Lectures: We Love Them but Left Them

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Steady State Circa 1992

By 1992, we had each been teaching at Paul Smith's College for nearly 20 years and had inherited a set of calculus-based physics courses about a decade before. We also were in the fourth year of a technical physics course we had been asked to develop for students in the surveying major. Our lecture notes had been through several revisions but were looking a bit tattered. In each of the physics courses, we lectured for three periods per week to some 16 to 30 students. These classes were quite informal and were held in the laboratory to make demonstrations more convenient. Students were encouraged to ask questions at any time. Although we presented the basic concepts in the lectures, we concentrated on the major derivations and solving many example problems. We tried to invent cute practical problems that would keep the students' attention. The students responded with interested faces and nodding heads. Lecturing was great fun.

Although we were pleased with our lectures, we were especially proud of our labs. Our lab space had four work stations each equipped with an 8088 Zenith computer set up with Quattro spreadsheets. We would place teams of up to four students at each station so we would often have two 3-hour lab sections per course. We developed labs that reinforced some important subject of the week. We even published a couple of our experiments in *The Physics Teacher.*

To insure the students would understand the lab activities, we would lecture to them for 40 to 50 minutes on the experiment they were about to perform. The experiments were not just designed to reinforce the week's subjects but also to progressively develop laboratory and reporting skills. Each student was required to turn in a carbon-copied lab report by the next lab meeting. We nearly drowned in the sea of yellow paper!

An Impulse Hits

In May of 1993 we attended *The Conference on the Introductory Physics Course*[1] at RPI in Troy, NY. The conference, held in honor of Robert Resnick's retirement from RPI, was of international scope. We expected to get a bit of fine-tuning on our physics courses.

Within hours of the commencement of the conference, we became aware that a tune-up would do little for the rods protruding through the head of our teaching engine. Speaker after speaker presented data that unambiguously showed lectures promote very little student learning. Their evidence showed that merely listening to an expert does little to shake a student's deep-seated belief in an incorrect mental model. We, too, had moments of disbelief -- no one wants to believe that they spent 20 years in the pursuit of student boredom. Nonetheless, the seed of discontent with lecturing had been sown.

We left the conference in a mild state of shock. Would our colleagues and administrators believe us? Did we even believe it? Were we too old to make a radical change? How could we afford the time and money to make a complete change in the way we did our business?

An Unsteady State

We spent a year fumbling through those old lecture notes. The year before they seemed so comfortable. After all, we had learned so much in preparing and revising those notes. Now, we looked deeper into the eyes of our nodding students. We listened more carefully to the few questions they asked. There seemed little doubt -- these polite young men and women were faking it! Even in lab we were talking them into a catatonic state.

We decided to jump on the wave of change. But how would we change? The 1993 conference had suggested several alternatives. Our small classes seemed to lend themselves to an approach where students would perform experiments in class. The kind of thing being done by Priscilla Laws[2] at Dickinson College (Workshop Physics) or Jack Wilson[3] at RPI (Studio Physics) caught our attention but the approach would require the accumulation of new equipment: computers, interface boxes, sensors, etc. We also would need time to learn how to use the equipment and even more time to develop the many experiments, since every class would involve experimental work.

Paddling Into The Wave

We needed to get a foothold in this new way of teaching. If we could just get some of the new equipment, perhaps we could learn the new methods. So, we went to our College President and proposed a trade. If he would buy a work station, we would learn how to use it and write a grant proposal to fundamentally change the teaching in our division. He agreed to find the funding for the equipment the following September but we would write the proposal the previous Spring. We were not going to get any training before we wrote this proposal.

We wrote a proposal to the National Science Foundation in their Course and Curriculum Development program. We involved three math faculty in the proposal designed to transform our physics courses and several calculus courses. Although we were asking for some equipment, we were mostly looking for funding of faculty time for course development. Our five person group was too large and diverse and so was the scope of our project. Moreover, our lack of experience was poorly disguised and NSF rejected our bid.

