The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) Project

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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 for large, introductory college courses. North Carolina State University and a group of more than two-dozen 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 of the pedagogy, classroom environment, and teaching materials that will support this type of learning. It includes the development, evaluation, and dissemination of new curricular materials in physics, chemistry, and biology. Here we will focus on the calculus-based introductory physics part of the effort. In comparisons to traditional instruction we have seen significantly increased conceptual understanding, improved attitudes, successful problem solving, and higher success rates, particularly for females and minorities. This chapter highlights the development of the SCALE-UP pedagogy, classroom environment, and teaching materials for calculus-based introductory physics at North Carolina State University.

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1. 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."*
>
> A. Arons (1997)[1]

Students learn more physics in classes where they interact with faculty, collaborate with peers on interesting tasks, and are actively engaged with the material they are learning.[2] 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 undergraduate classes indicate that they can significantly improve students' conceptual understanding. 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, and 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 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. The entire class is taught in the same room with the same students and instructors in each class. Because of this, all activities, including laboratory experiments, can be arranged to build on one another in sequence for greater learning impact. This is much harder when activities are taught in small sections running parallel to the lecture course. For example, 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 studio/workshop-style curricula[3] in the Physics Education Research (PER) literature including the Workshop Physics curriculum developed at Dickinson College. 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 activities in small class sections that supplement the lecture (recitation or laboratory sections) and interactive lecture activities for larger classes like Peer Instruction[4] and Interactive Lecture Demonstrations (ILDs)[5] that do not permit hands-on experiments and limit faculty interactions with individual groups. (There is some direct evidence that at least in biology, a studio approach is more effective than ILDs.[6]) 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 North Carolina State University's IMPEC (Integrated Math, Physics, Engineering, and Chemistry) project (1993-1997), part of the NSF's SUCCEED coalition.[7] Physics, chemistry, mathematics, and introductory engineering science were integrated into an experimental one-year sequence of studio courses. Although the IMPEC classes were highly 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 impractical to expand the program to more than a small fraction of the thousands of students entering the NC State Engineering program each year.[8] 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 and materials that permit use of research-based pedagogies in large-enrollment studio classes of up to 100 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 ranging from 24:1 to 50:1, which permits class sizes of

50-100 students with 2-4 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 calculus-based 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 80-100 students, dissemination efforts have resulted in successful implementations in classes ranging in size from 25 to 100 students.

This chapter 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. Details of the research on student learning and an evaluation of the project will be described in a separate article submitted for publication.

1.1. Pedagogy

The main pedagogy of the SCALE-UP approach is as follows:

- To create a cooperative learning environment that encourages students to collaborate with their peers, questioning and teaching one another.
- To use PER-based activities as much as possible and to minimize lecture during class.
- To coach the students during activities by assisting them in answering their own questions and by letting students present their results to the class for review by instructors and peers as opposed to just telling students the answer.

In SCALE-UP, students begin learning about a topic by doing assigned readings before the topic is discussed in class. Students are asked to focus on the key ideas and express them in their own words before completing an assignment based on the reading. In class, the student groups do activities that help them understand the basic concepts from the reading, practice basic skills including learning multiple visual representations, and apply these concepts in experiments and problems. Follow-up homework is assigned to help students practice what they have learned in class and deepen their understanding.

Many different physics education research groups have created a rich array of carefully refined teaching materials. 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*[9] developed by McDermott and the University of Washington Physics Education Group. We found that in large classes the lessons must usually be broken up into 5 to 15 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. In-class activities typically emphasize problem solving as well as conceptual understanding.

In SCALE-UP, textbook readings are used to mostly replace the lecture as an introduction to the course material. Online reading quiz assignments due *before* the material is covered in class 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. This allows topic coverage comparable to regular lecture sections. Lecture is not eliminated, but is limited to substantially less than one hour per week, usually given in 10 to 15 minute periods. Lecture is used primarily for motivation, to summarize, and to provide an overview of topics. 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.

Technology is used to provide a phenomenological focus for students, allowing data collection, analysis, mathematical modeling, microcomputer-based laboratories, and video-based laboratories as well as applets and simulations. As student attention is drawn into analyzing different physical situations, teachers circulate around the room and engage students in semi-Socratic dialogs.[10] The use of a web-based problem delivery and grading system, *WebAssign,*[11] encourages students to review the textbook before attending class, provides much needed student practice of simple physics problems, allows for follow-up of in-class assignments 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.

