The Student Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) project. Part I: Incorporating active learning in large classes

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The primary goal of the SCALE-UP Project is to establish a highly collaborative, handson, computer-rich, interactive learning environment for large, introductory college courses. North Carolina State University, the University of Central Florida, and a group of collaborating schools are folding together lecture and lab with multiple instructors in a way that provides an effective, economical alternative to traditional lecture-oriented instruction. The project involves the development, evaluation, and dissemination of new curricular materials in physics and chemistry that will support this type of learning. Here we will focus on the calculus-based introductory physics part of the effort. The activities and findings constitute a snap shot of what was done during 1998-2001. In comparisons to traditional instruction we have seen significantly improved performance in problem solving, increased conceptual understanding, improved attitudes, and higher success rates for females and minorities. This article highlights the development of the SCALE-UP pedagogy, classroom environment, and teaching materials and gives examples of the kind of activities that the authors found useful.

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Introduction

"...I point to the following unwelcome truth: much as we might dislike the implications, research is showing that didactic exposition of abstract ideas and lines of reasoning (however engaging and lucid we might try to make them) to passive listeners yields pathetically thin results in learning and understanding–except in the very small percentage of students who are specially gifted in the field."¹

Students learn more physics in classes where they interact with faculty, collaborate with peers on interesting tasks, and are actively involved with the material they are learning.^{2 3 4 5 6} Research on learning and curriculum development has resulted in instructional materials that can correct many of the shortcomings of traditional physics instruction. Careful study of these research-based introductory curricula in small classes indicate that they can significantly improve students' conceptual understanding.^{2 7 8 9 10} Not unexpectedly, the most effective instruction is where all components of the course work tightly together towards the same goal. While great efforts can be made to try to synchronize teaching in different parts of a course (lecture, laboratory, recitation), we believe that integrating all components of the course into a single studio-style class is the surest way to achieve this.

Studio/workshop classes^{15 16} like SCALE-UP offer instructors another choice by replacing the lecture/laboratory format with 4-6 hours of activity-based instruction per week, typically in 2-hour blocks. Since the entire class is taught in the same room with the same students and instructors in each class, all activities, including laboratory experiments, can be arranged to build on one another in sequence for greater learning impact¹⁷ than when some activities are taught in small sections running parallel to the lecture course. When a lab section is taught as a separate course, it is often either weeks or at best a few days ahead of or behind the lecture. For some students, the lab course is not even taken in the same term as the lecture. In addition to better integration of lab experiments into the course, a studio format also allows for a greater variety of hands-on activities including microcomputer-based laboratory (MBL) and simulations since each student group can have access to a computer and lab equipment during any part of the course. Last, but not least, an effective studio class will take place in a room where the instructors can easily move around to interact with each group, identifying and helping students with difficulties, as well as ensuring that no student can avoid interacting with instructors by hiding in the middle of the row, away from the lecture hall aisles. In the studio format, instructors can interact with any group at any time.

There are several examples of workshop/studio-style¹⁸ curricula in the Physics Education Research (PER) literature¹⁹ including the Workshop Physics curriculum developed at Dickinson College⁸ and the Studio Physics curricula at RPI¹⁵ and Cal Poly San Luis Obispo.²⁰ These curricula have the advantages described above, but are difficult to implement at large research universities because of class size limitations. Workshop Physics is designed for 20-30 students per class and Studio Physics is hard to implement in classes of more than 50 students. Introductory physics instructors with large classes who want to incorporate active learning into their classrooms must typically choose between hands-on activities¹¹ in small class sections that supplement the lecture¹² (recitation or laboratory sections) and interactive lecture activities for larger classes like Peer Instruction^{3 13} and Interactive Lecture Demonstrations¹⁴ that do not permit hands-on experiments and limit faculty interactions with individual groups. The SCALE-UP project is an effort to create studio classes that would be large enough to provide an effective, yet affordable alternative to the standard lecture/laboratory format at large research universities.

The project has its roots in the NCSU IMPEC project (1993-1997), part of the NSF's SUCCEED coalition. Physics, chemistry, mathematics, and introductory engineering science were integrated into an experimental one-year sequence of studio courses.¹¹ Although the IMPEC classes were successful in minimizing attrition, improving student understanding of the course material and providing a positive learning experience for 36 students per year, the project was suspended because it was impractical²¹ to expand the program to more than a small fraction of the thousands of students entering the NC State Engineering program each year. The SCALE-UP project was started to see if we could take what has been learned from smaller studio classes and "scale up" studio instruction to a size that would be viable at large universities. The project's main goal is to develop techniques that permit use of research-based pedagogies in large-enrollment studio classes of up to 120 students, even though many of these materials were originally created for small class settings.

