Student-Centered Activities for Large-Enrollment University Physics (SCALE-UP)

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Abstract

The primary goal of the SCALE-UP Project is to establish a highly collaborative, hands-on, computer-rich, interactive learning environment in large-enrollment physics courses. We know from extensive educational research that students should collaborate on interesting tasks and be actively involved with the material they are learning. The physics department at North Carolina State University has had considerable success with small classes taught this way and is now searching for the best way to "scale-up" the innovations so that students taking our large enrollment engineering physics courses can benefit. We are folding together lecture and lab with multiple instructors in a way that should provide an economical alternative to traditional lecture-oriented instruction. The project involves the development, evaluation and dissemination of new curricular materials that will support this type of learning.

In comparisons to traditional instruction we have seen significantly improved performance in problem solving, increased conceptual understanding, improved attitude and much higher success rates for females and minorities. This was accomplished at little or no additional expense. Because of these successes, we believe the SCALE-UP Project has the potential to radically change the way science, engineering and mathematics are taught at large colleges and universities.

Project Status

There have been three phases to the SCALE-UP project. The first phase was conducted in a traditional lecture hall with long narrow tables and fixed seating. We are currently in our Phase 2 implementation in a renovated room that seats 54. Construction of a 99-seat Phase 3 classroom will commence soon. Preliminary blueprints for a new Physical Sciences Instructional Lab Building also include space for two SCALE-UP classrooms.

Project evaluation continues as a vital, on-going series of tasks. We have had a researcher in the room during nearly every class of the previous academic year, writing field notes and capturing the interactions between students and with the instructors. Videotapes of each class are recorded for further analysis. Interviews with individuals and focus groups have been conducted throughout the project. These are providing great insight into how this type of learning environment is affecting students. We are continuing our attitude surveys, additional standardized testing and comparisons to our department's traditional classes.

The project objectives are listed below, along with our progress toward meeting them.

1. Design new modes of instruction for large enrollment sections.

This objective concerns classroom management more than teaching materials. We are trying to develop techniques that will permit use of research-based pedagogies in large enrollment classes, even though many of these materials were originally created for small class settings. For example, we are trying different ways to utilize the tutorials developed by the PER group at the University of Washington. We have found that they must be broken up into short segments. Interspersing brief, classwide discussions makes sure everyone is spending a reasonable amount of time on each part of the activity and provides opportunities to address difficulties before any group gets too far behind.

Technology has been utilized as an organizer. Most course materials are available on the Web, including the syllabus, a calendar, daily activities and examples of notes and lab reports. WebAssign, NC State's Web-based problem delivery system, is used both during and outside of classtime to present questions and problems for consideration. To ensure that students read the textbook and are well prepared for class, we use the system to assign questions and problems that are due just as those topics come up for discussion in class. If this was not done it might be difficult to cover all the standard topics in the depth we feel is necessary. The students are responsible for independently learning simple definitions and straightforward concepts, so time in class can be spent grappling with the more difficult ideas. Java applets and simulations are a major part of our instructional methodology. While students work on these carefully constructed activities, the instructor and assistant are able to move about the room, asking and answering questions.

2. Create student "neighborhoods" within a large university.

The Phase I lecture hall setting was not particularly supportive of instructional student groups. Although long tables replaced the original "paddle-type" individual desks in the room, the fixed nature of the seating arrangement caused great difficulties. Students who wanted to avoid probing questions from the instructors simply had to sit in the center of the room, where they were mostly inaccessible.

The Phase 2 redesigned classroom (supporting 54 students) has been much more successful in establishing the kind of learning environment for which we had hoped. Students readily work in their own teams as well as in groups of nine. Each table of students seems to become its own little society and develops a unique personality. Students particularly enjoy having each table work on a problem and then sharing their efforts with the rest of the class using the whiteboards that surround the room. Of course, each individual student is responsible for all the problems, ensuring good questioning when something is not clear in a table's presentation to the rest of the class.

3. Experiment with classroom layout.

Teaching in the Phase 2 classroom has enabled us to further test classroom layout and management concerns. As noted above, we have been very pleased with the performance of the room in promoting active and collaborative learning. Figure 1 shows the room before renovation. It was a crowded, traditional classroom with 55 desks. Figure 2 illustrates the dramatic change in the appearance of the room, which now holds 54 chairs. Each 6-foot round table supports interactions between and within three teams of three students each, with each team sharing a laptop computer. The flexible seating allows students to arrange themselves for the most convenient working space. This is important because of the wide variety of activities they work on during class. Figure 3 shows students measuring the coefficient of friction between their books and the table surface. Note how they have placed themselves in different locations and have (rather precariously!) moved the laptop out of their way.

