -
I am no longer a physics content autocrat
I see physics content as a means to foster the intellectual growth of students.

Figure 3

Beginning in the 1950's and 60's in the United States the epistemological roots of our present work were planted(see Figure 3). In your proceedings is the summary work of Joe Redish giving some of these ideas (Redish, 1994) I no longer see a physics course as primarily teaching only physics. Very few students in the physics class ever become physicists, one percent or less.

Ninety-nine percent are only studying physics to forward their other careers. Physics has a broader mission than just learning the physics content. This course tries to teach more than just physics. It uses physics as a way of fostering intellectual growth. How can we organize a classroom with no paper? (See Figure 4)

Classroom Structural Roots:

- Self-paced instruction - modules, Keller Plan, 1971.
- Karplus Learning Cycles, since 1975 physics teaching for the development of reasoning
- Workshop physics (Dickinson College) P. Laws, R. Thornton, D. Sokoloff (Real Time Physics)
- Studio physics (RPI) J. Wilson, E.F. Redish
- Multimedia laboratory physics (UNL) HHMI funds

Figure 4

In the 1970's in the United States there was a movement of to "Self-Paced Instruction". The students could go at their own speed and finish the course whenever they mastered all of the content. This was called "Self-Paced Instruction" There were articles about it in 1970s. In the United States it was called the " Keller Plan." (Green, 1971).

One of the things the Keller Plan did was to divide a course into separate units of knowledge which were called modules. It turns out our paperless course ended up being organized in these individual modules. The learning cycle an instructional strategy developed by Karplus in the 1970's. More recently the computer-based laboratory courses in the United States are "Workshop Physics" and "Real Time Physics" and, in a very large classroom setting, "Studio Physics". At the University of Nebraska we tried to combine these ideas into something we call "Multimedia Physics Laboratories".

Course History

Spring 1996 - Physics 110ZX - USAFA - Classical Mechanics
(each student owns a computer)
- used Physics *InfoMall* instead of a textbook
- developed variety of exercises based on the *InfoMall*
- OCP2 - Outside of Class Physics Problems

Fall, 1996 - Physics 213 - UNL - Modern Physics
- used combined text (Tipler) and *InfoMall*
- expanded exercises to include term papers

Spring, 1997- Physics 211 - UNL - Classical Mechanics, SHM, Heat
- "paperless" course 15 week-long modules
- 7 "hours" per week

Fall, 1997- Physics 212 - UNL - Electricity Magnetism, Optics - 4 "hours" per week

Fall, 1997 - Physics 213 - UNL - Modern Physics
- expanded exercises to include oral reports by all students

Spring, 1998 - Computer Intensive Physics Mechanics, SHM, Heat
- "paperlite" course - 4 "hours" per week

Figure 5

I started to try an electronically based physics course in 1996, (See Figure 5), as a visiting professor at the United States Air Force Academy in Colorado, where every student owned a computer. Every student in the physics class had their own computer and it was hooked into a network that served the whole University. I had them buy a CD-ROM instead of a textbook. So that content was electronic. They bought a CD-ROM which was called the "Physics ***InfoMall***" (See Figure 6). It's a mall just like a shopping mall of information about physics. It's on a CD-ROM.

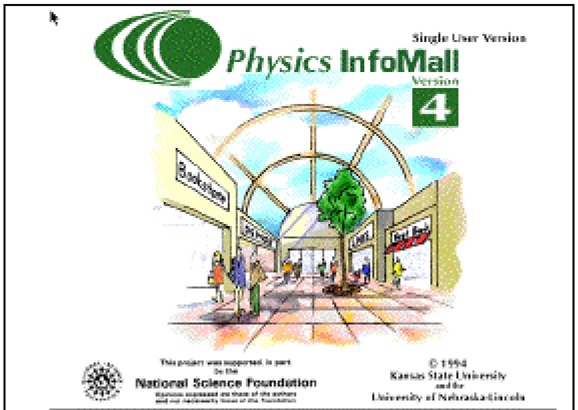


Figure 6

I began to experiment with the CD-ROM in the spring semester of 1996 with students at the US Air Force Academy. How do you give reading assignments when you cannot say go to page 12? When you use an electronic database, you can only find information by searching for it. If you search for common physics words like "Einstein" you get 5,000 hits. Then the students become confused. How do you find information?

The paperless course I am talking about here is the one I taught in the spring of 1997, so I had more than one year of experience using electronic teaching before I tried the paperless class. As it turns out the technology and I are not ready for teaching totally without paper. Here is the opening page of the "Physics ***InfoMall***." (See Figure 7).

Figure 7

It was originally designed and paid for by a grant to make a resource for secondary school physics teachers. It was not intended as a textbook for college students. It is organized like a shopping mall. There is the map of the mall and the little shops have names like "Article Attic"

"Calendar Cart" "Keyword Kiosk" and "Textbook Trove". The name of the store tells you what kinds of physics resources are in it. The physics ***InfoMall*** is equivalent to thirty-five thousand pages of text. This CD-ROM was full of 600 megabytes of data. It has no movies. It is just text and graphics. The "stores" that college students use in my physics class are less than half of the mall. They use the articles and the textbooks.

Contents of 19 textbooks are available in the
▪TEXTBOOK Trove
Conceptual Level Textbooks (5)
The Fascination of Physics, Spears, J. & Zollman, D. Addison-Wesley, 1985
Foundations of Modern Physical Science, Holton, G. & Roller, D. Addison-Wesley, 1958
Household Physics, Avery, M. The Macmillan Co., 1955
Physical Science, Its Structure and Development, Kemble, E. MIT Press, 1966
Physics: The Excitement of Discovery, Greenwood, M. S. Wadsworth, 1983

Figure 8

In the Textbook Trove there are nineteen physics textbooks (See Figure 8). You can organize them into levels of mathematics used to discuss the lowest mathematical level we call "conceptual physics," very few equations. For example in these textbooks if you write "Newton's Second Law" it's in words, e.g. force is proportional to acceleration. There are five textbooks at the conceptual level of physics.