As with the other research-based curricula described above, in SCALE-UP classes the students work through activities in small groups of 3-4 students each. However, in SCALE-UP classes, both the activities and the classroom have been modified for larger student/faculty ratios of 25-33 to 1, which permits class sizes of 50-120 students with 2-3 instructors (faculty & TAs). Thus SCALE-UP makes it practical to offer activity-based classes with integrated hands-on labs even at schools like North Carolina State University (NCSU) and the University of Central Florida (UCF), where thousands of students are enrolled in the introductory physics classes each year. This format takes advantage of cooperative learning techniques and helps students form learning communities which can make education at large universities seem much less impersonal, particularly for students taking mainly large introductory classes in their freshman and sophomore years. Although SCALE-UP was developed for classes of 80-120 students, early dissemination efforts have resulted in successful implementations at six colleges and universities in classes ranging in size from 25 to 120 students. Another seven colleges and universities are in the process of implementing their SCALE-UP adoptions.

This paper will describe some of the changes we incorporated into the IMPEC physics curriculum, pedagogy and the classroom environment to facilitate active, collaborative learning in large classes at NCSU and UCF. Results of research on student learning and an evaluation of the project are described in a companion article.²²

Pedagogy

In SCALE-UP, textbook readings are used to replace the lecture as an introduction to the course material. Homework assignments due before the material is covered encourage students to be well prepared. Students come to class already acquainted with the material and are able to perform in-class activities at a higher level. While this is not guided inquiry since the students are introduced to new material through the readings, it does allow topic coverage comparable to regular lecture sections. Lecture is not eliminated, but is limited to substantially less than one hour per week, often given in 10 to 15 minute periods. We find that a formal discussion is still useful for organizing material, to motivate a topic, supplement the text, or to show applications of the topic.

A rich array of carefully developed and refined teaching materials have been created by many different physics education research groups^{3 6 7 12 23 24}. A substantial fraction of the SCALE-UP curriculum is based upon this work. In some cases very little needed to be done to utilize existing materials. For some of the lessons, considerable revision had to be carried out before the materials would work in a large classroom setting. For example, we tried different ways to utilize the excellent *Tutorials*¹² developed by the PER Group at the University of Washington. We found that in large classes the lessons must usually be broken up into 5 to15 minute segments interspersed with brief, class-wide discussions. This format 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 is used to provide a phenomenological focus for students, allowing data collection, analysis, mathematical modeling, microcomputer-based laboratories, video-based laboratories and advanced simulations. As student attention is drawn into analyzing different physical situations, teachers circulate around the room and engage students in semi-Socratic dialogs^{25, 26}. Lecturing is minimal and is used primarily for motivation and to provide an overview of topics. The use of *WebAssign*,²⁷ a web-based problem delivery and grading system, encourages students to review the textbook before attending class, provides much needed student practice of simple physics problems, allows for a follow-up in-class assignment to insure that every student has completed the task, and greatly reduces the amount of hand grading. This technology also facilitates in-class polling and permits students to conduct evaluations of each other's work.²⁸

Semi-Socratic dialogs, where students are asked to explain their thinking, are often used to help students resolve cognitive conflict. Because we believe the best learning is done while wrestling with ideas, we try to encourage students, even when they are wrong. If the class is working the way it is supposed to, students are willing to take risks and make mistakes. An interaction from class illustrates how this happens: The instructor approached a small group that was discussing the details of an electrical circuit they were working with. (The relative brightness of bulbs provided a qualitative measure of current as the circuit was modified.) Knowing that despite their own observations, some students might still be laboring under the common belief that current gets "used up" in circuit elements²⁹, the instructor asked about the current that flowed into and out of a particular light bulb. Although several students gave the correct answer (based on their observations), one of the students commented that less current leaves the bulb. Rather than simply saying, "No." or "That's wrong!", the instructor brought up an analogy that is often used to help students grasp circuit concepts. "Let's imagine we have water flowing in pipes and there are two gallons of water flowing into one end of a pipe every second. How much flows out the other end in one second?" As expected, the students all (the entire table was now involved) answer "Two gallons." The instructor replied, "Right! The same amount flows in as out. Would it work any differently for charges? If we have two Coulombs per second flowing into something, how much will come out the other side in one second? After the students answered correctly, the point was reinforced

by asking students to consider what would happen if there were fewer charges coming out than going in. They realized that an excess electrical charge would build up, and from their experience with the real circuit they knew that was not the case. Now that the students were where they needed to be, the instructor asked them for another name for 'Coulomb per second' to which several answered "Amps." They were congratulated for recognizing that the current out of a bulb had to equal the current flowing in. Then to complete indicating approval of their taking a risk at answering questions, the instructor commented that at first they might have been thinking of energy instead of charges. The energy that each Coulomb of charge carries out of the bulb is less than the energy associated with each Coulomb flowing in. "Where does the missing energy go?" The students quickly recognized that it ends up as light and heat from the bulb. The instructor ended the discussion by asking for the name given to "energy per charge" (electrical potential, measured in Volts). The instructor finally commented that what they have realized is that there must be a voltage drop across the bulb. During the conversation, the students who began with an incorrect idea about current flow came to understand it in everyday terms and saw the connection between current and energy in a circuit. This is an example of how a teacher in the SCALE-UP environment can start with a wrong answer from a student and turn it a positive learning experience for a group.