Fortunately, several months went by before the rejection arrived. This was enough time to press the President for the money to purchase the workstation. In our proposal, we had bragged about the generosity of our administration funding an experimental workstation to prepare us for course reform even before NSF funding arrived. When the President tried to back away from his offer, we asked “What would the folks at NSF think?” We got our workstation.

Climbing Back On

We played with our new computer, Pasco interface box and several sensors. We accumulated and studied information on a variety of activity-based teaching techniques and we designed a few exercises and even incorporated the new equipment into some class demonstrations and laboratories. By the Fall of 1996, we had begun to write another proposal to NSF's Instrumentation and Laboratory Improvement program.

The proposal, entitled "Louder Than Words", sought funding for seven more workstations to reform five courses. We had decided that this time we would only work with the courses that we taught: three physics courses and two environmental technology courses. The proposal was only for equipment. We had no idea of where we would find the time to do the project.

We felt much more confident in this new proposal. In fact, to prepare for the project, we even gave our physics students the Force Concept Inventory[4] (FCI). This widely used, multiple choice, non-mathematical exam attempts to measure student understanding of basic mechanics concepts. When used as both a pre and post test, the FCI can be used to evaluate the students' conceptual learning in an introductory physics course. If we got funding, this would give us some comparative material for evaluation of the project.

Sometimes, good luck arrives in multiple and unusual ways. We heard that our NSF proposal was funded in June of 1997 (NSF grant # DUE-9751018). At the same time, the College was in the process of getting a new President and the year before a new Academic Dean had been hired. The upheaval in administration created a screen of confusion. Our division chairperson was interested in the project and assigned both of us to some of the same courses. Our teaching loads dropped from 15 -18 hrs to12-15 hrs and no one seemed to notice.

Getting Our Balance

Our plan called for the two of us to start with the reform of a single course in the Fall of 1997. The course was Physics 241, the first of a two-course calculus-based sequence. Our hope was that we could learn enough about the reform process by collaborating on a single course that we could each take the lead on another course the next semester.

We reviewed the work of several researchers in physics education including Laws[2], Wilson[1], Redish[5], McDermott[6] and Arons[7]. After this review, we set up the following general guidelines for our reformed class:

1. Lecture no more than 15 minutes before the students do something.

2. Divide the students up into groups of three.

3. Get student groups to discuss options and make predictions before they try

something.

4. Get student groups to draw conclusions and present them after they have experimented.

5. Create activities requiring the student groups to do problems similar to the ones that we used to do for them.

6. Have each group submit four formal lab reports each semester.

7. Give the same kind of homework problems and use the same text book

8. Continue to give problem solving questions on exams but add conceptual questions.

9. Accept some slippage of syllabus coverage.

By the time we had heard of our success with the NSF grant, the Fall schedule was in place. Our course was slated for the typical three one-hour lectures per week and two three-hour lab sections per week with all students assigned to one of these lab sections. With some minor adjustments to the schedule, the Registrar was able to free up all of the students for both lab sections. We had to choose any six hours out of the nine hours that were now scheduled for all students. In the spirit of experimentation we chose to meet three times per week: A Monday class of one hour; a Wednesday class of three hours; and a Friday class of two hours.

Although we had looked through example exercises of several authors, the most complete set of exercises that we had available was *Workshop Physics*[2] by Priscilla Laws. Wiley had just published the set of workbooks and we had obtained a copy. These books contain many clever exercises that Laws and her colleagues have tested over several years. The books also reveal sketches of the class atmosphere that Laws creates.

Studying Laws' workbooks certainly gave us some ideas of student exercises but she did things a bit differently than we had in our long developed lecture notes. We decided that we could not comfortably adopt someone else's workbook any more than we could comfortably adopt their lecture notes. Although initially we nearly replicated a few of Laws' exercises, we found we were most comfortable in creating our own exercises based on the kinds of example problems we used to only talk about in lecture or adaptations of some of the labs we had designed.