Semi-Socratic dialogs, where students are asked to explain their thinking, are often used to help students resolve cognitive conflict.[12] 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 students were studying a system with fans placed on low-friction PASCO carts on tracks to learn about constant force motion. A group was

having trouble reconciling their free-body diagram with their motion graphs. Their free-body diagram showed a net force and their motion graphs showed constant acceleration and the velocity changing at a constant rate. This group felt that a constant force should produce a constant velocity. The instructor asked them to recall what they learned from a previous activity where they pulled an air puck (a small hovercraft) with strings connected to spring-scales. "How much force was needed to pull the puck so it moved with constant velocity?" One student answered that they had to stop pulling to get the air puck to move with constant velocity. "What do the rest of you think? Is she right?" The other students agreed. "So how much net force is needed to make something move with constant velocity?" The students answered "none." They quickly recalled that when they pulled the air puck, it accelerated. "So if there is a net force on the fan cart, how should it move?" The students responded it should accelerate. "Does this have anything to do with Newton's laws of motion?"…

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 into a positive learning experience for the entire group.

1.2. Course Goals

Before beginning any journey, it is always good to know where you want to go. We strongly suggest that every faculty member carefully consider their instructional goals for what students should learn from their class. Many people simply take the list of topics from the textbook table of contents. This is a good starting point, but don't limit yourself to just topical coverage. There are other areas that you may wish to consider. Each SCALE-UP school has their own set of objectives. Those for the NCSU calculus-based engineering physics sequence are listed in Table 1. Note that most of these SCALE-UP objectives strongly overlap many elements of the American Board of Engineering and Technology's accreditation standards for required program outcomes.[13]

1.3. Cooperative Groups

There is a large body of evidence indicating that students learn best when working together. Alexander Astin's famous book[14] *What Matters in College* is based on the largest ongoing study of American higher education, incorporating longitudinal data from half a million students at 1300 schools. In it, he concludes that peer involvement and student/teacher interaction are by far the most significant influences on retention and achievement. His work and that of many others (*cf.* the Johnson *et al.*

meta-analysis of cooperative learning[15]) indicates that the frequency and nature of interactions with peers and faculty have the most crucial influences on attitude and psychological change during college.

Table 1. SCALE-UP course objectives at North Carolina State University (left column) and ABET 2000 Criterion 3 requirements[13] (right column).

NCSU SCALE-UP Objectives for calculus-based introductory physics	***ABET 2000 Criterion 3: Program Outcome Requirements.***
Scale-up students should:	*Engineering programs must demonstrate their students have:*
• develop a good functional **understanding** of physics.	(3a) an ability to apply knowledge of mathematics, science, and engineering
• begin developing expert-like **problem solving** skills.	(3e) an ability to identify, formulate, and solve engineering problems
• develop **laboratory** skills	(3b) an ability to design and conduct experiments, as well as to analyze and interpret data
• develop **technology** skills.	(3k) an ability to use the techniques, skills, and modern tools necessary for engineering practice.
• improve their **communication**, interpersonal, and questioning skills	(3d) an ability to function on multi-disciplinary teams (3g) an ability to communicate effectively .
• develop **attitudes** that are favorable for learning physics.	(3h) the broad education necessary to understand the impact of engineering solutions in a global and societal context (3i) a recognition of the need for, and an ability to engage in life-long learning
• Should have a **positive learning experience**	

Combining these research findings with employer surveys placing the highest priority on team skills led us to focus on promoting cooperative groups in our classrooms. Most schools have limited group size to three students. The three members are carefully chosen (based on criteria such as pretest scores or grades in previous coursework). We attempt to make each team heterogeneous in academic background, but with the same average ability as all the other groups. This is done by first ranking all the students by relevant criteria and splitting the class into top, middle, and bottom thirds. The very best students are evenly distributed around the room, one to each table. (The room layout will be described later.) These “star students” can act as resources for the rest of the students at his or her table. The remaining students are then randomly assigned to groups, subject to two constraints. First, we make sure every group has students from the top, middle, and bottom thirds of the class ranking. Second, we ensure that students who are commonly underrepresented in engineering are not alone in a group. For example, if there is one female in a group, at least one of the other two students in that group will also be female. Similar rules are applied to minorities. This is done because women and minorities are often not as influential in group settings as they should be.[16]

We switch groups three or four times per semester, typically after each exam. We have found if we don’t do this, the class’s groups become so comfortable with each other that their in-class discussion topics are no longer about physics, but rather about their out-of-class interactions like movies or sporting events attended together. In addition, there is often a two-week lull somewhere in the 8-12th week where class performance drops appreciably. Changing groups only once in the middle of the semester is traumatic because the students have formed strong friendship bonds that are now severed. However, rotating group membership every three or five weeks seems to avoid this problem. For the 2nd and 3rd assigned groupings, while we continue to fill groups with students from across the class’s ranked thirds (which are now based on exam scores), it is no longer necessary to carefully match women and minorities. Somehow, students find a way to make their voices heard within a group after only a few weeks. This is an important result that we intend to investigate.