Activities

An outline of each day's class is usually presented on a single web page. This brief overview usually fits onto a single computer screen and provides students with an advance organizer³⁰ of the day's work. If a student wishes to review what was done in class, these pages are invaluable. A typical class is comprised of a series of different activities to build understanding on a single topic that actively involve the students in their learning. 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 difficulty¹⁹. In addition to these short activities, we have longer, more open-ended lab and problem solving activities.

Tangibles

Tangible activities typically present a physical situation that requires some form of observation and often data collection. These activities vary from qualitative observations of a bouncing ball to brief MBL experiments with data analysis in *Excel*. Short experiments tend to use the predict-observe-explain model to address student conceptual understanding. Quite often order of magnitude calculations are required and students are encouraged to make reasonable estimates of information they cannot conveniently measure. For example, groups are given a piece of paper with a pair of concentric quarter-circle arcs. Their task is to roll a racquetball through a curved path between the arcs. Students sometimes tip the paper or spin or blow on the ball to accomplish the task. They are asked why they need to do this (and references are made to Newton's Second Law.) Once they state that they are applying a force to the ball to change the direction of its motion, they are asked to specify the direction of the force. Socratic dialoging eventually results in the recognition that the force is always directed toward the center of the concentric arcs. They quickly recognize this as a centripetal force and then have to

approximate its magnitude from the mass of the ball and an estimate of its speed. Several more of these 10 to 15 minute activities are presented below:

Examples of "Tangible" Activities

1. "Find the thickness of a single page from your textbook. Use this result to find the diameter of a period at the end of a sentence in the book." Students invariably start by dividing the estimated or measured thickness of a large stack of the pages by the number of sheets of paper in the stack. Although they usually don't think of it in these terms until prompted, the reason for using many sheets at once is to increase the number of significant digits in the final answer. In a Socratic dialog, students are asked questions about why they tackled the problem as they did. (This is often done by having them consider what answers they would have gotten from a different approach). By recognizing for themselves how significant figures play a role in measurement, they are much more likely to continue to consider the uncertainty in their measurements throughout the course.

2. "Find the coefficient of kinetic friction between your book and the table." Here the students slide their books across the table, estimating initial velocity and measuring stopping distance.

3. "Determine the angular acceleration of a rotating racquetball as it spins to a stop on your table." or "What is the impulse that the floor applies to a bouncing racquetball?" These types of very brief activities help students build an intuitive understanding of otherwise abstract concepts.

4. "Find the number of excess charges on a piece of tape pulled off the table." This exercise, adapted from Chabay and Sherwood's textbook³¹ always prompts discussion as students compare the different answers written on the whiteboards surrounding the room.

5. "Use a laser pointer to determine the thickness of a single hair from your head" (or the spacing of the tracks on a CD). In what is essentially a mini-lab, students spend a few minutes deciding how they will approach the problem, making measurements, and sharing their results with others.

Ponderables

There are times when considering certain questions is very enlightening, even though making measurements is impractical. Mazur's ConcepTests³ are a prime example of this pedagogy using short, multiple-choice questions. We also utilize McDermott's *Tutorials*¹² for qualitative elicit-confront-resolve activities to address student conceptual understanding as well as problems that require numerical answers so that students can see others' results and challenge their approaches. Several ponderables are listed below:

Examples of "Ponderable" Activities

1. "How many two-step paces is it across the US?" This activity is done the first day of class as an individual effort. After reporting the wide-ranging answers, students work in ad hoc groups to answer the same question. They are surprised to discover that the range of answers is much smaller, often within the same order of magnitude. This provides an opportunity to discuss the benefits of working in teams, as well as scientific notation, estimations, units, and standards. (The mile was originally defined as 1000 paces of a Roman Centurion.) Some students on their own initiative have started using route-mapping software on the Internet to make very accurate determinations of the distance.

2. "How far does a bowling ball travel down the lane before it stops skidding and is only rolling?" This is a very difficult problem and requires a lot of estimation. The insight students gain into what happens to the frictional force when skidding stops and pure rolling begins makes it worth the effort. An *Interactive Physics* simulation provided for the students gives them confidence in their answers.