We spent from six to ten hours of preparation for each class period. This work included:

1. Reviewing the examples in the old lecture notes.

2. Reading and sometimes trying what Laws had done.

3. Reviewing our old laboratories.

4. Assembling a combination of the old and new equipment.

5. Writing the Science Workshop templates and/or setting up Quattro spreadsheet templates.

6. Running and debugging the exercises.

7. Writing up the exercises in the form of a workbook, complete with brief summarys of the information to be presented in short mini-lectures.

Although we were rarely seen out of our classroom, the work was exhilarating. We often hauled colleagues out of the hall and said "You've gotta see this!" For the first time, we were actually seeing some physics that we had previously only talked about. We felt a bit like Galileo must have when he first peered through that eyepiece at Jupiter.

Taking the Ride

Although the students' level of euphoria was perhaps an order of magnitude below ours, they accepted their role as guinea pigs with good humor. We were impressed with how lively the group discussions were. Groups occasionally even had heated arguments over physics concepts! Many more questions were asked by the students and many more responses were volunteered from the student groups. We found that the three person groups were an excellent buffer for student shyness and embarrassment. Being publicly wrong in a group seems to be much less inhibiting than being wrong as an individual.

We often asked the student groups to predict the outcome of an experiment before they performed it. We were pleased to see their interest and excitement in getting experimental confirmation of their ideas. There also seemed to be genuine surprise when their ideas did not work out and their openness to a new idea was evident. Although we had originally feared that the Pasco Science Workshop software would be confusing and detract from the students understanding of their experimental outcomes, the students learned quickly and seemed to find the software quite transparent.

We also spent some class time on traditional physics problem solving. We used the same text book and assigned the same homework problems but we did not do example problems for them. Instead, we had the student groups work on an example problem and we wandered around the room getting them started or getting them over some stumbling block if someone in the group didn't help first. This was a real revelation! The students were getting stuck in places we did not anticipate. A simple algebraic or arithmetic step was often stopping them. No wonder they got so little out of our working the problems for them – we lost 10 or 20% of the class at each rearrangement of an equation!

Four times during the semester we asked the student groups to collect data on an experiment related to a concept we had been studying. Generally, the data collection and its reduction in a spreadsheet took a two-hour class period. Each group was then required to produce a word-processed report describing the experiment and interpreting its results. The groups decided when they would meet outside of class and how they would split up the work. Few groups allowed their partners to slip out of doing any work.

A Snap Shot From the Album

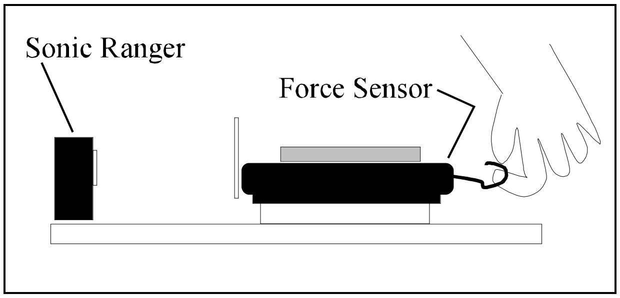

Figure 1 Kinetic Friction Apparatus

When we discussed dry kinetic friction in a lecture we would describe it as the making and breaking of microscopic welds and prod the class to get them to tell us what they thought would affect the friction force. Of course, only a very few students would participate and they would respond with weight (normal force), surface type, and surface area. We would then give then the standard formula and explain away the lack of area dependence with the usual discussion about there being only a very few points of “true” contact regardless of the gross contact area. There would be no excitement, there would be no questions, there would be no arguments, and almost certainly there would be no belief!