Algebra-based Textbooks (10)
An Introduction to the Meaning and Structure of Physics, Cooper, L., Harper & Row, 1968
Atomic Age Physics, Semat, H. & White, H. E., Holt, Rinehart and Winston, 1959
Energy: Insights from Physics, DiLavore, P., John Wiley & Sons, 1984
Introductory Physics: A Model Approach, Karplus, R., Benjamin, 1969
Modern College Physics, White, H. E., Litton, 1972
Physics for the Inquiring Mind, Rogers, E., Princeton Univ. Press, 1960
Physics Foundations and Frontiers, Gamow, G. & Cleveland, J., Prentice-Hall, 1960
Physics in the Real World, Lockett, K., Cambridge Univ. Press, 1990
Physics Including Human Applications, Fuller, Fuller, & Fuller, Harper & Row, 1978
The New College Physics: A Spiral Approach, Baez, A. V., Freeman, 1967

Figure 9

The largest number are what we would call algebra based, they do not use calculus they use primarily algebraic and trigonometric equations (See Figure 9).

Calculus-based Textbooks and Special Topics (4)

Elementary Modern Physics, Tipler, Paul A., Worth Pub. Co., 1992
Elementary Radiation Physics, Hurst, G. S. & Turner, J. E., John Wiley & Sons, 1970
Physics for Science and Engineering, Williams , D. & Spangler, J., Van Nostrand, 1981
Spacetime Physics: Introduction to Special Relativity, Taylor , E. F. & Wheeler, J.A., W.H. Freeman & Co., 1992

Figure 10

The highest level books are the Modern Physics, Radiation Physics, a calculus based Engineering Physics Course and a text that deals with special relativity (See Figure 10).There are nineteen complete textbooks on the ***InfoMall***. The students bought the ***InfoMall*** for about $80 instead of a textbook.

Article and Abstract Attic

- *American Journal of Physics* (1451) 1933-1991
- *Physics Education* (24) 1989-1991
- *Physics Today* (925) 1948-1992
- *The Physics Teacher* (679) 1963-1994

TOTAL 3079 articles

Figure 11

There are over 3,000 articles complete text articles from the physics journals (See Figure 11). Most of them are from "Physics Teacher", "American Journal of Physics" and the "Physics Today" magazines. They are introductory level articles designed and selected for teachers. Well what can you do with a large electronic database you cannot do with a textbook (See Fugure 12)?

What can you do beyond a textbook with the *InfoMall* ?

- Learn about levels of explanations and write about them.

Figure 12

You can help the students learn that there is more than one way to write about physics. We all know that because we have all learned different kinds of physics from different authors. Beginning students do not know that. They think what is written in the textbook is the only way to explain the physics. We developed the series of tasks that try to get the students to realize there are many different ways of writing about the same physics idea.

For example I gave them an assignment to look up the concept “linear motion.” (See Figure 13).

Searching the Textbook Trove
You can use the search software of the *InfoMall* to find information related to a specific concept or word in physics.
Choose the words, *linear motion* [simple search] in preparation for class on Wednesday.
Now search for the words in the Textbook Trove.
- Pick *linear motion* and find information about this concept in two different textbooks in **each** level listed below:
- Conceptual Level Textbooks
- Algebra-based Textbooks
- Calculus-based Textbooks and Special Topics

Figure 13

Find different articles and different paragraphs about *linear motion* in different levels of textbooks. All of these textbooks are in digital form and you can copy them and paste them into your word processor. So the students can copy a paragraph and paste it into the word processor. They have the list of textbooks so they know which textbooks are at which level. They can search the database and find paragraphs related to the task that they have to do (See Figure 14).

1. Cut and paste a sentence or two from each of your three selections and give the exact citation for each selection.

2. Write a paragraph that compares and contrasts the three selections.

3. Finally, write a summary paragraph explaining which one of the three selections helps you to best understand *linear motion* and explain why you think that selection is best for you.

Figure 14

Then they copy and paste articles, paragraphs and then they compare them. The students are thinking about what they are reading in physics and then picking the one they like the best. The last part of the assignment is write an explanation of what you read from these books and select the one that makes the most sense to you and explain why you selected it. This is one example of what you can do with a large, electronic database that you cannot do with one textbook.

What is something else that we can teach students with the ***IntroMall****?* They can learn to find physics problems by the concept they use to solve them (See Figure 15).

What can you do beyond a textbook with the *InfoMall* ?
- Learn about levels of explanations and write about them.
- Find problems by physics concept

Figure 15

I developed what I call the “O.C.P. Squared Homework Problem” That is called "Outside-of-Class Physics Problem". I gave the students a problem to do. The students figure out how they solve this problem. What physics did they use?

Outside-of-Class Physics Problem

{ OCP^2 }

Every Outside of Class Physics Problem consists of three parts for you to hand-in.

(1) an assigned problem for you to solve, and you must identify the physics concept(s) used to solve it.

(2) you will be asked to find another problem on the *Physics InfoMall* that tests your ability to use the **same** physics concept(s) to solve it

(3) to work out the solution to the problem you found on the *InfoMall*.

Figure 16

What physics concept must they use to solve this problem? Then they go to the "***Physics InfoMall***" and they find another problem [there are thousands well 19 books, study guides, thousands of problems on the "*InfoMall*"]that uses this same concept for its solution (See Figure 16). They have to identify whatever the concept is and find another problem somewhere in the "*InfoMall*" that needs that same physics concept for its solution. They work out the solution to that problem.

What other ways can a large electronic database be used in ways not permitted by a textbook?

What can you do beyond a textbook with the *InfoMall* ?

- Learn about levels of explanations and write about them.
- Find problems by physics concept
- Study the sociology of physics
  - standard type
  - more creative type

Figure 17

You can actually study sociology, the sociology of physics (see Figure 17), using this large database. You can do both standard sociology and creative sociology. Let me give you an example of each kind.

standard type sociology of physics

Today there is concern among physicists in the U.S.A. because of the relatively small number of women who pursue studies and/or a career in physics.

Your task is to use the *InfoMall* to study this topic. You are asked to compare the points of view expressed in an article that was published in the 1930s with more current articles about this topic.

1) The earliest article related to this topic that appears in the *InfoMall* is an article published by John B. Daffin in the American Journal of Physics in 1937. Find the Daffin article and list the reasons he gives for the small number of women in physics.

2) Find two much more recent articles, i.e. more than 30 years newer than the Daffin article (i.e. published since 1967) and summarize their points of view. Give the complete citation for each of the two articles (Hint: you can do "wild card" searches by using a * to substitute for a specific letter or number, e.g. 199* would search for all of the 1990s.)

3) Compare and contrast the earlier article (1937) with the more recent articles. How are they the same? How are they different?