3. "Design a car radio antenna optimized for your favorite FM station." This type of activity makes it easy for students to see how physics is involved in their everyday lives. It certainly is not difficult to get students involved in the problem when they have a chance to debate the merits of different radio stations! More than one student has come back to class the next day having made a measurement on their car that verifies their earlier calculation.

In all the activities, the underlying question is "Why are we doing this?" or "What am I supposed to learn from this?" At the end of a task, we will often stop class for a minute or two while students add comments to their notes that specifically address these questions. Having students explicitly deal with these questions is a basic component of the SCALE-UP curriculum.

Labs

In addition to the short tangible activities, at NCSU we have more extensive, groupbased laboratory work that requires a formal report. Equipment for the labs is kept nearby so that students can gather what they decide they need. Following suggestions from the cooperative learning literature³², as part of some labs each individual examines the teamsmanship of themselves and their group mates. The quality of the justifications given in their evaluations is worth 10% of the lab grade. We also have created practical lab exams where each student must demonstrate key skills required for the labs. This insures that everyone gets an opportunity to use the equipment and learn how to take an analyze data. Individual accountability and group responsibility (critical components for successful cooperative learning) are built into the lab activity. Because of the active nature of the classes, we do not rely exclusively on the labs to provide hands-on experience with physical phenomena. This allows us to focus some attention on hypothesis generation, student design of data collection,³³ and uncertainty considerations (how can you tell if one number is different from another). We increase our expectations during the semester instead of expecting students to know how to write a complete, detailed report right from the start. By the end of the course, the reports are often extensive, following the style of scientific and engineering articles.

Real World Problems

Some of us have also adapted a problem-solving activity called Real World Problem Solving based on the Cooperative Group Problem Solving (CGPS) approach^{9, 34} developed by the Physics Education Group at the University of Minnesota. Like CGPS, Real World Problem Solving uses a problem-solving protocol based on the work of Polya.³⁵ The protocol is represented by the acronym GOAL: Gather information, Organize and plan, perform the Analysis, and Learn from your efforts. Some of our Real World Problems are modified from the Context Rich Problems created by the Minnesota group, others we have created in-house. In every case we are trying to give students challenging problems that are best solved by working in groups and following a problemsolving protocol. Several examples of Real World Problems are given below.

Examples of Real World Problems

Some involve student interests:

1. You are at a Durham Bulls baseball game, waiting for another home run by the Bulls so you can see the giant "bull board" flash its red eyes, blow smoke through its nose, and swing its tail. You have been watching the digital display that shows the speed of each pitch as measured by the radar gun behind the catcher. Now you wonder how fast the ball travels off the bat when one of the players hits a home run over the 8-foot outfield wall. You notice the distance markers at the end of the left, center, and right-field lines: respectively 305, 326, and 400. With this information, you realize that you can use the physics you have learned to answer your own question.

Some relate to technical jobs:

2. You have a job with a semiconductor processing lab that uses MBE (molecular beam epitaxy) to make transistors and other multi-layer electronic devices. A quartz crystal oscillator is used to measure the thickness of a thin film being deposited on a sample in the vacuum chamber. The crystal monitor is vibrated by a frequency generator and operates essentially like a mass on a spring so that the 6 MHz characteristic resonant frequency of the crystal is reduced as more material is deposited on its surface, which is exposed to the same conditions as the sample. The crystal has an exposed diameter of about 1 cm and a mass of about 0.1 g. The digital display for the instrument shows 4 digits. What is the resolution (smallest change in thickness) of this instrument? (Hint: How does a change in mass correspond to a change in the frequency of oscillation?)

Some are just fun:

3. You are a technical advisor to the Dave Letterman Show. Your task is to design a circus stunt in which Super Dave Osbourne, who weighs 170 pounds, is shot out of a cannon that is elevated 40 degrees from the horizontal. The "cannon" is actually a 3-foot diameter tube that uses a stiff spring and a puff of smoke rather than an explosive to launch Super Dave. According to the manufacturer, the spring constant of the cannon is 1800 N/m. A motor compresses the spring until its free end is level with the bottom of the cannon tube, which is 5 feet above the ground. A small seat is attached to the free end of the spring for Super Dave to sit on. When the spring is released, it extends 9 feet up the tube. Neither the seat nor the chair touches the sides of the 12-foot long tube. After a drum roll, the spring is released and Super Dave will fly through the air amidst sound effects and smoke. There is a giant airbag 3-feet thick and 10 feet in diameter for Super Dave to land on. Where should this airbag be placed for a safe landing?

