

Visual Physics

Proposal for Reform of First-Year Physics for Calculus-Based First-Year Physics

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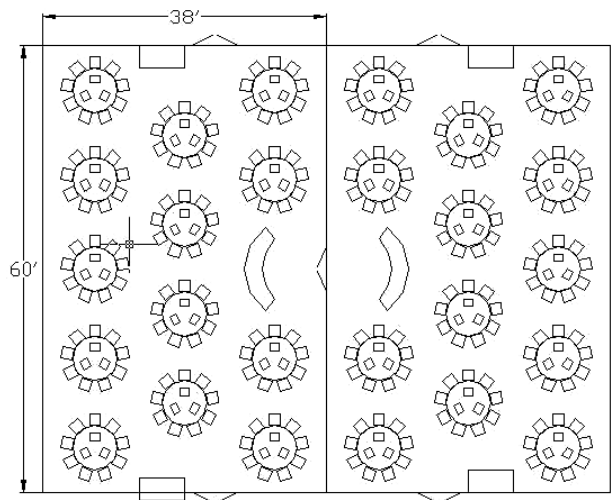
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A comprehensive reform of the first-year physics course for engineering and science majors is proposed. Visual Physics embraces a number of innovations¹ that build upon two decades of pedagogic research in how students learn physics and how best to address their conceptual and problem-solving road-blocks. The reform also integrates instruction in technical writing, for which the laboratory reports are the writing assignments. The lab reports are written in the genre of the short technical report, the most common mode of written communication in all of the engineering and science disciplines.

Highlights of the proposed reform are:

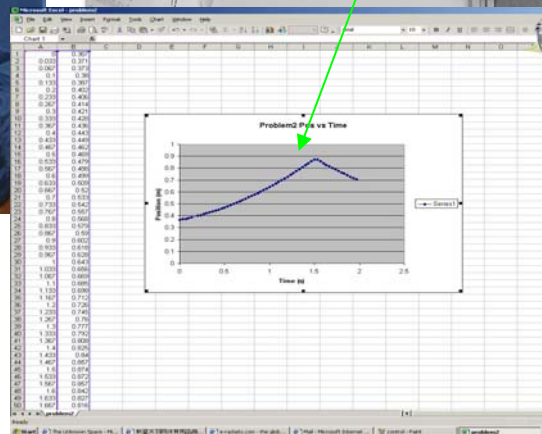
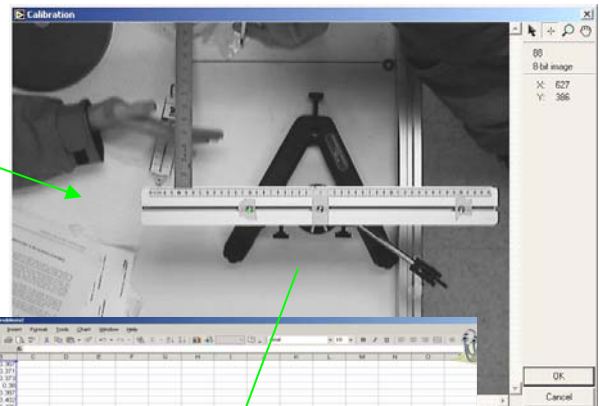
- The lecture and recitation are integrated in an interactive classroom, following the model of the SCALE-UP program². Students are seated at 9-person round tables, clustered around the lecture dais. Lecture is interspersed with problem-solving: the students attack a concept-rich problem in 3-person teams while the professor and teaching assistants circulate the room and help whenever a team stalls. This technique facilitates peer instruction and has been shown to be highly effective in building problem-solving skills.



- Laboratory experiments utilize appropriate technology to build skills of visualization and connection of physical phenomena to mathematical modeling. In the first semester (mechanics) experiments utilize a high-resolution video camera to record image streams of experiments in kinematics and dynamics. The images are ported onto a PC within LabView software that enables the students to precisely measure the frame-to-frame motion of an object within the experiment. The measurements of position and time are ported into an EXCEL spreadsheet in which the students construct a physics analysis of the motion.