4) Write your own summary paragraph. On the basis of these three articles, what can you conclude about the role of women in physics in the U.S.A. ? Be sure to give evidence to support your conclusions.

Figure 18

I have had a long history of interest in the role of women in physics. It turns out that if you search "women" and "physics" in the "*InfoMall*" the earliest article in the database about the role of women and physics was published in 1937. So I asked my students read this article, it is written by a man to see why he says there are so few women in physics in 1937. He makes a list of why he thinks there are so few women in physics. Then the students must search the "*InfoMall*" to find another article on the same topic, published 30, or more, years later.

In the 1960s, the 1970s, and the 1980s, there are many articles about women in physics. The students must read one of these articles and compare how does the thinking of the physics community about women in physics changed from 1937 to a time more recent than 1967. The students write a summary conclusion, their own ideas from these two articles about the role of women in physics in the United States now. Here is a way of getting students to look at physics as a community activity, which you cannot do with a textbook. I call that "Standard Sociology."

more creative type sociology of physics

Search the *InfoMall* for :

Hutchings
Fuller
Einstein

How many hits in how many documents do you get for each?

What can you conclude about the contribution of each of these physicists to the world's body of physics knowledge?

Figure 19

But you can also do more creative sociology with the database. I was teaching this course with a post- doctoral person by the name of Hutchings. My name is Fuller . There was a physicist at one time who's name was Einstein.

I asked the students to search the database on "Hutchings", "Fuller" and "Einstein" (See Figure 19) and then write a paragraph about the impact of each these people on physics. It turns out Fuller is an English word that means "more than full." So if you searched the database any the time it says, for example, "the glass is fuller" with more water in it than less, you get a hit. So Fuller turns out to be a very popular word.

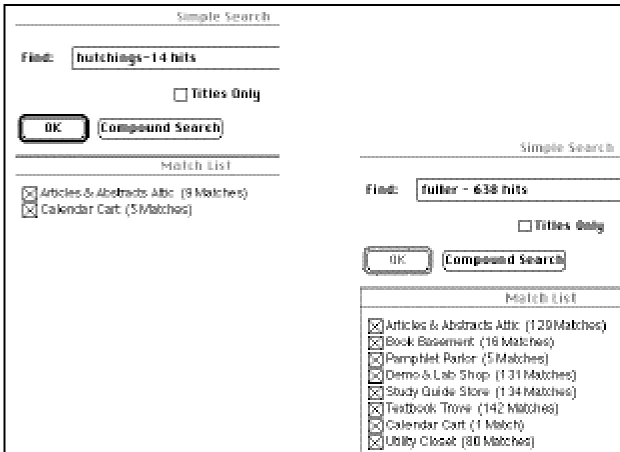


Figure 20

If you do this search for "Hutchings" you only get 14 hits. A few in articles and a few in the Calendar Cart. Fuller is not too bad, 638 hits, but first all of the adjectives "Fuller" are counted (See Figure 20). Also my father and my brother are physicists.

We wrote a textbook together in the 1970's called "Fuller Cubed." (Fuller, Fuller and Fuller, 1978), Every time the name "Fuller" appears it may appear three times, Father Fuller, older brother Fuller and Robert Fuller. So my count may be three times bigger than it ought to be because every time it counts Fuller it counts all the other Fullers also. Good students will discover this . When they look at this they say, " Oh, well it's a lot of hits." Then they see it's Harold, Richard and Robert as well as the adjectives. So "Fuller" gets an inflated count.

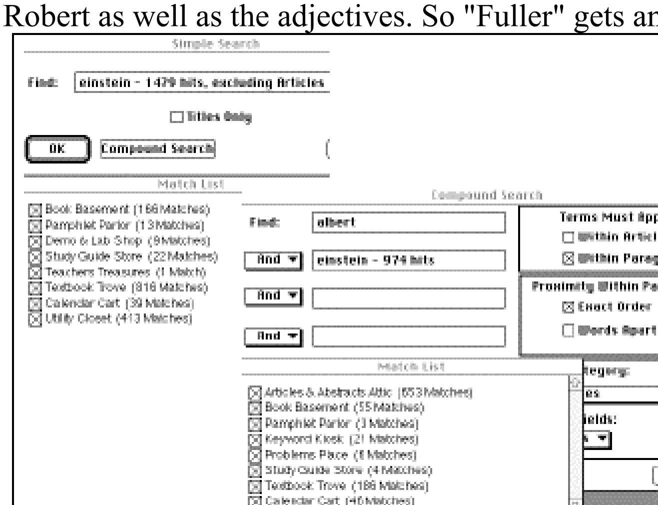


Figure 21

If you search on "Einstein," it blows the database away. There are so many it says it cannot count them all. You have to limit your count for Einstein. If you exclude the 3,000 articles, you get 1500 hits. And if you search combinations for Albert and Einstein together you get almost 1,000 hits (See Figure 21). The evidence is quite clear right, Einstein made a substantially different contribution to physics than Fuller did, even the three Fuller's put together. And the Fullers have made a substantially different contribution to physics than Hutchings. This is another way that you can use the database to ask students questions you can not do using a single textbook.

The existence of this large electronic database made us want to try to teach a course with no paper. The students buy the electronic database, all of the lesson assignments are given to them electronically, all of the students work is submitted back to us electronically. So we had to setup a classroom (Figure 22).

Figure 22

Here is what the paper-less classroom looked like at the University of Nebraska. It turns out it has Macintosh Computers in it. The tables are arranged in a kind of disarray. You can see me there teaching. You notice I projected something on the wall but only one of the students is looking at it. The others are watching their computer screens.

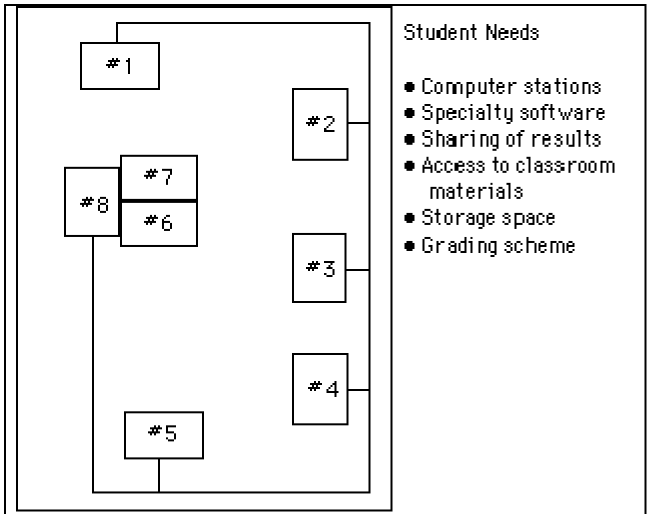


Figure 23

This classroom was organized so that all the students were networked together (Figure 23). We had eight computers so we could do a class of 24 and they were networked together as shown.