4. Super Dave has just returned from the hospital where he spent a week convalescing from injuries incurred when he was "shot" out of a cannon to land on an airbag which was too thin and improperly placed for a safe landing. Undaunted, he decides to celebrate his return with a new stunt. He intends to jump off a 100-foot tall tower with a bungee cord tied to one ankle, and the other end tied to the top of the tower. This elastic cord is very light but very strong and stretches with a linear spring force so that it can stop him without pulling his leg off. For dramatic effect, Dave wants to be in free fall as long as possible, but you know that his maximum acceleration should not exceed 5g for his own safety. You have been assigned to purchase the cord for the stunt, so you must determine how long the bungee cord should be and the elastic force constant that characterizes the cord. Before the calculation, you carefully measure Dave's height to be 6.0 ft and his weight to be 170 lbs.

Homework

We take full advantage of the *WebAssign* homework delivery system.²⁷ A principle benefit of this technology is that it persuades students to prepare in advance for class and motivates students to keep up with the class material. By asking students to do a few straightforward problems before coming to class, we ensure that most of them have read the textbook. This allows us to focus the activities on areas of difficulty rather than spending valuable class time on the basics. This is critical since we have found that active learning usually takes longer than simple lecturing. Even so, by using reading quizzes, SCALE-UP topic coverage parallels that of the traditional lecture sections.

We also use *WebAssign* for follow-up homework, too. Because we put so much emphasis on a systematic approach to solving problems, we sometimes collect written solutions to the homework assignments. *WebAssign* ensures that everyone completes the problems. So that we do not have to grade stacks of papers, homework is randomly selected by the rolling of a 12-sided die. The selected random table hands in their detailed

solutions or other assigned work. Thus all the students have to be thorough in their work, but only nine papers need grading. A similar scheme allows some of us to check the quality of the class notes. This has worked so well for some instructors that within a few weeks students are asking to hand in their notes because they know they have done such a good job on them.

After students complete a Ponderable or Tangible activity, many concepts are still just partially formed. It is useful to bring the activity to closure. One way that has proven to get all of the students involved is to have an "in-class" assignment in *WebAssign*. This assignment is short, asks specific questions that are directly related to the activity. The format of the questions is varied to keep students motivated. Computerized answer checking is turned off so students will discuss their approach in solving the exercises. This produces lively discussions at a table as students are arguing why their answer has to be correct. To keep students from jumping ahead and completing these assignments before class, students are unable to access an in-class assignment until the instructor has given them the password.

We occasionally use *WebAssign* during class to poll students and have also experimented with some novel uses like having students rank the quality of each others' essay answers to conceptual questions²⁸. In addition to *WebAssign*, some classes have also made use of paper and pencil conceptual homework from Knight's workbook that accompanies *Physics: A Contemporary Perspective*³⁶.

Scheduling and Staffing

Although we had to match the overall contact hours of our traditional course offerings (five hours per week at NCSU and six hours per week at UCF), the SCALE-UP class combines the lecture and lab times together. At NCSU, the class meets on Mondays and Wednesdays for two hours, with a short break in the middle of class, and Fridays for one hour. On Mondays and Wednesdays, a graduate teaching assistant and sometimes an undergraduate assistant join the lead faculty member in the 99-student classes. On Fridays, the two assistants give guizzes, go over homework, and occasionally guide students through short activities. In smaller classes (up to 54 students) we were able to have students present their solutions to Real World Problems on guiz days. Since our lecturers normally have only three contact hours per week, asking them to come to all five or six hours of SCALE-UP classes seemed excessively demanding. Instead, the faculty members do not come to class on Fridays. In exchange for the extra hour per week of teaching, they get extra flexibility for research, travel, or other work during the latter half of the week. At UCF, the 80-student class meets for 2 hours Monday, Wednesday, and Friday. On Mondays and Wednesdays the lead faculty member is joined by two graduate teaching assistants. On most Fridays the class is run by the TAs, sometimes joined by an undergraduate TA). Friday's are used for weekly guizzes and Real World Problem Solving, including student presentations.

Collaborative Grouping

Since many of our activities are open-ended, we have taken a number of steps to promote successful groups. The three group members are carefully chosen (based on a variety of criteria, such as pretests, GPA, gender, age, major). We attempt to make each team heterogeneous in academic background, but with the same <u>average</u> ability as all the other groups. Early in the semester, students receive brief training in group functioning and create their own contracts of responsibility. We have a protocol so that teams can "fire" lazy group members. Some of the assigned tasks are simply too difficult to tackle individually, so students avoid being fired. In the six years of this project and its precursor studies, only a few groups have had to fire a member. Some instructors encourage students at the other end of the spectrum–those who would feel "held back" by the rest of their classmates–to participate through the offering of teamsmanship bonus points on exams. If the team average on any given test is at B level or better, each team member has 5 points added to their score. Thus it is in the best interest of the top students to teach the others in their group.