Similarly in the second semester (electromagnetism) students perform a sequence of experiments in which they

- observe individual point-like particles (electrons) and measure their charge and mass;
 - measure action at a distance in classic experiments for gravity, electricity, and magnetism;
 - observe the line emission of light by atoms and the photoelectric effect in which photons liberate electrons from the surface of a metal;
 - construct and analyze simple circuits using electric and magnetic fields.
- Students work in 3-person teams in both lecture-recitation and labs. They learn to work in structured roles within a team, but each student writes an individual lab report on a distinct topic for each experiment.





- Technical writing instruction is given by a professional English instructor in weekly evening lectures. The lab reports constitute the writing assignments of the course. Reports are graded according to a structured rubric by both the physics teaching assistant (for physics content) and the technical writing team (for technical writing). Some of the reports are graded using calibrated peer review (CPR), in which the students actually grade one another's papers. An example report from late in the first semester is attached.

The technical writing instruction in the course would satisfy the Communication requirement within the Core Curriculum, replacing English 210 for this purpose. Instruction would be specific to the genres most widely used in science and engineering. It would complement the W-course requirements in which writing assignments are integrated with one or more upper-division courses to give students writing experience on topics specific to their majors.

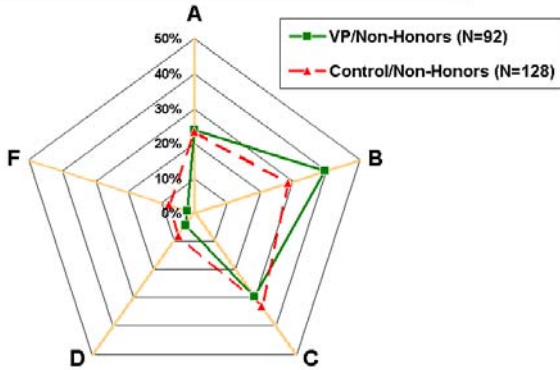
Assessment of Visual Physics

Visual Physics was first offered to the Honors students in Fall 2003 for Physics 218 and in Spring 2004 for Physics 208. After working through the many issues of technical implementation, TA training, and documentation, the development was expanded to include six sections of regular Physics 218. The sections were taken from those taught by three lecturing professors; in each case two sections had lab and recitation under VP while two other sections had lab and recitation using the traditional approach. We thus had an effective treatment/control structure that could support valid assessment.

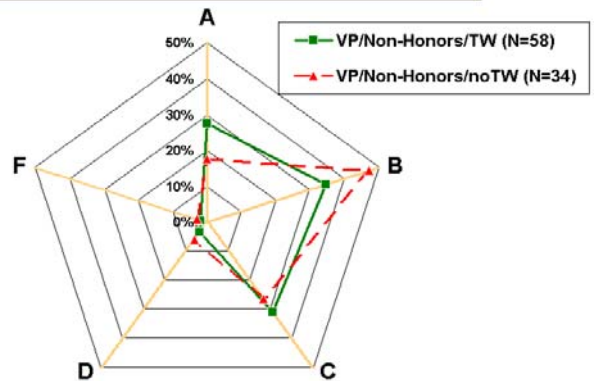
The assessment report³ presents details from the assessment. Highlights are as follows:

- VP adds a third of a letter grade in the final grade in the course.
- VP doubles the improvement in post- vs. pre- tests of conceptual learning (FCI).
- Technical writing of lab reports improves the students' performance on their *physics* exams. When a student must articulate what he has learned, it drives the understanding.
- The writing evaluation of the final lab reports was increased 50% for those students receiving writing instruction compared to those who did not.