Then we added an instructor workstation to it and when we were doing the paper-less course we also used ***Power Point*** and made projections (See Figure 24).

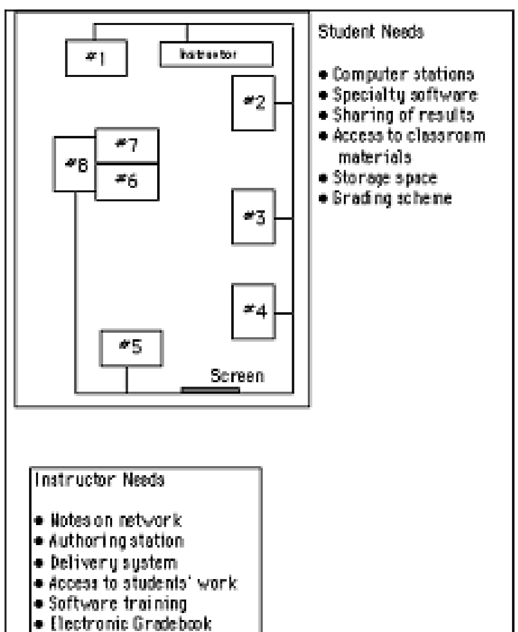


Figure 24

You will notice that as I add the support software that you need to make paperless physics work the task gets bigger and bigger. It is one of the problems with it. Now the instructor can send messages to the students and they can send messages to the instructor. You have to grade everything electronically so you need some kind of electronic grading book. If you're not going to use paper then the student needs some way to get the information if they're not in class.

You now need to connect this classroom to the world wide web or something like the world wide web so the students can get access to the to the information outside of class (See Figure 25). You now have e-mail, you have the World Wide Web, Internet access news groups and things like that. You add the more support that is needed for this course.

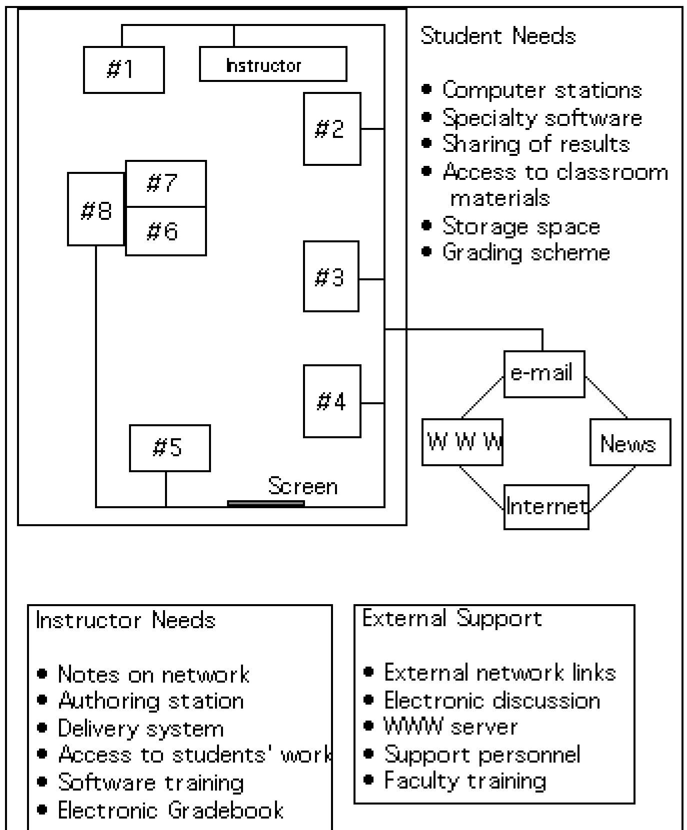


Figure 25

We organized the classes something like workshop physics (Laws, 1994). All of the physics was put into seven periods during the week. We had 350 minutes of class each week. Each class period at Nebraska is 50 minutes long. All of the normal lecture time and the problem solving time and the laboratory time were put together into unified course period and we met three times a week for about 2 .5 hours. The only way we could figure out how to do this was to divide the course into week long modules around a fundamental concepts.

We did "linear motion" one week, the next week we did "two dimensional motion", then the next week "Newton's Second Law", etc. We organized the traditional physics content in blocks of time. We tried to have all of these different ways of learning a concept every week (See Figure 26).

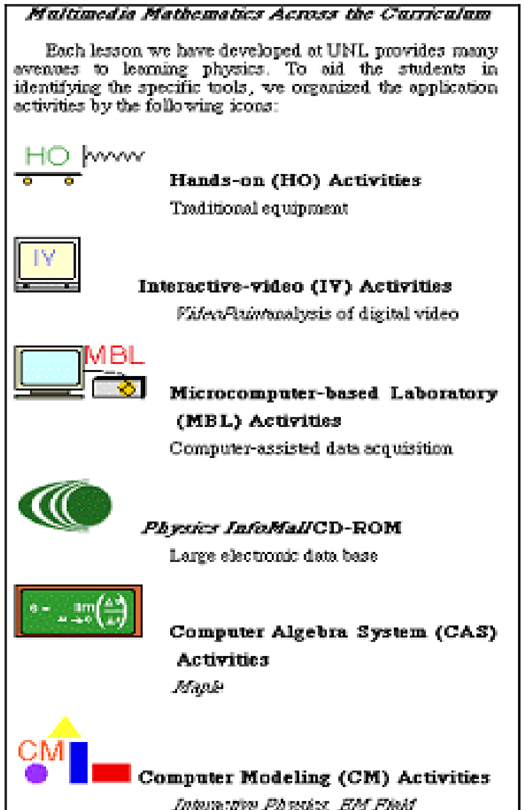


Figure 26

We included hands on lab activities, used interactive video, and had micro computer based labs, or the computer-based, real time labs. We had the students do CD-ROM searches in class and as homework. We used a symbolic mathematics program called “***MAPLE*™.** We used the computer simulation, for example programs called “Interactive Physics” and EM Fields.” We also had homework and examinations. All of these were done electronically. You can see it was too much. I did not know that at the beginning but students had to learn all of these things in addition to the physics.