According to Johnson, Johnson, and Smith³², there are a few absolutely critical characteristics of successful cooperative learning. The five defining aspects are:

- 1. *Positive interdependence*. Team members have to rely upon one another and benefit from working together.
- 2. *Individual accountability*. Each member is responsible for doing his or her own fair share of the work and for mastering all the material.
- 3. *Face-to-face interaction*. Some or all of the group effort must be spent with members working together.
- 4. *Appropriate use of interpersonal skills*. Members must receive instruction and then practice leadership, decision-making, communication, and conflict management.
- 5. *Regular self-assessment of group functioning*. Groups need to evaluate how well their team is functioning, where they could improve, and what they should do differently in the future.

By the nature of how the SCALE-UP classes function, most of these aspects are intrinsically a part of the way students interact in the class.

Classroom Environment

A great deal of effort went into designing, testing, and modifying the classroom space. There were three separate phases to the process. Figures 1 through 4 show how the development of the room evolved between 1997-2001 at NCSU. Phase 1 was located in a fairly traditional lecture hall (see Figure 1). The paddle-top seats were replaced with long, narrow tables and fixed chairs. This was far from ideal, but allowed us to see what the possibilities and limitations of the space might be. In this classroom we were not able to utilize student computers, but students were assigned to groups and they could do simple "string and sticky tape" activities. Nonetheless, we were not satisfied with the room. Students could not easily share their work with the class and if students did not want to interact with the instructors, they would sit in the center of the room where they were nearly inaccessible. The experienced instructor who taught in this room felt frustrated because of the inability to control a large number of students doing activities without being able to make contact with each student individually. The second and third phases involved a specially designed room layout to create a multimedia, collaborative classroom that can be used for group activities with or without the computer, class discussions, and laboratory experiments. These rooms include additional features to encourage collaboration and allow students access to multimedia technology (see the accompanying article²² for more details). Figure 2 shows the Phase II room before renovation. It was a crowded, traditional classroom with 55 desks. Figure 3 shows the dramatic change in the appearance of the room after renovation, which now holds 54 chairs. Each 6' 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



Figure 1. The Phase I SCALE-UP classroom, a lecture hall with long tables.

Figure 2. The Phase II classroom, seating 55 before renovation.



Figure 3. The Phase II SCALE-UP classroom, seating 54 after renovation.



Figure 4. The Phase III classroom, seating 99 students.

important because of the wide variety of activities they work on during class. We utilize the tables as an organizational system. Each table is numbered and each group at a table is assigned the letter A, B or C. This allows a single table to be selected to turn in homework, present their work, or be assigned part of a task. Similarly, asking all the "B" groups to work on something disperses the effort across the entire room. Paper collection and distribution is greatly facilitated by maintaining the table-level grouping.

Figure 4 shows the Phase III classroom for 99 students. For larger rooms like this one, 7' round tables provide more workspace for each student group. During the IMPEC project, 9 and 10' tables had more space for students to work and interact, but were found to be too large to be placed into normal-sized classrooms.

Tables must be placed so that instructors can freely circulate between them. Laptop computers are preferred, even though they are more expensive than desktop units. Laptops take up a minimum of desk space and can easily be moved out of the way when not needed. Also, unlike desktop computers or even desktop LCD monitors, laptops don't obstruct sightlines and are easy to talk over so they don't isolate a group from the rest of the table. In addition, with laptops, the instructor can tell the class to put the "lids down" at times when attention should not be diverted by sending instant messages or web surfing. (Note that there are additional laptops visible in Figure 4 because other classes use the room. Most instructors agree with our original recommendation of only one laptop per group of three students. Sharing key resources promotes group cohesion. Other instructors note that one computer for each student is ideal if you give individual in-class assignments, quizzes, and tests. There are activities that can utilize more than one computer per group, such as taking data and analyzing it at the same time. Also, spare computers are handy when a laptop breaks down.)

The redesigned classrooms have been successful in establishing the desired learning environment. Students readily work in their own teams of three as well as in table-sized 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 by either using the whiteboards that surround the room or by presenting from handheld whiteboards shared within each group. Each student has a nametag (which are color-coded by table for easy distribution) so that no one is anonymous, even in a room with 99 students. One of the strongest reasons that students give for preferring a SCALE-UP class is the ability to work and get to know others in the class. Often students say that SCALE-UP is their favorite class.

One piece of equipment that has proven surprisingly valuable is a wireless microphone. Because of the long, narrow shape of the Phase III room at NCSU, an instructor at one end of the room is often ignored by groups at the opposite end who are concentrating on an engaging activity. With a wireless microphone, the instructor's voice is not localized and everyone stops to see what the instructor wants since he or she could be nearby.