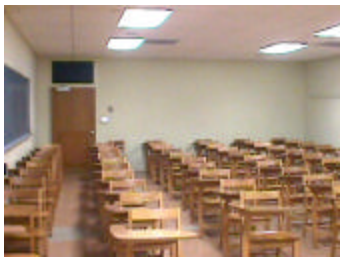

Figure 1. The Phase 2 SCALE-UP classroom before renovation, seating 55.

Figure 2. The Phase 2 SCALE-UP classroom after renovation, seating 54.

Figure 3. Students in a tangible activity, estimating the coefficient of friction between a book and the table top.

Figure 4. There is no "front" to the SCALE-UP classroom, as you can see by noting the students looking toward both ends of the room.

The technological components of the classroom have worked very well. We have had surprisingly few computer or networking problems. The projection system for the instructor's computer and the Elmo Visual Presenter have worked flawlessly. Students have no difficulty picking one of the two screens for convenient viewing (see Figure 4). All syllabus material and daily schedules are kept on the class Web site. The majority of the activities are there also. We have found that the laptop computers are an absolute requirement. In the pilot project (which utilized desktop computers) the monitors essentially eliminated within-table discussions by blocking lines of sight. Keeping the computers themselves below the tables reduced, but did not eliminate this problem. In addition, this stopgap measure meant that plugging in the computer interfacing equipment required crawling under the table to make the necessary connections. Switching to laptops has completely alleviated these difficulties. When the laptops are not needed or are causing a distraction, asking students to "close the lids" instantly removes the computers from the scene. We are strongly recommending to visitors that the extra cost of using laptops instead of desk computers is worth it. In comparisons with the Phase 1 classroom, we have also seen that continuous student access to computers is a vital part of the classroom environment. Basically, the technology provides a focus for the students, bringing their attention to bear on the physical phenomenon being examined, whether that study is conducted through data collection and analysis, constructing mathematical models, running a simulation or gathering other relevant information. This frees the instructor, who doesn't have to always be in front of the classroom but instead can move about and talk with the students.

4. Write instructional materials.

We have developed a large series of what we call "tangibles" (short hands-on activities) and "ponderables" (interesting questions to consider). Most of these tasks are based on known areas of student difficulty. In addition to developing our own activities, we are also modifying existing materials, such as the University of Washington Tutorials and Mazur's ConcepTests. As an effort to move these ideas into the "mainstream," some original materials have been incorporated into Serway and Beichner's *Physics for Scientists and Engineers*, 5th ed., as seen in Figure 5. This textbook and the accompanying instructor's manual and student guide also incorporate the GOAL problem-solving protocol that was utilized throughout the SCALE-UP curriculum. Figure 6 is from the text and describes the protocol. We have seen increased performance in problem solving compared to the traditional classes here at NCSU.

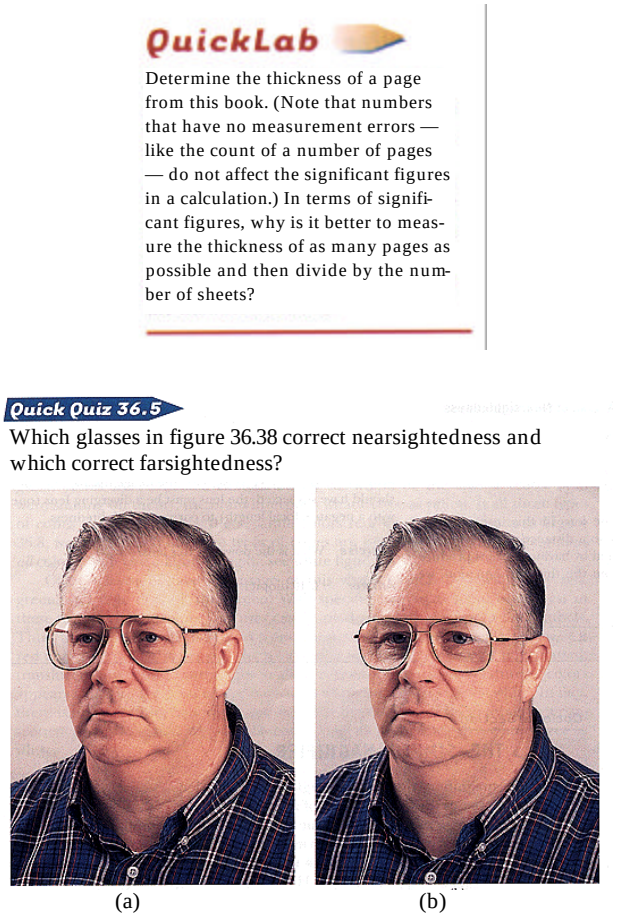

Figure 5. Examples of tangible and ponderable activities incorporated into Serway & Beichner, *Physics for Scientists and Engineers*, 5th ed. (2000) Philadelphia: Saunders.