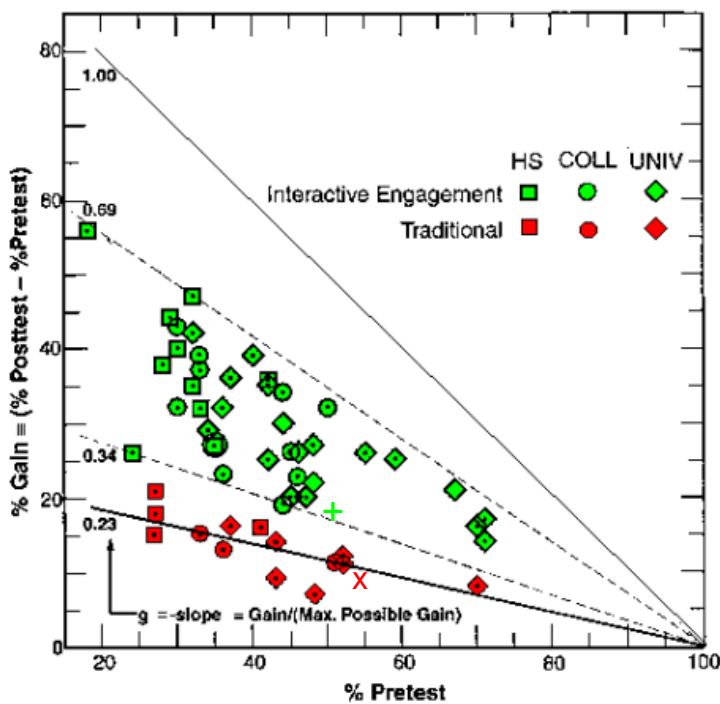
PHYS-218 (Fall 2003)
Letter Grade Distributions: VP vs. Control Groups
(Non-Honors)



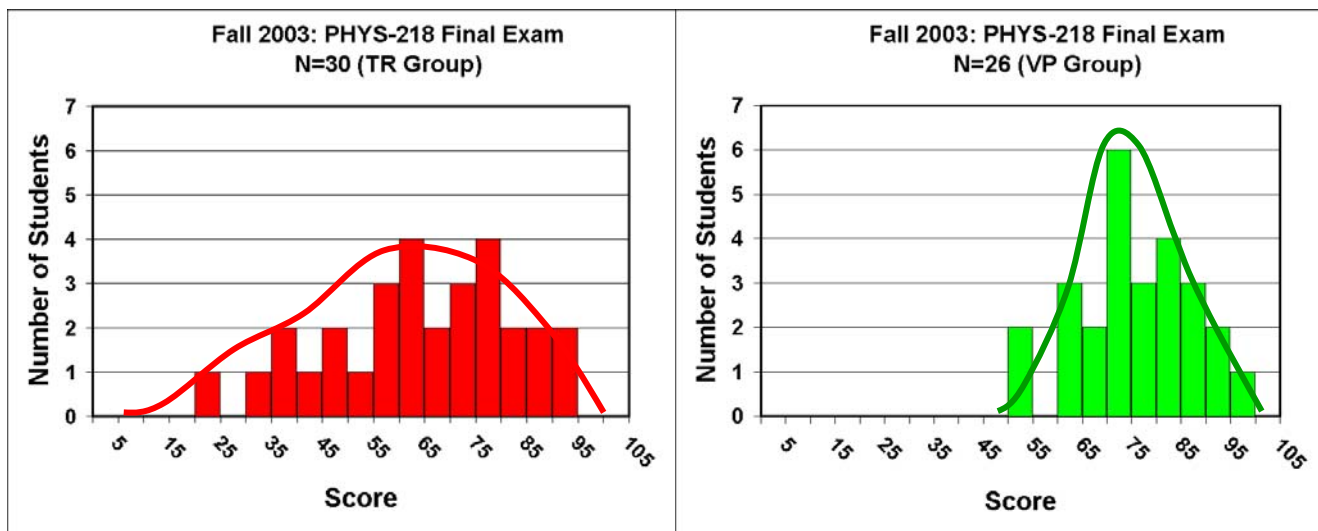
PHYS-218 (Fall 2003)
Letter Grade Distributions: TW vs. noTW Groups
(VP/Non-Honors)



Grade distributions comparing a) students in VP and traditional sections, b) VP sections with and without instruction in technical writing.