In our active learning classroom we start out almost the same way. We ask each of the student groups to discuss the things they think will affect the sliding friction force. After a few minutes of discussion, we pole the groups and ask each group to report on their thinking. They virtually all come up with the same three ideas: weight (normal force), surface type and area. Here we take the time to have a discussion of weight versus the idea of normal force. We also ask the groups to elaborate on the direction of an effect. Interestingly, half the groups think that the friction force will go up with area and half think it will go down. Nearly everyone in the class seems to have an opinion.

The students are genuinely curious to discover who is correct. Each group has a wooden block with two different surfaces. The motion of the block will be monitored with a sonic ranger that is programed to plot position vs. time and a force sensor connected to the block is set to monitor the force with which the block is pulled across the table. Figure 1 shows the apparatus. The mass of the block and force sensor is about 500 grams and each group has two accessory 500 gram bars. The area of the block can be varied by placing it up on edge. This cuts the area in half.

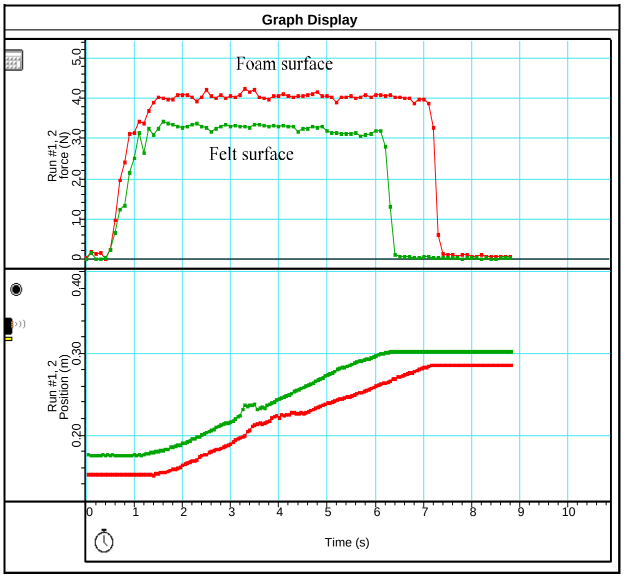

Figure 2 Surface Type Dependence

We ask the groups to discuss how they will have to pull the blocks so they can be sure that the force sensor is reading the magnitude of the friction force, and furthermore, how they will know if they are doing this. At least some of the groups realize that they will have to pull with constant velocity and that the graph of position vs. time will be straight.

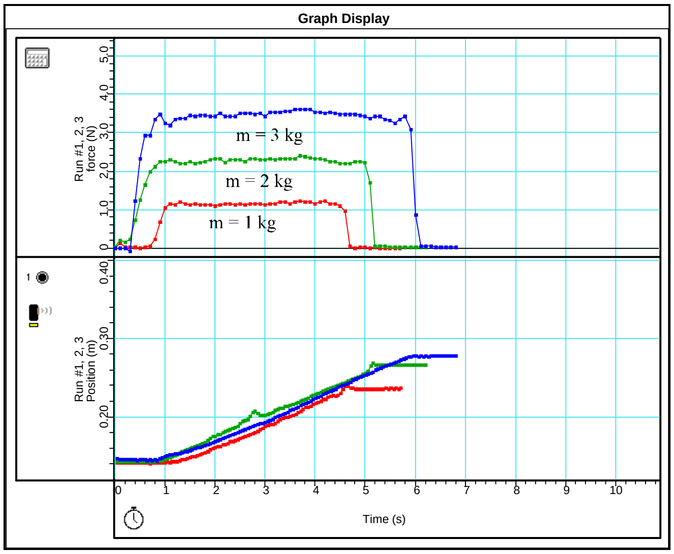

Figure 3 Normal Force Dependence

We then ask the groups to separately test the dependence of kinetic friction force on normal force, surface type and area. Note that they find a clear dependence on surface type and normal force as shown in Figures 2 and 3. In addition, the friction force doubles and then triples as the mass of the dragging block is doubled and tripled for the same surface type. Also, notice that in figure 4 there appears to be no change in friction force when the area is reduced by 50%. Interestingly, the students in the first groups to complete the area test create quite a buzz. They think there is something wrong. They anxiously wait to see how the other groups do. When all the groups are done and all get the same lack of dependence, they believe what they have seen, but now they want to know why!