Besides what you might expect to learn about physics concepts, a very valuable skill you should hope to take away from your physics course is the ability to solve complicated problems. The way physicists approach complex situations and break them down into manageable pieces is extremely useful. We have developed a memory aid to help you easily recall the steps required for successful problem solving. When working on problems, the secret is to keep your GOAL in mind!

GOAL Problem-Solving Steps

Gather information

The first thing to do when approaching a problem is to understand the situation. Carefully read the problem statement, looking for key phrases like "at rest" or "freely falls." What information is given? Exactly what is the question asking? Don't forget to gather information from your own experiences and common sense. What should a reasonable answer look like? You wouldn't expect to calculate the speed of an automobile to be 5×10^6 m/s. Do you know what units to expect? Are there any limiting cases you can consider? What happens when an angle approaches 0° or 90° or when a mass becomes huge or goes to zero? Also make sure you carefully study any drawings that accompany the problem.

Organize your approach

Once you have a really good idea of what the problem is about, you need to think about what to do next. Have you seen this type of question before? Being able to classify a problem can make it much easier to lay out a plan to solve it. You should almost always make a quick drawing of the situation. Label important events with circled letters. Indicate any known values, perhaps in a table or directly on your sketch.

Analyze the problem

Because you have already categorized the problem, it should not be too difficult to select relevant equations that apply to this type of situation. Use algebra (and calculus if necessary) to solve for the unknown variable in terms of what is given. Substitute in the appropriate numbers, calculate the result, and round it to the proper number of significant figures.

Learn from your efforts

This is the most important part. Examine your numerical answer. Does it meet your expectations from the first step? What about the algebraic form of the result-before you plugged in numbers? Does it make sense? (Try looking at the variables in it to see whether the answer would change in a physically meaningful way if they were drastically increased or decreased or even became zero.) Think about how this problem compares with others you have done. How was it similar? In what critical ways did it differ? Why was this problem assigned? You should have learned something by doing it. Can you figure out what?

When solving complex problems, you may need to identify a series of subproblems and apply the GOAL process to each. For very simple problems, you probably don't need GOAL at all. But when you are looking at a problem and you don't know what to do next, remember what the letters in GOAL stand for and use that as a guide.

Figure 6. The GOAL Problem-Solving protocol utilized in the SCALE-UP mechanics class and incorporated into Serway & Beichner, *Physics for Scientists and Engineers*.

In addition to the short tangible activities, we also have more extensive, group-based laboratory work that requires a formal report. Following suggestions from the collaborative learning literature, as part of their lab each individual examines the teamsmanship of themselves and their group mates. The quality of their evaluation is worth 10 percent of the lab grade. We also have created practical lab exams where each student must demonstrate every skill required for a lab. This has worked well to ensure that

everyone gets an opportunity to use all the equipment and thoroughly understand all parts of the lab. Thus individual accountability and group responsibility are built into each lab activity.

As time goes on, we are more fully utilizing WebAssign, our system for posing questions and problems over the Web for homework or to promote classroom discussion. Java applets appear to be especially promising in this regard. We are using many of the Physlets® developed by Wolfgang Christian at Davidson College. We hope to create our own video analysis applet and perhaps a Web-based simulation engine as well. The main advantage of this type of software is that it is readily available outside of class for student homework or review. Non-Web-based applications require multiple user licenses or else students must go to a special computer lab where the software is available. Web-based applications are available on any computer (including those in dorm rooms) that has an Internet connection.

5. Create teachers' guides.

We are taking the materials developed during the project and fitting them into a template that incorporates several important features, including objectives, known student difficulties, tasks to assign, reasons for assigning them and pitfalls to avoid. We will continue to develop and modify these as we complete additional classroom trials. There has been widespread interest in the curriculum and redesigned classroom space. We have had more than 30 visitors so far this year, including faculty from four foreign countries.

6. Improve student learning.

We have been looking at several different aspects of learning, including problem-solving, conceptual understanding, and even attitude development. We measured problem-solving skills by taking problems from the department's common examinations and giving them to the SCALE-UP students. In the previous fall semester, the SCALE-UP students outperformed their peers 88 percent of the time. During the next semester we looked more closely at specific types of problems. We found that the SCALE-UP students had higher scores on 20 of the 29 common problems selected for comparison. When the traditional students did better, the problems tended to be one-step problems like simple unit conversion.