Early in the semester, students receive brief training in group functioning and create their own contracts of responsibility. (Each time new groups are formed, their first assignment is to develop new contracts.) 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 eight 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 ”B” or better, each team member has 5 percent added to their score. Thus it is in the best interest of the top students to teach the others in their group. Since the best students are often highly motivated by grades, this has been quite successful.

According to Johnson, Johnson, and Smith,[17] 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.

1.4. 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.” 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. Midterm exams are weighted somewhat lower than normal (10-15% each) so that students can recover if they do poorly on an individual test. This is important as allowing students to drop a test prevents some students from giving their best effort for their group. Particularly, if they decide *a priori* to drop a test, this can limit group effectiveness in preparing for tests as well as the effectiveness of offering a group bonus. Peer pressure is quite effective at maintaining average attendance rates above 90%, even when attending class is not a course requirement. At NCSU a very detailed grading rubric is used to grade lab reports. This ensures fast, objective grading and also gives the students insight into what should be present in high quality work. The rubric is available at the SCALE-UP website.[18]

2. Activities

We are strong believers in the need for actively involving students in the classroom. Descriptions of current models of student intellectual development[19] and implications for the classroom[20] have been provided by Felder and Brent. Among other things, they explicitly recommend a student-centered learning environment where students are simultaneously challenged and supported, given clear expectations, and are presented with a variety of learning tasks. Edgar Dale[21] provided a graphical display of different types of classroom tasks and how they impact learning. This is shown in Figure 1 and can be summarized as “the more you do, the more you learn.” Carmean and Haefner[22] describe the phrase “deeper learning” as social, active, contextual, engaging, and student-centered. Page 29 of their review of learning theories incorporates a nice table (included here as Table 2) which itself points to the work of Bransford, Ann L. Brown, and Cocking,[23] John Seely Brown,[24] Chickering and Ehrmann,[25] Marchese,[26] and Merrill.[27] This article and the second Felder and Brent paper [see ref. 20] provide an excellent summary of how classroom instruction should be modified to help students learn. We have attempted to incorporate most of their suggestions into the SCALE-UP approach.

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 organizer[28] 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 collection of what we call “tangibles” (short, hands-on activities) and “ponderables” (interesting questions to consider). Many of these tasks are based on known areas of student difficulty. In addition to these short activities, we have longer, more open-ended lab and problem solving activities.

Table 2. Deeper Learning Principles from Carmean and Haefner[22]

Learning is....	***When...***
Social	It involves cognitive apprenticeships[23] It promotes reciprocity and cooperation among students[24] It offers prompt feedback[24] It encourages contact between students and faculty[24] It emphasizes rich, timely feedback[25]
Active	It is engaged in solving real-world problems[26] It is intertwined in judgment and exploration[23] It is situated in action[23] It uses active learning techniques[24] Practice, reinforcement and involvement in real-world tasks are emphasized[25]
Contextual	New knowledge builds on the learner's existing knowledge[26] New knowledge is integrated into the learner's world[26] Knowledge is applied by the learner[26] New knowledge is demonstrated to the learner[26] Students have a deep foundation of factual knowledge[22] Awareness that students come to the classroom with preconceptions about how the world works[17] Students understand facts and ideas in the context of a conceptual framework[22] Learning is concrete rather than abstract[23]
Engaging	It respects diverse talents and ways of learning[24] It communicates high expectations[24] It is done in high-challenge, low-threat environments[25] It emphasizes intrinsic motivation and natural curiosities[25]
Student-centered	Students organize knowledge in ways that facilitate retrieval and application[22] Students take control of their own learning: noting failures, planning ahead, apportioning time and memory to tasks[22] It emphasizes time on task[24] It emphasizes learning independence and choice[25] It allows time for reflection[25] It emphasizes higher-order thinking (synthesis and reflection)[25]