Grading

To encourage students to work together, grades are not curved (norm-based grading), but based on the achievement of well-specified objectives that are made available to the students (criterion-based grading). Curving tends to discourage student collaboration since someone has to do poorly for someone else to get an "A." At NCSU, we also use a carefully crafted grading rubric for lab reports. This ensures objective grading and also gives the students insight into what should be present in high quality

work. Points can be earned through a variety of means, including tests, quizzes, homework, lab reports, and class notes. Homework is weighted heavier than normal (20-25%) to encourage students to put in the effort to do it. Peer pressure is quite effective at maintaining average attendance rates at well above 90%, even though attending class is not a course requirement.

Technology Supporting Pedagogy

Technology is used both as a learning tool and a course organizer. Nearly all materials are available on the web, including the syllabus, a calendar, daily activities, and examples of notes and lab reports. As mentioned earlier, *WebAssign* is used both during and outside of class time to present questions and problems for consideration. Java applets and simulations are a major part of our instructional methodology. While students work on these purposely constructed activities, the instructor and assistants are able to move about the room, asking and answering questions in a semi-Socratic style. The technological components of the classroom have worked well. We have had surprisingly few computer or networking problems. The ceiling-mounted projectors and the document viewer (essentially a video camera on a stand) have worked flawlessly. We can even aim the viewer's camera at the whiteboards, zooming in for better display of student work.

The technology used in the SCALE-UP classroom 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 instructors to interact with the students since they do not have to always be "on stage" in front of the classroom.

Dissemination

Instructor Materials

In an effort to move these ideas into the "mainstream," some original SCALE-UP materials have been incorporated into Serway and Beichner's *Physics for Scientists and Engineers*³⁷. The tangibles are called "QuickLabs" while the ponderables take the form of a series of "Quick Quiz" questions. The textbook and the accompanying *Instructor's Manual* and *Student Guide* also incorporate the GOAL problem solving protocol that is utilized throughout the SCALE-UP curriculum.

In addition, we are creating a large body of detailed lesson plans. (An example is in the appendix.) Eventually each activity will be described in a step-by-step document with information on timing, objectives, known areas of student difficulty, etc. Associated computer files, student handouts, suggested equipment lists, etc. are described in the lesson plans. We also provide guidelines for collaborative grouping, problem-solving suggestions, grading rubrics, and other materials that are of interest to faculty using the SCALE-UP approach. Materials are continuing to be developed, tested, and modified. As more schools adopt active learning pedagogies, we hope to add their materials to the collection. A database of the instructional materials developed to date is available online³⁸. All of the questions associated with labs, in-class activities, quizzes, tests used in *WebAssign* are available for other teachers.

Visits and Workshops

We have had more than 40 visitors each academic year, including faculty from many foreign countries. Members of the project staff have given many colloquia as well as consulted with architects and planning teams at other institutions. We have given half-day introductory workshops at several AAPT meetings and also presented two-day workshops for faculty from adopting schools. As a result of our dissemination efforts, thirteen colleges and universities have or are in the process of adopting SCALE-UP for their introductory physics classes. (More details on SCALE-UP adoptions can be found in the accompanying paper²².)

Expansion into other areas

Efforts are underway at NC State to apply the SCALE-UP pedagogy to large enrollment chemistry classes. Students work with very tiny quantities of materials ("microchemistry") during many of the tangible activities. At UCF, a collaboration of physics and education faculty are applying SCALE-UP methods to physics and physical science classes for pre-service and in-service K-12 teachers. Western Kentucky University is teaching algebra-based physics. Plans to expand into mathematics and engineering courses are progressing at several schools.

Conclusion

In summary, we found 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 needed to compare to the control group of our traditional students, we were constrained as to how much we could 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, without reducing topic coverage. Students are learning substantially more than in traditional settings, both in terms of conceptual understanding and problem solving ability. Other universities are interested in our curriculum and learning environment and we have established a website for materials distribution. Details of the learning assessment effort and members of the collaboration are described in the second part of this article²².

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courses to keep the separate courses tightly integrated. They believed it would be difficult to find many other faculty willing to invest the time and energy required.

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Appendix Bouncing Ball

Students have a great deal of difficulty making the connection between motion events and the graphs representing that motion. The purpose of this exercise is to help students make that connection and see an example of the strengths and shortcomings of *Interactive Physics* simulation software.

Objectives:

After completing this exercise, students should be able to sketch graphs of position, velocity, and acceleration versus time when they are presented with a simple motion event. They will recognize the relationships between these graphs and be able to produce either of the other two graphs when given one of them. They will also be able to create simple simulations using *Interactive Physics*.

Misconceptions:

Students have a great deal of difficulty interpreting kinematics graphs. They can often construct graphs from data points, but don't really know what those graphs represent. The most common mistake is called the "graph as picture" error. They expect graphs to be similar to a photographic representation of the motion event. Basically they believe all kinematics graphs will look like a graph of y vs. x. Making the transition from an abscissa of x to one of t is a very subtle point that we often skip over.