Software students will learn to use

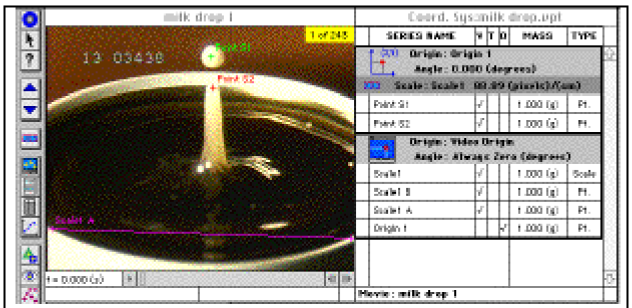
- Word
- Excel
- PowerPoint
- VideoPoint
- Maple
- Netscape
- Science Workshop
- MoviePlayer
- Interactive Physics

others .

Figure 27

For example here is the software that the student needed to use during the semester (See Figure 27). ***Word***, ***Excel***, ***PowerPoint*** [they made oral presentations], and ***Video Point*** is a digital video software (I'll show just a little bit of it), "***MAPLE***" is the symbolic algebra program. ***Netscape*** is to get onto the World Wide Web. ***Science workshop*** does the computer-based real time labs. ***Movie Player*** plays video and ***Interactive Physics*** does simulations of physics systems.

Let me just make a little aside. I am not sure how many of you are aware of the ***Video Point*** kinds of interactive video software programs. There are quite a few of them now on the market at least in the United States and I am sure in England also. What those programs do is play some video sequence in a window on the computer screen. Then with the mouse you can click on some point on the screen and the software will automatically give you the location of that point in x, y coordinates on the screen. If you calibrate the screen with a scale first, then the software will give locations in meters. If not then it gives it to you in actual pixel location on the screen which you can then later to convert to meters if you want.



filmed at 4000 frames per second

Figure 28

The person that who developed high speed photography, Harold Egerton at M.I.T., was from Nebraska. He grew up in a little tiny small town in Nebraska so we like to use his videos in our course.

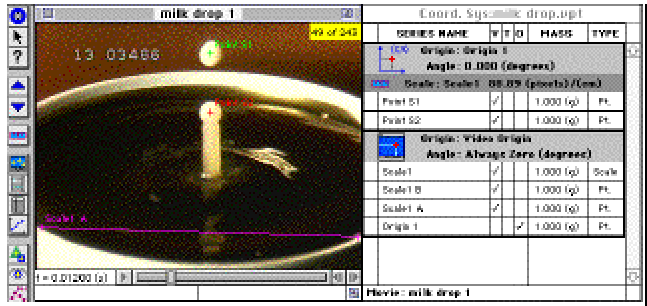


Figure 29

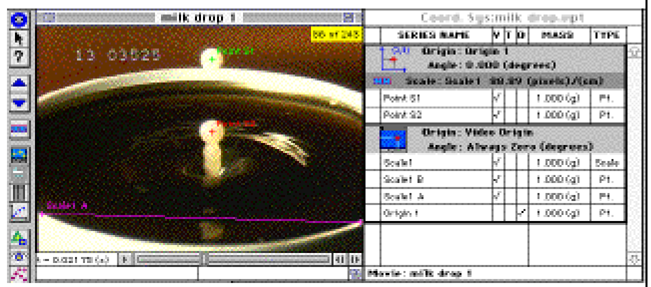


Figure 30

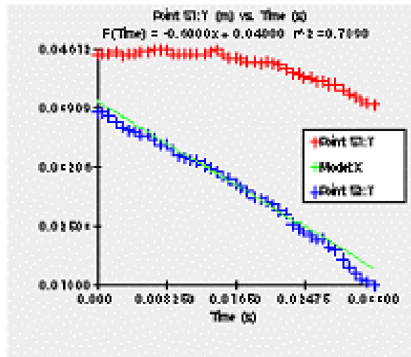
Figure 31

He is famous for a milk drop filmed at 4,000 frames a second. If you drop milk into coffee and it makes this beautiful pattern (See Figures 28- 31).

We asked our students to figure out if the drop that separates falls at the same rate as the drop that is still connected to the coffee.

Knowing some physics and surface tension we would guess that the surface tension will pull this bottom drop down and it will come back faster.

If you play through this with your ***Video Point*** software and you click on both points, then the software automatically records the locations of those drops for you. When you get done you can draw two lines on your graph (See Figure 32).



Red Dots: free falling drop

Blue dots: drop connected to surface

Figure 32

You can ask your students to discuss the physics of the motion of these two different drops of milk. This software allows you to take video images of real events and have students do a detailed numerical analysis.

Now let us go through what a typical week might be like for the students showing the different kinds of things the students would have to do. I am going to take the week where we were studying falling objects in which you have to take into account the air resistance (See Figure 33).

Typical Week of Classroom Work
e.g. the coffee filter
Exploration:

How do things fall?
Comparing sandbags and coffee filters

Figure 33

The first thing we did was have the students drop a bag of sand and a coffee filter. They hold them up and then drop them. The sandbag falls and the coffee filter floats like a feather slowly down to the ground. [By the way coffee filters are very good scientific equipment. Because of the way that they are shaped they fall very nicely down straight (Derby and Fuller, 1997).]

We asked the students to explore how these two different things fall. Then you work with them to invent, what the necessary physics concepts are when you have to talk about gravity.

Invention:
What are the forces acting on a falling coffee filter?
- free body diagrams
- gravity
- air resistance

find references on the *InfoMall*

Figure 34

You have the students draw a free body diagram of all the forces on a falling coffee filter and they have to talk about air resistance (Figure 34). You can send them to the "*InfoMall*" to look for some references of about air resistance.

Application:

Hands-On or Interactive Video:

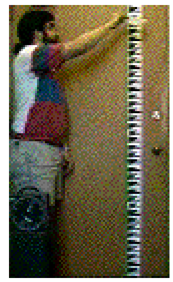
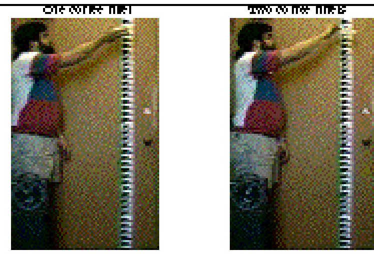


Figure 35

One of the things we provided, in addition to, was a video of a person holding up a coffee filter in front of a marker on the wall where there is a clock running (See Figure 35). The students can play this video sequence. They can read the time of the coffee filter fall from the clock and also find the location of the filter as it falls down.