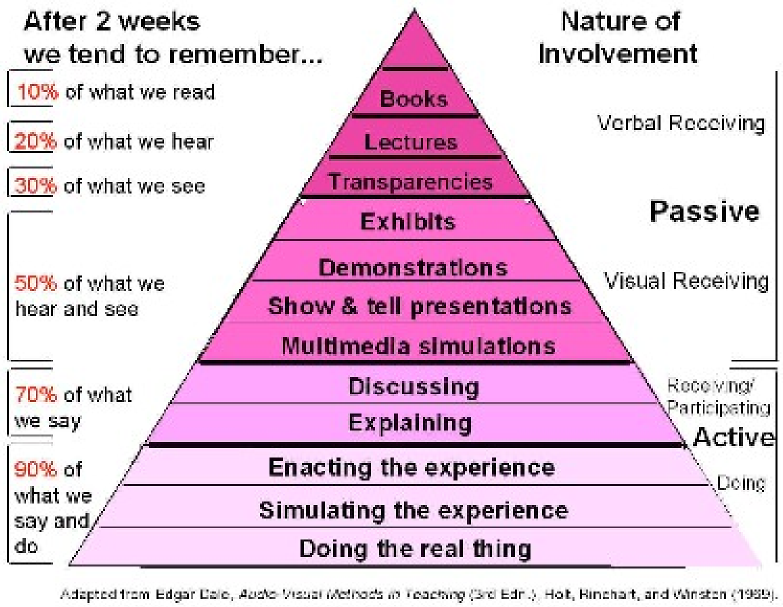


Fig. 1: Dale's Cone of Learning

2.1. Tangibles and ponderables

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 using *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 in Table 3.

Carefully worded conceptual questions are a key instructional tool for recognizing student difficulties with fundamental principles. Mazur's ConcepTests [see ref. 4] are a prime example of this pedagogy using short, multiple-choice questions. We have also been guided by McDermott's *Tutorials* [see ref. 9], which suggest qualitative elicit-confront-resolve "ponderable" activities to address student conceptual understanding. Of course, we also offer problems that require numerical answers so that students can see others' results and challenge their approaches.

Table 3. Sample Tangible and Ponderable Activities

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 textbook 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.
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! Many students 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 (or their neighbors) that specifically address these questions. Having students explicitly deal with these questions is a basic component of the SCALE-UP curriculum. Requiring them to occasionally write these notes for their neighbors ensures they put careful thought into their work.

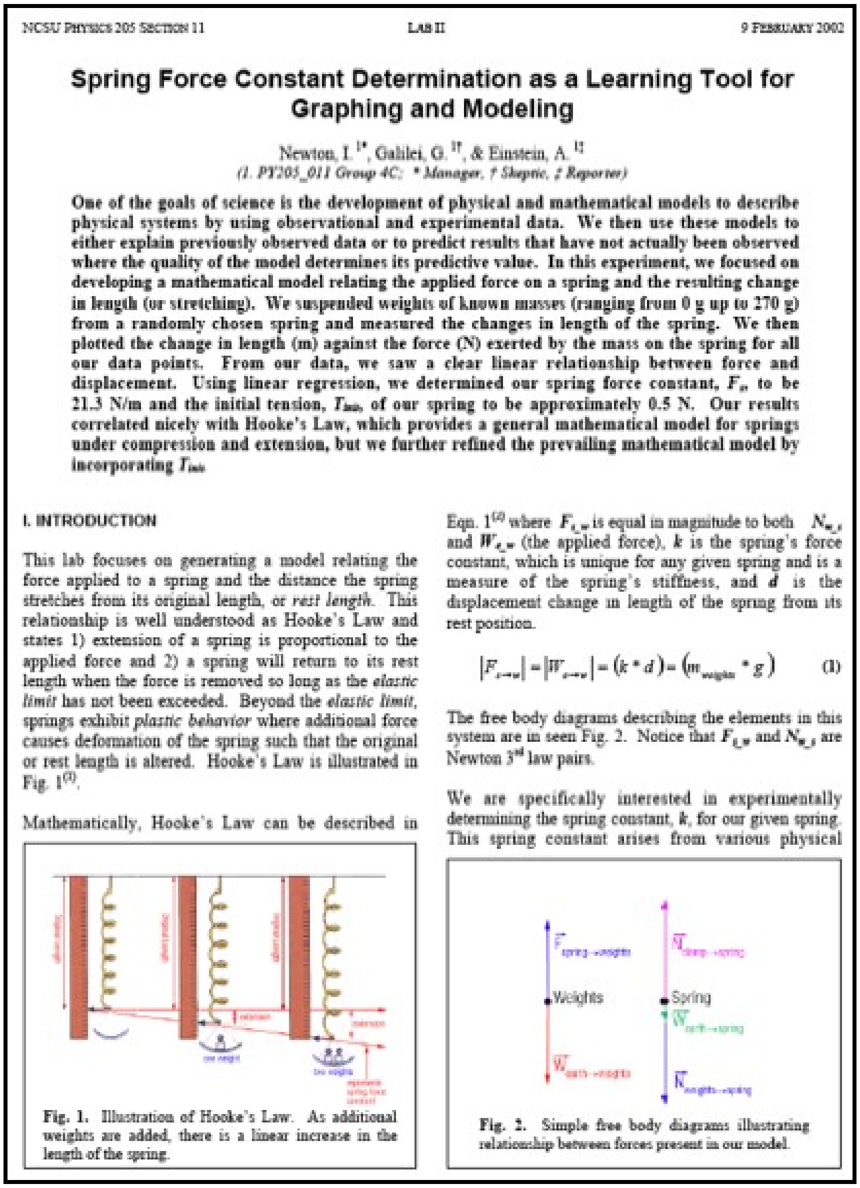
After students complete a Ponderable or Tangible activity, many concepts are still just partially formed. It is useful to bring the activity to closure. One way that has worked to get all of the students involved is to have an "in-class" assignment on *WebAssign*. This assignment is very short and asks questions 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 argue 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 a password.