Pre/post improvement in performance on the Force Concept Inventory assessment: Texas A&M students are shown with + for VP sections and x for traditional sections. All other data give scores at high schools, 4-year colleges, and universities for traditional and interactive teaching methods.



The gains shown above have been made by bringing interactive strategies into the lab and recitation, but not into the lecture classroom. The more dramatic gains at some other universities benefited from the use of interactive engagement strategies in the classroom as well.

A remarkable impact of the VP approach is that it ‘leaves no student behind’. Shown above are grade distributions on the final exam for students under the traditional approach and for students taking Visual Physics. The grades in the traditional sections exhibit a bi-modal distribution that is all too familiar in technical courses. In effect there is a contingent of students who are basically engaged in the course and learning, and another contingent who are simply lost. In the VP sections the grades are consistent with a single normal distribution – essentially all of the students are engaged and learning.

Lessons that we learned and what we will do differently

Our greatest challenge in maintaining the vigor of interactive engagement in recitations was the teaching assistant. We devoted focused effort to the training and supervision of the TAs in the strategy and psychology of interactive engagement. We provided training in a one-week ‘boot camp’ before the semester began, we observed the TAs in practice, and we gave constructive feedback and further training in weekly ‘family meetings’ of the course staff. Even so there was a wide variability in the success of TAs in operating an interactive classroom.

We propose to address this limitation by taking the interactive engagement strategy into the classroom using the SCALE-UP design². The lectures will be delivered in a classroom that is configured so that each 3-student team sits together facing a PC as shown in Figure 2. The lecture is interspersed with team problems, which appear on the screen of each team. The teams have a fixed time to attack each problem; while they do so the professor, the TAs, and undergraduate peer instructors circulate the room. They try to spot when teams are ‘hung’ in their efforts to model and solve a problem, and help them off the sticking point. This approach produces maximum impact in building student understanding of both concepts and methods for modeling physical problems.

A second thing that we learned concerns the pacing of technical writing instruction. For practical reasons we concentrated instruction in technical writing entirely within Physics 218,

and for the follow-on Physics 208 we simply required students to write their reports in the genre that they had learned the previous semester. This had two problems: the students were overworked in writing 6 reports with the full rigor required for a short technical paper; and many deteriorated significantly during the following semester, indicating that they did not fully retain what they had learned about writing.

We plan to remedy these problems by pacing the technical writing instruction and grading through both courses, so that 4 reports will be rigorously graded by the writing team each semester and writing will be graded on the other reports using CPR.

Practical Implementation

In order to plan the implementation of the proposed reforms of Physics 218 and 208, let us summarize the logistics by which the course is currently taught. For Fall 2004 there are 41 sections of Physics 218 and 24 sections of Physics 208 (out of sequence). In Spring semester the numbers roughly reverse. Section size limit is 32, with a mean enrollment of ~30. A professor typically lectures to 4 sections (total 120 students) in an auditorium-style lecture hall. Such halls are inappropriate for implementing interactive engagement of student teams.

The techniques of interactive engagement and the VP labs cannot work effectively with such large sections. Studies of section size have found that 21 is optimum; we have found that we can work effectively with 24 students (8 teams). We therefore must accommodate a total of 50 sections of Physics 218 and 30 sections of Physics 208.

Each section's recitation is currently taught in the hour preceding its lab. Recitations are taught by TAs, and their workload is 3 sections. Recitations are held in small lecture rooms on the first floor of Heldenfels Hall. These rooms are un-usable for interactive engagement strategies. We propose to re-habilitate an existing building space to create two interactive classrooms, shown in Figure 2b. Each classroom would accommodate 13 round tables of 9 students each, a maximum of 127 students. We will assume a re-clustering of sections so that 5 24-student sections (120 students) share the same lecture and recitation.