One of the nice things about the coffee filter is that you can stack filters inside of one another and they look exactly the same to the air but, of course the mass goes up two, three, four, times as much. You can increase the gravitational force on the coffee filter while keeping the air resistance essentially the same (See Figure 36).



Time	One	Two
0	5	6
0.1	10	12
0.2	15	19
0.3	21	27
0.4	28	39
0.5	36	55
0.6	49	70
0.7	60	82
0.8	70	96
0.9	80	109
1	91	123
1.1	102	138
1.2	114	153
1.3	125	172

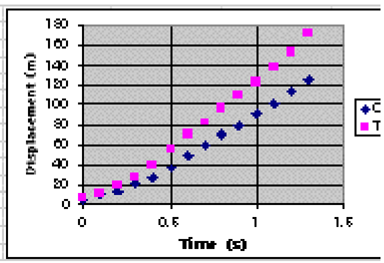
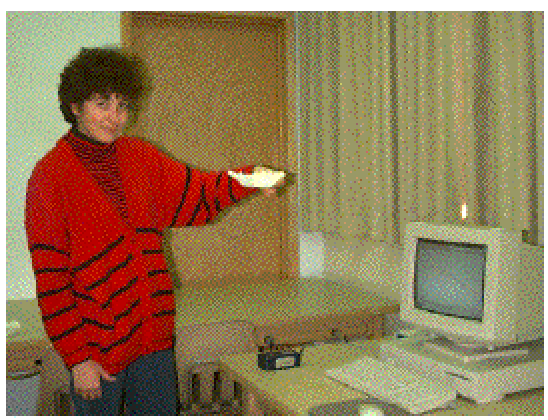


Figure 36

Another way to collect the same information is by using the computer-based real time physics software. In the United States PASCO sells "Science Workshop". But there are several examples of others available in Portugal. It has a little motion sensor. Here is a graduate student holding the coffee filter above the motion sensor (See Figure 37). You can drop the coffee filter and use the motion detector to measure the displacement. You get curves that look like this (See Figure 38).



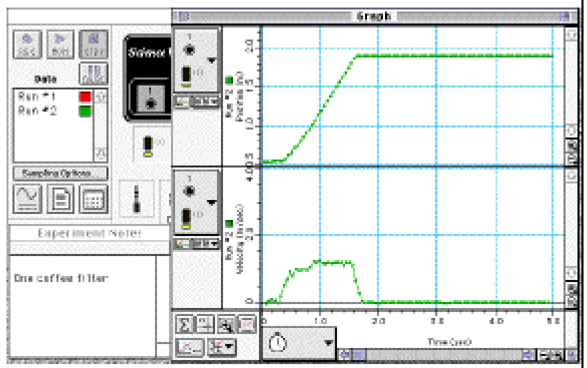


Figure 38

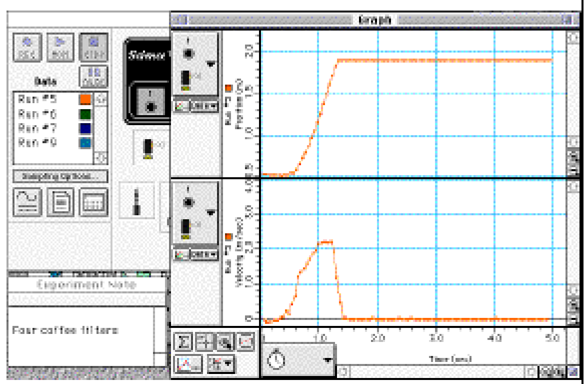
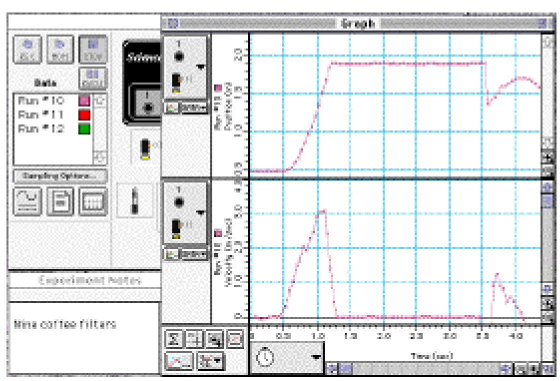


Figure 39

Here are the curves for four coffee filters. Now the terminal velocity gets to be about two meters per second filters (See Figure 39). Here are the curves for nine filters and you see that terminal velocity is about three meters per second. You can ask your students do this kind of analysis (See Figure 40).



If $v_t \sim$ sq. rt.(m); then $F_{drag} \sim v^2$

Figure 40

They can show from the data that the drag force is proportional to the square of the velocity. So they do this experiment and they find that the terminal velocity increases as the square root of mass of the coffee filters, then they can use Newton's second law to find that the drag force of the air increases as the square the velocity of the falling coffee filter.

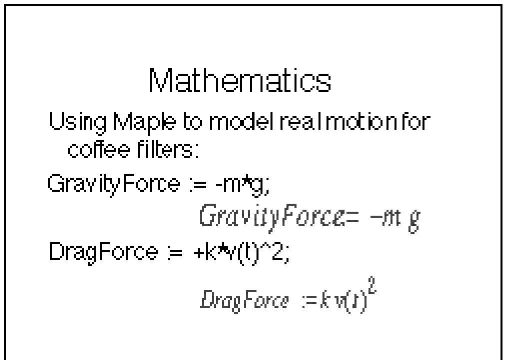


Figure 41

Now you are ready to use a symbolic mathematics program to solve the equation. Here you can use Maple[TM], or any of the symbolic programs. You can write down the gravity force is mg and that the drag force is proportional to the square of the velocity (See Figure 41). If you go through this process and do the Maple commands it looks like Figure 42.