Replicating the Ride

The next semester we continued the reform process in the second semester of the calculus-based physics sequence and in the one semester technical physics course. We each separately took the lead in one of these courses, but we were both present in the classroom for both courses. Fortunately many of the exercises we had developed in Physics 241 could be adapted to Technical Physics so our development time did not double. By the end of the Spring semester of 1997, we had created a very rough first edition of three workbooks.

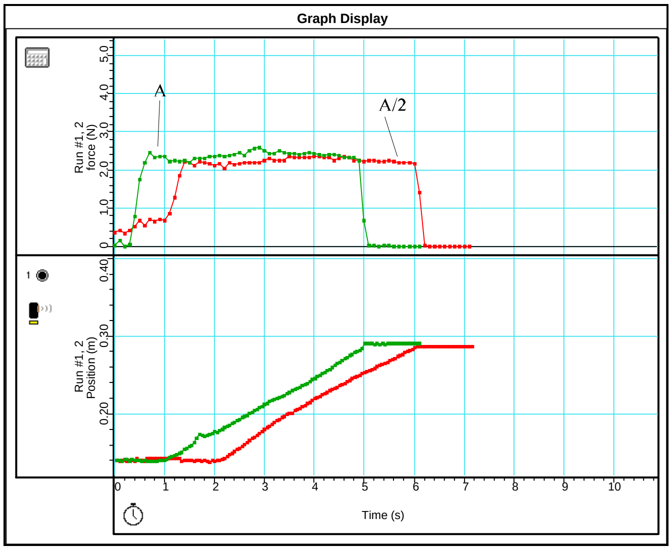

Figure 4 Area Dependence

In the fall of 1998 we created a second edition of the Physics 241 workbook and branched out into another field. We applied our general guidelines to an introductory environmental engineering course (Principles of Environmental Engineering) in an environmental technology curriculum. This had been another course where we had previously concentrated on doing example problems in lectures. Although we made more use of spreadsheets and less use of the Pasco Science Workshop equipment than we did in physics, we were able to adapt a number of physics exercises including graphing, energy, pressure and fluid mechanics exercises.

While we had planned to reform a second environmental technology course, we have been unable to find the time to do it. Order was finally restored to our administration and their priorities have once again demanded our time. We have, however, continued to revise our four workbooks. And since we are no longer able to assist each other in our classes, we have started to employ a student teaching assistant to assist in our larger classes.

The Learning Response

Since two of the courses we taught were introductory mechanics courses (Physics 241 and Technical Physics), we used the Force Concept Inventory as an evaluation of a change in the students' conceptual learning. In anticipation of funding, we had given this exam as both a pre-test and a post-test before we reformed either course. The results of the testing is shown in Tables 1 and 2. The pre-test was given on the first day of class and the post-test was given on the last day of class. To minimize anxiety on the first day of class, we did not require the students to put their name on the exam unless they were interested in tracking their own progress. We also have made a special effort not to specifically discuss the exam and in fact it has been three years since we have even read through the exam. We hope this has minimized any chance of us "teaching to the exam".