Recitation for these 5 sections will be held during a one hour session each week; the recitation will either precede or follow a lecture time. Thus we require the same number of teaching faculty (10 in Physics 218, 6 in Physics 208 for Fall semester), but we require that each faculty member teaches one additional hour per week (under the present system recitation is taught by a TA, not by the faculty member). And we require 20% more graduate student TAs. The TA workload under VP is marginally greater because of the time required to prepare for the labs and the increased grading time for the lab reports; these considerations are offset in that the TA will be assisting the professor in the recitation for one hour each week, rather than leading three distinct recitations himself.

Scheduling

The following time schedules demonstrate that the VP lectures and recitations could be accommodated in a single lecture hall for each course (one for 218, one for 208), and the labs could be accommodated in the same three lab rooms that are presently used for fewer sections of

larger size. Note that while we will need to create two SCALE-UP classrooms, we will liberate a suite of 5 small recitation classrooms in Heldenfels Hall.

The technical writing instruction will be given in a one-hour weekly lecture/writing session. In order to accommodate the number of students taking the course and the various schedule conflicts that arise with an evening schedule, sessions of the same lecture will be given multiple times each week for each of the first- and second-semester technical writing programs. Eight lectures are scheduled in each of the two SCALE-UP classrooms, indicated by TW on the schedule below. Each student will be required to attend any one session each week. By using the SCALE-UP classroom to provide technical writing instruction, the students will benefit from the interactive methods used in the physics instruction.

Based upon the experience in teaching technical writing to the 150 students in the trial implementations, we project that it will require a team of 3 instructors and 12 TAs to provide the technical writing instruction and report grading for the total of 1900 students. Of these, two instructors and 8 TAs will teach writing in Physics 218, and one instructor and 4 TAs will teach in Physics 208. Just as we have built a sense of family among the entire team teaching the VP course, so we plan to develop a similar family amongst the team who are teaching and grading technical writing. We envisage recruiting TAs for technical writing not only from English graduate students but also from the ranks of engineering and science graduate students who have appropriate interests and/or abilities: at any given time several physics graduate students have career interests in physics education, and quite a few Indian graduate students in engineering are seeking TAs in physics. By teaming a few such students with a core of English instructors and graduate student TAs, we hope to build a solid core of writing instruction within the house of science and engineering.

The above schedule for Fall enrollment of Physics 218 shows accommodation of Visual Physics for 1200 students in one SCALE-UP lecture room and three labs. The parallel accommodation of 208 requires a second SCALE-UP classroom and two labs.

Laboratory schedule (3 lab rooms)					
Day	Time	Lab 1	Lab 2	Lab 3	Lab Prep
Monday	8:00-9:50	x	x	x	
	11:10-1:00	x	x	x	
	2:20-4:10	x	x	x	
	5:30-7:20	x	x	x	
Tuesday	8:00-9:50	x	x	x	
	11:10-1:00	x	x	x	
	2:20-4:10	x	x	x	
	5:30-7:20	x	x	x	
Wednesday	8:00-9:50		x	x	x
	11:10-1:00	x		x	x
	2:00-3:50	x	x		x
	4:40-6:30	x	x	x	
Thursday	8:00-9:50	x	x	x	
	11:10-1:00	x	x	x	
	2:20-4:10	x	x	x	
	5:30-7:20	x	x	x	
Friday	8:00-9:50	x	x	x	
	11:10-1:00	x	x	x	
	1:00-5:00				x

Lecture/rectitation scheduling (one SCALE-UP room)				
	Monday	Wednesday	Friday	
8:00-8:50	L1	L1	L1	
9:10-10:00	R1	R2	TW	
10:20-11:10	L2	L2	L2	
11:30-12:20	L3	L3	L3	
12:40-1:30	R3	TW	R4	
1:50-2:40	L4	L4	L4	
3:00-3:50	L5	L5	L5	
4:10-5:00	TW	R5	R6	
5:20-6:30	L6	L6	L6	
6:40-7:30	TW	TW		
	Tuesday	Thursday		
8:00-9:20	L7	L7		
9:30-10:20	R7	R8		
10:30-11:50	L8	L8		
12:00-1:20	L9	L9		
1:30-2:20	R9	R10		
2:30-3:50	L10	L10		
4:00-5:20	TW	TW		
5:30-6:20	L11	L11		
6:30-7:20	R11			