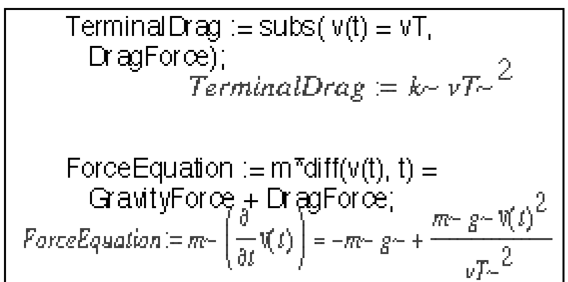


Figure 42

You can ask Maple for the terminal velocity. First you can write down "Newton's Second Law," mass times the acceleration (the derivative of velocity with respect to time) is equal to the weight down minus the drag force up (second equation, Figure 42).

Then you ask Maple ™ to solve this equation. It integrates the equation for you there solves the distance versus time solution of the equation (See Figure 43). At the beginning level this equation is too difficult for the students to do by hand. These students are just beginning calculus so this equation would be too difficult for them to integrate.

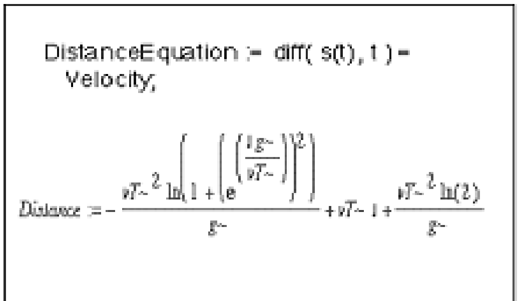


Figure 43

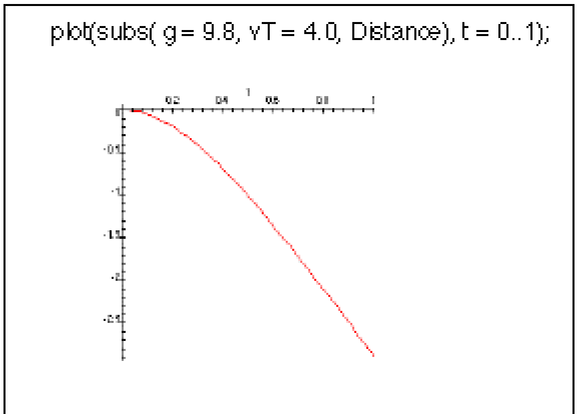


Figure 44

Maple[TM] enables them to set it up and then it gives them a solution. If you teach them the plot command they can actually plot the distance of the coffee filter as a function of time as it falls to the ground. (See Figure 44). You will notice it curves and then becomes linear as the filter reaches a terminal velocity.

In summary, this was a typical week-long lesson that had everything. Hands on, ***Info Mall***, video, MBL, Maple™, and homework problems. Now I will tell you what we found when we evaluated the course.

Dr. Amy Speigel, a Ph.D. in psychology, evaluated the course and has written a report on lessons learned from Paperless Physics. If you are interested, you can send her e-mail and she will send you the printed report (aspiegel@unlinfo.unl.edu). All I have done is pull out the big ideas of what she saw in her evaluation of "Paperless Physics." Then I will tell you my own feelings about it and I will tell you what we're doing now.

First of all having this kind of interactive learning going on in the students was extremely important to the whole design of lessons (See Figure 45). It increased the students interest in the course and they saw the value of using mathematics to model the behavior of real physical symptoms.

- The inclusion of interactive components is an important part of lesson design.
- high student interest
- mathematical modeling

- The inclusion of multimedia components require more technical instruction and support.
- wide variability in computer experience

- Student-instructor interaction is vital to the successful implementation and development of the lessons.
- as novices, students need reassurance

Figure 45

All of this technology required much more technical support than you would normally have in a physics course. You have just got to make sure that the software works every time when you go to class and that the students know how to use it. Every one of those software packages I mentioned in the beginning, except for Word and Excel which are sold by Microsoft, are sold by different companies. They all have slightly different key strokes. They all behave in slightly different ways. It blew the minds of the students. I don't know how to explain it any other way, all of those different keystrokes just wiped them out. It has nothing to do with the physics. It is learning the key strokes. I had the idea before this course that typing computer key strokes is just like typing a typewriter, that you only needed to know which key to hit. That seemed to be wrong, because when you type a key stroke like "save" it's doing something and you need to have some image in your head of what that key stroke is doing. So just teaching key strokes is too simple. It is more complicated than that. I do not know how to do it yet, but I know it is a problem.

The students need lots of instructor interaction. They easily get lost in the software. You need to be active in the classroom. Giving them assurance that it is O.K. to get lost. You can just turn the computer off and start over again. Frequently they lock the keyboard. They hit a key and nothing happens . The instructor needs to be there to provide some help for them. It turned out to have been very beneficial in this class to have the mathematician and a physicist working together on the lessons (See Figure 46). When the Maple lesson was taught it was taught by a mathematician. When we decided what maple lesson we were going to do at the end of the week we adapted the physics so the students had experience with the physics before they saw the mathematics, that turned out to be a very powerful learning experience for the students.

- Lesson implementation is enhanced by providing opportunities for students to interact with instructors from more than one field.

- It is important to limit the total amount of new learning required in a lesson.

- It is important to modify course requirements in light of lesson requirements.

Figure 46

We did not properly reduce the amount of physics to cover when we asked them to do all this software. It was too much. It turns out you cannot teach software and the same amount of physics that you have always taught. When you start putting these additional things in, like searching the CD-ROM, you have to change the way you do the physics.

If you are teaching new software as well as new physics concepts, and new mathematics, you can not just do that what you used to do, you have to modify the physics you are going to do. You also need to state explicitly what the new requirements for the course are (See Figure 47). For example at the Universities in the United States attendance at lectures is an optional activity. Students do not need to come to a physics lecture. They can read the book. Students cannot miss

- It is important to explicitly address the requirements inherent to the lessons, especially if they conflict with student expectations. Some of these requirements include
- Class attendance and participation
- Technology access and restricted study opportunities
- Learning through "discovery"
- Taking notes on lessons

Figure 47

a Paperless Class. Nothing happens if the students are not there doing it themselves. If they have missed the class they have missed everything! There are no lecture notes, there are no data for them to analyze.

This was a difficult action for the students to take. They are used to doing what you are doing in this talk, come and sit, and write down notes. In the paperless course students can not do that. They have to be there doing something with the computer or nothing happens.