Task	Reason	Notes
1. Drop a racquetball from rest, let it bounce three times, and catch it. Have each individual write down as thorough a description of the motion as they can, using words.	Eventually we want them to see how compact, yet complete graphs can be. They allow trends to be seen without obscuring the details.	Warn students that "gravity" and "force" are not allowed words since they haven't been covered yet.
2. Have a few people read what they wrote. Discuss the motion as a large group.	We want them to thoroughly examine the motion situation.	Make sure everyone hears what is said. You will probably have to repeat it.
3. Have students follow along while you (and they) create a ball with IP and run the simulation. Ask where is it going slowly, where is it going fastest, does it rebound to the same height each time, etc.	See if they recognize that it is accelerating.	Stress the similarity to a graphics package. Show them what is different by having them run the simulation and watching the ball fall.
4. Ask how one would simulate the bouncing ball. Someone will probably suggest that you draw a floor somehow. Have them use the rectangle tool to do just that. Ask the students to predict what will happen when they run the simulation this time. They'll quickly see the need for the anchor tool, so show it to them. Now they will have a good simulation of the bouncing racquetball.	If you like, you can discuss the equal accelerations of the ball and the rectangle before it is anchored.	Note: watch out for students going off and trying all kinds of strange things. In fact, if you suspect that this will be a problem, specifically assign two minutes to drawing whatever they want, just to get it out of their systems. Tell them to stay away from the menus for the time being.

5. After telling them to just watch, create a graph of vertical position vs. time, but don't run the simulation. Ask student groups to sketch their predictions of the graph shape. Circulate and when you see that a group has made a reasonable guess, have them draw it on the board. Then give that group permission to have <i>IP</i> create the graph . Continue until all groups are done.	Building their interest.	Don't take too much time or the faster groups will get bored or be distracted.
6. Resize your <i>IP</i> graph so that the vertical axis directly corresponds with the vertical motion of the ball. This will help them make the connection between the motion and the graph. Compare to the graphs on the board.	Talk about differences between the graphs in terms of the motion they describe. Ask them what a graph of <i>y</i> vs. <i>x</i> would look like. (Just a vertical line.)	Just about everyone will have noted that the ball does not go as high after each bounce. You will probably see some with cusps representing the times when the ball hits the floor, others will look like sine waves. (The only real difference is the time scale of the bounce itself.)
7. Ask about whether the bounces happen at uniform intervals . Listen for a student suggesting that you let it bounce many times the ball is in the air for shorter and shorter intervals. Actually let the ball bounce and have students listen for the sound of the bounces. Tell the students to carefully sketch the correct graph onto their paper, taking special care to account for the details you have discussed.	They are learning to be careful observers.	Be sure to look at their work. Many will be sloppy and not attend to the important little differences that are so important.
8. Now ask them to predict what a graph of vertical velocity versus time would look like. This will be much more difficult for them than the first graph. Have the four groups at each table compare their work. If you can, bring the entire class to consensus about the shape of the graph.	We are trying to get them away from thinking of the graph as a photograph.	There will often be at least one student who is close at each table. A very common mistake is to think that the graph will look like a series of "V" shapes. Lead them through a discussion of the meaning of that type of graph. You may need to "manufacture" some numbers for the vertical axis to make it more real.
9. Have everyone create the IP graph and compare to their prediction. Create your own graph and carefully align it so that its time axis with the position graph.	Make the connection between the two kinematics graphs.	Step through the simulation and discuss the bouncing points and the maximum height points. Ask what the slope of the position graph represents, if they haven't used this fact to determine the velocity graph. Show how the varying slope of the position graph shows up as varying velocities on that graph.
10. Ask what the slope of the velocity graph should be. Most will now see that it is the acceleration due to gravity.	Start connecting to the acceleration graph.	This seems to be fairly straightforward for them.
11. Ask them to predict the acceleration graph. Have them create it and compare to their expectations.	To understand the acceleration graph, to build confidence in their abilities, and to recognize limitations of the simulation engine.	They will be quite confident at this point and will very surprised when the simulation does not match what they expect. (It doesn't show the big spikes in acceleration when the ball hits the floor.) Because the collision

between the ball and the floor takes
so little time, the simulation engine
does not model it very well. Even
though it is clear that there should be
a large positive acceleration when the
ball hits the floor (how else could the
velocity go from large negative to
large positive values?), and this can
be seen as a slope on the velocity
graph, the large spikes do not appear
on the acceleration graph.

Sample Interactive Physics output:



Related activities:

Graphs and Tracks software exercises and group challenges.

Use of sonic ranger to get kinesthetic experience and relate to graphs.

Curve fitting and model making from position & time data with Excel.

VideoGraph or VideoPoint analysis of freefall or coffee filter drop.