Score	Physics 241 Pre-Test % of students in score groups				Physics 241 Post-Test % of students in score groups			
Acad. Yr.	96-97	97-98	98-99	99-00	96-97	97-98	98-99	99-00
>60%	0	4	10	12	15	24	45	28
50-60%	14	13	10	8	16	28	25	24
40-50%	36	31	15	24	46	24	20	36
<40%	50	52	65	56	23	24	10	12
Mean	37%	39%	37%	39%	46%	51%	58%	54%
# of students	13	21	20	25	13	21	20	25

Table 1. FCI results for Physics 241

The pre-test results are typical of students across the country that have not previously taken a physics course[4]. Notice that in the 1996-1997 academic year there is only a little improvement. This was the year before we reformed the course when lectures mostly consisted of derivations and example problems. The greater improvement of the calculus-based Physics 241 students undoubtedly reflects their better academic preparation. The shaded post test scores are after we reformed the courses. With the exception of the 97-98 year in Technical Physics, there is a significant improvement in the students' scores, which presumably reflects their improved conceptual learning. The 97-98 Technical Physics class showed disappointing improvement but it was an unusually undisciplined group that took physics from 3:30 to 5:30 PM after they had been in the field surveying!

Score	Tech. Physics Pre-Test % of students in score groups			Tech. Physics Post-Test % of students in score groups		
Acad. Yr.	96-97	97-98	98-99	96-97	97-98	98-99
>60%	0	0	0	5	0	17
50-60%	12	0	14	5	0	25
40-50%	6	22	14	28	38	42
<40%	82	78	72	61	62	17
Mean	30%	35%	34%	36%	36%	49%
# of students	17	9	14	18	8	12

Table 2. FCI results for Technical Physics

Since we have nearly completely stopped doing example problems for the students, we were curious if the new teaching method would show a decrease in the ability of the students to do traditional problem solving. To study this possible effect, we analyzed final exam scores. We chose final exams because they have changed little over the years. The students do not get their final exams back so copies are not circulating (at least that is our assumption). In the Principles of Environmental Engineering course the final exam was still unchanged after we reformed the course. In physics, however, we had modified the exam to be 40% conceptual and 60% problem solving. Previously the exams had been 100% problem solving. In Table 3, we display the mean exam scores over several years preceding the reform and the years after the reform. In the case of physics, we only looked at the percentage of correct responses to the problem solving portion of the revised exams which contained the same problems that were on the previous exams. Again, the shaded cells are after the courses were reformed.

Final Exam Mean Scores							
Academic Yr	93-94	94-95	95-96	96-97	97-98	98-99	99-00
Physics 241	72	66	75	72	72	86	77
Technical Physics	67	NA	68	69	51	70	NA
Physic 242	65	66	72	62	67	75	NA
Princ.of Env. Engr.		69	58	68	65	84	79

Table 3 Final Exam Mean Scores

The final exam data generally show that the students' ability to solve problems has either improved or is unchanged with the exception of that '97-'98 Technical Physics class. The students apparently learn how to solve problems when they do their homework and when <u>they</u> do problems in class. Instructors doing example problems for them does not appear to be an efficient use of class time.

Both the FCI results and the final exam data also seem to indicate that we are adapting to the new teaching methods. In every course, our subsequent years of using the active-learning classroom shows improved student performance over our first year.

Advice from the Battered Beginners

<u>On Group Size</u>: Over the past three years we have tried to operate with a student group size of three. We did this because the experts have said that three is the "right" size. However, equipment limitations or classes not being divisible by three have necessitated our going to occasional groups of two or four. While we have had a few very productive groups of two, two person groups do not usually have a very lively discussion. It seems to be easy for one person to dominate or the group just doesn't get started on the question posed to them. A group of four is definitely a "crowd". We have two benches in our classroom that will accommodate four people, but invariably the fourth person does not participate well. It is difficult for four to see the computer screen at once and one person usually just gives up trying to see it. The fourth person also is generally left out of discussions. Our observation is that the experts are correct – three is best.

<u>On Class Scheduling</u>: As we mentioned, on our first attempt at activity-based instruction, we had a one-hour, a two-hour and a three-hour class each week. The three-hour class was definitely too long. Once we moved beyond two hours, fatigue and impatience set in for instructors and students alike. The one hour class was also unsatisfactory. Often, the class would end in the middle of an activity and time would be lost getting back on track for the next class. An uncompleted activity also leads to a mid-class equipment change which consumes additional class time. We have found that classes approaching but not exceeding two hours worked best.