Technical technology access turns out to restrict the study opportunities. For a normal physics course the day before the homework is due, say, midnight you go get your textbook, you find page 27, you copy down the homework problem and solve it. Midnight of this paperless course, homework due the next day. You have to find a computer if you do not own one. You have to make sure it will play the CD-ROM. You find out you cannot just open a book. You have to type in a search of the ***Info Mall***. If you search on "Einstein" you get 5,000 hits, too many; search on "linear motion", 200 hits, too many. You have to figure how can you find the information you want. You cannot just do it the last 5 minutes before you go to bed. And you have to have access to the technology, a big problem for the students.

These activities were designed around the Karplus learning cycle where you don't tell them the answer at the beginning of the week so the students are learning by discovery.(See Figure 47). It was uncomfortable for our students. They do not like to be stumbling along. They think they should be "learning" and getting 100% of everything, no false steps. For them to wander around and have the software crash was difficult for them. I need a whole new generation of students! Take these away and bring me some new ones.

Because we did not use paper the students did not use paper, even for notes. They could use paper. They just could not hand in paper for me to evaluate. They would frequently not take notes on what they were doing with the computer. The computer crashes - - - gone. Or they mail it to the wrong address - - - gone. They did not even take notes on paper. We tried to encourage them to write notes for themselves. They just could not send them in as part of their grade. It was a problem for the students.

It was important for us to try to solicit student feedback (See Figure 48). The evaluations would send e-mail and ask how did it go this week? What happened? Was it good? Was it bad? And try to get information. Then they would write notes to us, e.g. saying 5 of the students said "MBL didn't work." Would you please fix it up. We were doing what is called action research.

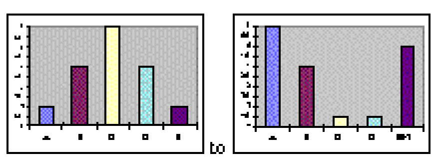
- During lesson implementation, it is important to solicit student feedback and attend to mismatches between student and instructor expectations.
- Lesson development may be enhanced by piloting fewer lessons in one semester, and the soliciting additional feedback from students and staff.

Figure 48

Trying to change the course so it would fit student expectations. Finally they told us that doing 15 new lessons was too many. We did 15 weeks. We did a new lesson every week that we had never done before. The evaluator suggested we do a few pilot lessons first. In conclusion those are the results of what the evaluator found. If you are interested you can get the report from Dr. Spiegel.

Paperless Physics/Mathematics Perils

- no real multitasking on computers
  - screen flipping
- student computer access
- grading-giving electronic feedback difficult
- need better ways of teaching computer learning metaphors.
  - more than keystrokes
- changes physics content coverage
- changed distribution of student grades from



- many (30%) students drop out.

Figure 49

Here is what I found (see Figure 49). First of all the computers we used do not really do multi-tasking. If you have a set of instructions on the screen and now I need to use computer-based real time labs. You have to open up "Science Workshop" but it comes up on top of the instructions of what you are suppose to do. Now you have got the setup that you are going to measure say the coffee filter. Oh you forgot what you are supposed to do now, so you have to click on this screen here and this image goes away and a new one comes out.

While you are doing this you are waiting a few seconds for the computer to go back and forth between the programs. The computers we have today do not really do multi-tasking. It does not work well. It takes too long. The students can not keep track of what it is they are suppose to do. All of my students at Nebraska did not own their own computers (See Figure 49). They had to go to the Physics Learning Center or to the Computer Center, or to some place in their residence hall to get access to the computers. It is a big problem in doing "Paperless Physics".

Grading and giving electronic feedback is difficult. For example if students are working in a small group at computer 6 in the classroom. At the end of the class they mail their class activity to me. I grade it. If I reply it goes back to the classroom computer 6. I need some way of knowing the personal e-mail addresses of the students and so when I reply the grades go automatically back to them. I did not have a way of doing that. So I would collect electronic homework and try to distribute the grades somehow electronically. My software did not really support this. It takes a long time to read homework on a computer screen.

The next point goes back to the topic that I mentioned before (See Figure 49). I need a better metaphor for teaching software. It is not just key strokes. It is some mental picture of what is happening when you do key strokes. I have not figured it out how to teach this. I just know it is a problem for my students. Going to "Paperless Physics" changes the physics I can do (See Figure 49). I did not adjust the physics content properly. I just took the regular course that I teach in 15 weeks and I tried to teach everything just as I would normally. It had a big impact on the distribution of student grades. Normally in the United States we have a the Bell Curve. We give a few "A's" a few more "B's" lots of "C's" a few "D's" and a fewer "F's". In this class there were students who could do it and students who could not do it. And it divided the class into two groups. The students that could not do it quit. They dropped out. That was a fairly large percentage, about 30%. I am not exactly sure why that is. It may be that some students thought learning from a computer is like a computer game. They discovered learning from a computer is much more work than learning from a book.

What are the promises of "Paperless Physics"? (See Figure 50). Ten years from now, or 15 years from now, if we can figure out how to do this I think most the learning may be done like this. Thus it is important for us to learn how to do it.

Paperless Physics/Mathematics Promises

- the way of future learning
- can improve as we learn how to teach this way
- faster computers, bigger screens will help
- more universal computer access

Figure 50

I think I can improve the learning of physics electronically. It is much more interactive once I learn how to do it. When we get faster computers and bigger screens and they can do multitasking the interaction that goes on in the classroom will be better. As soon as all the students come to the University with their own computer then that access problems will go away. What, then, is the future for "Computer Intensive Physics"? (See Figure 51). Well I am still going to try it! I refuse to give up until I get it right. We have cut back on the number of hours the students spend in class now from 7 to 4.It is a very interesting and challenging

Future of Paperlite Physics/Mathematics

- Repeating Physics 211 this semester with "paperlite" 4 credit hour format
- Enjoyable teaching
  - Team Teaching
  - Multidisciplinary
  - Challenging
- Adding Electronic Homework
- Adding Homework Bonus activities
- We think we are learning how to do it better
- Continuing to evaluate it

Figure 51

way to teach. You are involved with a team of people, software people and mathematicians help you teach. So it is a multidisciplinary style of teaching instead just teaching with other physicists. That is interesting for me.

I think we are learning how to do this course this semester. It seems to be going along pretty well. We are continuing to evaluate it. So hopefully, at some future time, I can give a talk and say "It was very successful," "Computer Intensive Physics," the physics of the future.

Adapted from an online publication at http://physics.unl.edu/~rpeg/paperlesstalk/lisbon.html