Conceptual understanding in the mechanics course is also greatly enhanced. Results on the Force Concept Inventory (FCI) and the Force and Motion Conceptual Evaluation (FMCE) have been very encouraging. According to a study by Richard Hake, normalized gains on the FCI from pre-test to post-test for traditional mechanics classes average 23 percent. Our fall and spring semester mechanics classes averaged normalized gains of 43 percent and 50 percent, respectively. This compares very favorably with the most successful innovative classes around the country, which were typically smaller classes. The spring semester class also posted fractional gains on the FMCE, an alternative mechanics-concept test, which

were nearly four times higher than their peers in our traditional classes. We have not seen such successful outcomes in our electricity and magnetism course and are working to see if this is a problem with our measuring instruments or our instruction. Nationally normed assessment tools are not nearly as well developed for second semester topics and this may be influencing our results. We are participating in the beta testing of an electricity and magnetism concepts evaluation that may provide additional insight.

7. Improve student attitudes.

Results from focus groups and individual interviews have been quite encouraging. Students seem to genuinely enjoy the course and how they were taught, as illustrated in these quotes from transcribed audio tapes.

On the classroom design:

> *I can deal with the lecture class, it is just that I enjoy...getting more into the interactive projects. It is more hands-on. If you don't understand something you just ask the guy next to you, nobody yells at you for talking.*
>
> *…you have your professor right in the middle and you have a couple of guys spread out and you can flag them down—'Hey, can you answer this question for me?' In the lecture, you are sitting 100 rows back, 25 rows back, you really don't have anyone but the two people next to you and they don't know. You really don't have anyone with some knowledge to help you out.*

On what is learned in SCALE-UP:

> *I actually know how I learn through the SCALE-UP physics…through the way that it is set up, through the way they taught us by solving problems. It helped me to learn not so much to get an answer but to actually understand concepts. I also apply that to the rest of my classes. I think from now on, I will do a lot better in my classes just by taking this class—through all the teaching we learned how to solve problems and think through problems.*
>
> *I have studied for a test with some of the traditional 205 students and like they always point to the book for everything, like looking for a formula for everything. Dr. Beichner makes sure that we understand the concept, we can almost derive the formula for whatever we need. And we seem to understand more of the aspects of physics. I definitely feel that, compared to traditional, we have a more in-depth understanding and knowledge of what is going on.*

In addition to these individual and focus group interviews, we have been measuring student attitudes with the MPEX attitude survey that our

postdoc helped develop. This test not only examines attitudes about the content of the course, but also students' ideas about science and learning in general. The MPEX is evaluated in terms of an overall score and six subscales: Independence, Coherence, Concepts, Reality Link, Math Link and Effort. Previous MPEX studies found that even classes that show improvements in other areas show deterioration of their MPEX scores over time, particularly in the Effort subscale. Hence, little or no change is a good result. The MPEX scores for the spring semester mechanics class showed no significant change in four of the six subscales, resulting in no overall change. The exceptions were the Reality Link and Effort subscales. Both shifts are comparable to those observed for innovative curricula implemented at other schools. There was an impressive 1.5 standard deviation increase in the coherence subscale that looks at student belief in the coherence of physics knowledge.

8. Promote instructional reform.

As noted above, Beichner has been involved in rewriting a leading physics textbook. Some of the project's hands-on activities have found their way into the revision as "QuickLabs." Many ponderables will appear as a series of "Quick Quiz" questions embedded in the chapters. Beichner is on the steering committee of a national group working to promote the reform on undergraduate physics instruction. Team members have also given keynote presentations at the American Association of Physics Teacher's New Faculty Workshops. (We feel the work with new faculty is especially important because we can have the greatest impact on teachers who are still forming their own instructional styles.) We also continue giving talks and searching out schools interested in trying our instructional methods. Several of the graduate students involved in the project worked at nearby Duke University, helping them implement the University of Washington's Tutorials and even teaching several sections of their classes. Other team members provided teaching assistant training at Duke University. We continue to welcome visitors from both large and small institutions. Colloquia and talks at national conferences appear to be working well to stimulate interest in reforming instruction.

Conclusions

In summary, we are finding ways to maintain an active learning environment, even with large numbers of students. Collaboration is possible (and desirable) in these large classes and has many of the benefits seen in smaller classes. We have learned a great deal about the importance of careful design of classroom settings. Because we need to compare to the control group of our traditional students, we are constrained as to how much we can change the overall list of topics covered. Nonetheless, we have been able to add skills like note taking, group work, project planning, evaluation, presentation and practical lab skills to the more typical objectives of

an introductory physics course. We have continued to develop “tangibles” and “ponderables” and students seem to be learning substantially more than in traditional settings, both in terms of conceptual understanding and problem-solving ability. During the coming year we plan to develop materials that are especially aimed at helping students with varying learning styles. Other universities continue to be interested in our materials and we are organizing them for paper and Web distribution.

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