The role of Visual Physics in building technical writing competence

The integration of technical writing instruction into the curriculum of first-year physics is germane to the overall requirements for technical writing that pertain to all engineering and science majors. Currently most degree programs in these fields require students to either take English 210 or English 301 or complete a similar course elsewhere. The great majority of our students in fact satisfy the requirement in the latter manner, so that the fraction of them taking the TAMU courses is quite small. Unfortunately the result is that many of our students leave Texas A&M with a degree in science or engineering but with poor skills in writing, a handicap that costs them dearly in their future careers. The deficiency in communications skills has been identified as an important target in the college-level effort to improve the undergraduate degree programs in engineering.

By integrating technical writing into first-year physics at Texas A&M we have the opportunity to build writing competence at the *beginning* of each student's college years, and to provide a consistently high level of instruction to *all* students who take first-year physics within their degree program.

One question that was asked as we demanded this increased effort is whether it would detract from students' performance in their physics education, which is the primary objective of the course, or whether an increased effort would compromise their performance in other courses. The specifically physics education that is the primary objective of the course, or more broadly whether it would compromise their performance in their other courses. In our assessment we found that the added workload does increase the aggregate load on the students, but their performance in the physics course actually *improved*. The effort to articulate the modeling of their physics experiments is a material benefit to their learning the physics – which is of course why we do experiments in the course, but this it is only in Visual Physics that this benefit is realized. We therefore deduce that they are not compromised in their ability to carry the aggregate academic workload of their first year, at least as far as performance in physics is a measure.

Indeed, we propose a broader vision of teaching communication skills, essentially as a two-step process. The first step comes in freshman year with our instruction in freshman physics. Since there is no equivalent mode of instruction in field-relevant technical writing at other Texas colleges and universities, *all* students taking Physics 218/208 would be required to participate in the technical writing instruction (there would be no release from transfer credit). This serves the important function of establishing a discipline-specific base competence in all of our students in the degree programs that require Physics 218/208.

The second step comes with the W-courses, in which upper-division undergraduates take a writing-intensive course in or allied to their major field. Technical writing in VP builds an excellent foundation for the subsequent W-courses. The W-courses focus communications skills more specifically on modes of communication particular to that discipline, once a student has gained a sufficient knowledge base in his field to make that possible. We hope to demonstrate that this one-two punch offers an optimum strategy by which to realistically teach our students to write well.

Core Curriculum credit for technical writing

Learning how to write well takes time and teaching how to write costs salary funds. We propose that the technical writing instruction in Physics 218/208, taken together with the W-course, satisfies the Communication requirement in the Core Curriculum. We propose to keep the same 4 credit hours per semester, and to charge a Writing Fee (\$60/semester). As shown in the following cost analysis, this fee would fully fund the cost of providing technical writing instruction and expert grading of writing assignments.

The proposed technical writing instruction would come for most students in their freshman year, so that the improvement in their writing skills can benefit them through the rest of their college years. They will receive further experience in technical writing in upper-division W-courses in their major field. This two-step approach offers the best prospect to build a solid base of communication skills for all students.

Context of the proposed technical writing instruction with plans in the English Department

The Writing Programs Office in the English Department is currently pursuing a plan to consolidate and focus its service offerings in technical writing. They will continue to offer general writing instruction for entering students in English 104. Over the next two years, however, they plan to phase out English 210 and restructure English 301 as an online course in professional writing, in which all majors and minors seeking careers as technical writers and editors can get practice in a good range of skills needed in the kind of work they will do beyond the walls of the university. That course would also address the needs of majors in science and engineering who wish to hone their skills in writing for non-specialist audiences. The course would be perfect, for example, for students seeking careers as professional engineers and scientific advisors and trainers in government, industry, and education.