Another aspect of class scheduling is allowing time between classes to take down and set up equipment. Moreover, the equipment and its interfacing with the computer often requires experimental manipulation and prayer! In addition, the large number of exercises that are done in the course of a semester often has forced us to run at least some of the exercises before a class to refresh our memory on potential problems. A fifty minute period is generally sufficient for the task.

<u>On Workbooks:</u> Perhaps the most terrifying thought about abandoning traditional lectures is the loss of control over the course. A lecture is a powerful organizing and controlling device even if it does not promote much learning. We have found that in an active-learning classroom it is relatively easy to slide into a state of chaos. To at least direct that chaos, we have written workbooks for each course. These workbooks keep all of us from losing our way in the heat of the learning battle. They also document our ownership in the course just as lecture notes document ownership of a lecture class.

The workbooks are all bound in three ring notebook binders. Students can add their own notes at the appropriate spots if we have not given them enough room. They also can insert printouts from their computer exercises. We, too, add pages when we want to clarify or reinforce an exercise that caused problems. Thus, these books document both our learning and the individual student's learning. They do not replace the textbook in the course.

<u>On Instructional Assistance</u>: A single instructor can serve about five groups without much help on most exercises. Once the class gets to six groups it is difficult to get to deal with all the questions. As a result the group with the problem will stop working on the subject matter and they can lag significantly behind faster moving groups. The resulting delay in the next exercise frustrates the faster groups. A student teaching assistant, who has been through the class, can relieve most of the problems. We have served as many as eight groups (our classroom capacity) with a faculty instructor and a student teaching assistant.

<u>On Equipment Needs</u>: We have found the sensors, computer interface boxes and software produced by Pasco Scientific to work quite reliably. We quickly learned how to set up Science Workshop experiment templates. This was fortunate since the large number of small experiments that the students perform requires a large number of templates. We also have found that at least a computer LAN is required so that templates only need to be loaded at one location. Our network includes a laser printer with three-hole punched paper, which allows students to organize their print-outs in their workbook binders.

<u>On Furniture</u>: We have two large tables (40" by 120") that are at desk level. Each of these serves a group as a discussion and written work area, as well as an experimental bench. They serve neither function well. The students spread out too far to have a good discussion. Furthermore, the students don't have to physically move to do experimental work so they miss an opportunity to stretch and wake up.

Our remaining six workstations consist of experimental benches (30" by 96") at counter height with a small adjacent classroom table (30" by 42") at desk height. These workstations have

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classroom chairs at the desk and stools at the bench. This arrangement works well. Although the desk is crowded with three, this facilitates discussions, and when more space is needed, the third person uses a stool as a writing desk. For exams we use both the desks and the benches to spread out the students.

On Loss of Course Content: We went into the reform process with the attitude that we would not be preoccupied with “getting through” all of the material that we did before. The research we had studied certainly showed that the coverage of lectures had little relationship to the conceptual learning of the students. Surprisingly, even with our willingness to let some content slip, most of our courses lost very little. Physics 241 (mechanics) seems to have suffered the most with perhaps a 10 % loss of material. Interestingly, in Physics 242 (waves, electromagnetism and thermodynamics) we have picked up almost all we lost from Physics 241 and still cover about the same amount of material we previously covered in Physic 242.

On Leaving Lecture: Find a partner. The course reform experience is very exciting and rewarding, but it is also extraordinarily demanding. You need to be able to brainstorm with someone and when you try something new in class, you need your partner there to tell you if it worked. Time will evaporate and you won’t be ready for the next class unless you get help. When you think you are ready for class, the computer will lock up or the file you wrote the night before won’t open or station six won’t print. It takes two to get out of these disasters, as well as to learn enough from them to avoid them later.

Kick over that lectern, get your buddy, and start paddling. The surf is up!

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