The model proposed in the new physics course fits into this plan nicely. It would provide closely guided instruction in the most basic specialized writing in science and engineering, provide a foundation for upper-division "W" course, and facilitate practice in a more appropriate genre and context than the more general course offered heretofore.

The Writing Center would play a valuable role in the proposed instruction. Students would be given the advice to use the Writing Center as a resource for mentoring and individual guidance in writing their lab report assignments. The Writing Center would provide a focused, low-stakes support base for students as they improve their writing abilities.

The importance of assessment, training, and pedagogic research

University faculty do not always accord value to pedagogic research, to assessment of the elements of an instructional program, and to training of teaching staff in the best techniques for successful instruction. A look at the measures of success on the national scene in science education, however, illustrates the central importance of these elements in building and sustaining an introductory science course that achieves in its students a high level of mastery of concepts and problem-solving skills.

A bitter truth is that we do not do this well here at Texas A&M. A second bitter truth is that, except for the notable work of Prof. Bob Clark (who left Texas A&M several years ago) we have never undertaken in our Department any systematic pedagogic research, any valid assessments, or any substantive training of faculty or TAs in effective teaching techniques.

Visual Physics undertakes to do all three. Provision is made in the requested budget for a science education professional who would work with our faculty to implement VP, to undertake further improvements that could make it work better or address problems that may arise, to train our faculty in interactive engagement strategy pertinent to VP, and to train the TAs that are key to its success.

Provision is also made to augment our lamentably minimum level of support for the teaching labs and demonstrations for the course. Our support of the lab program is inadequate to the more effective and energizing experiments that have been developed for VP.

Cost drivers for implementation

The obvious cost drivers for the proposed reforms are facilities and teaching personnel. The table above summarizes the one-time and annual costs associated with implementing Visual Physics for all 1,700 students/semester in Physics 218/208. The costs are considerable, although either two-thirds or all of the cost of technical writing instruction would be offset by the increased tuition paid by the students.

Conclusions

Visual Physics offers two immense benefits to all of the students who pass through Physics 218/208 (most of our engineering majors, ~20% of all Aggies!). First, it is markedly more successful in teaching them the concepts and problem-solving skills that they will need to succeed in their following courses. Second, it builds their writing skills at the beginning of their college years so that those skills will help them in their follow-on courses and of course throughout their careers. We submit that the cost of the proposed course reform is amply justified by those benefits.

#Classrooms	2	2		500,000	convert spaces to SCALE-UP
# Labs	5	5		300,000	convert 3 labs to VP
Physics faculty	16	18	2		each course has 1 coordinator; re-allocate within Dept.
Physics TAs	24	28	4	72,000	each course has 1 lead TA, 1 lab prep TA
Technical support	1	2	1	30,000	additional tech support staff
Assessment/development/training	0	1	1	40,000	ongoing assessment, development, and TA training
				800,000	142,000
Technical writing faculty	0	3	3	94,500	
Tech writing TAs	0	12	12	108,000	
				0	202,500
Student Writing Fee (1700 students, \$60/semester)					-204,000 fee revenue fully supports cost of writing instruction

References

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- D. W. Johnson, R. T. Johnson, and K. A. Smith, "Active Learning: Cooperation in the College Classroom." Edina, MN: Interaction Book Company (1998). This includes a review of cooperative learning literature which reports a student achievement gain of 0.88 standard deviation across many studies. Collaborative Learning is also described at URL: <http://www.wcer.wisc.edu/nise/cl1/cl/>
- R.R. Hake, "Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *American Journal of Physics* **66**, 64 (1998).
- ² <http://www.ncsu.edu/per/scaleup.html>
- ³ C. Ezrailson *et al.*, "Visual Physics: Implementing visual experiments and interactive learning recitations in first-year physics", <http://visual.physics.tamu.edu/Visual%20Physics.pdf>, journal paper in preparation.