We often use individual electronic response units to poll students in class. This allows them to work individually at first to select an answer. After this is completed, the instructor displays a histogram of their choices. If there is disagreement (and there often is), students are given the opportunity to debate with each other and vote again. It is amazing to see how students rapidly converge to the correct choice. The logic of the correct answer "overpowers" that of the wrong choices. Engaging students in this type of evaluation and justification is a valuable cognitive exercise at the top of Bloom's taxonomy.[29]

2.2. Labs

In addition to the short tangible activities, at NCSU we have more extensive, group-based 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 literature [see ref. 15] each individual examines the teamsmanship of themselves and their group mates. The quality of the justifications, which focus on each student's performance of their assigned team role[30] (manager, recorder, or skeptic), 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 and 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, and uncertainty considerations (how to tell if one number is different from another). We increase our expectations during the semester instead of believing students 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. The best of these can be quite impressive, as seen in Fig. 2.



NCSU PHYSICS 205 SECTION 11 LAB II 9 FEBRUARY 2002

Spring Force Constant Determination as a Learning Tool for Graphing and Modeling

Newton, I.[1*], Galilei, G.[1†], & Einstein, A.[1‡]
*(1. PY205_011 Group 4C; * Manager, † Skeptic, ‡ Reporter)*

One of the goals of science is the development of physical and mathematical models to describe physical systems by using observational and experimental data. We then use these models to either explain previously observed data or to predict results that have not actually been observed where the quality of the model determines its predictive value. In this experiment, we focused on developing a mathematical model relating the applied force on a spring and the resulting change in length (or stretching). We suspended weights of known masses (ranging from 0 g up to 270 g) from a randomly chosen spring and measured the changes in length of the spring. We then plotted the change in length (m) against the force (N) exerted by the mass on the spring for all our data points. From our data, we saw a clear linear relationship between force and displacement. Using linear regression, we determined our spring force constant, F_s, to be 21.3 N/m and the initial tension, T_{init}, of our spring to be approximately 0.5 N. Our results correlated nicely with Hooke's Law, which provides a general mathematical model for springs under compression and extension, but we further refined the prevailing mathematical model by incorporating T_{init}.

I. INTRODUCTION

This lab focuses on generating a model relating the force applied to a spring and the distance the spring stretches from its original length, or *rest length*. This relationship is well understood as Hooke's Law and states 1) extension of a spring is proportional to the applied force and 2) a spring will return to its rest length when the force is removed so long as the *elastic limit* has not been exceeded. Beyond the *elastic limit*, springs exhibit *plastic behavior* where additional force causes deformation of the spring such that the original or rest length is altered. Hooke's Law is illustrated in Fig. 1[1].

Mathematically, Hooke's Law can be described in Eqn. 1[2] where F_{s_w} is equal in magnitude to both N_{w_s} and W_{e_w} (the applied force), k is the spring's force constant, which is unique for any given spring and is a measure of the spring's stiffness, and d is the displacement change in length of the spring from its rest position.

$$|F_{s\to w}| = |W_{e\to w}| = (k * d) = (m_{weights} * g) \qquad (1)$$

The free body diagrams describing the elements in this system are in seen Fig. 2. Notice that F_{s_w} and N_{w_s} are Newton 3[rd] law pairs.

We are specifically interested in experimentally determining the spring constant, k, for our given spring. This spring constant arises from various physical

Fig. 1. Illustration of Hooke's Law. As additional weights are added, there is a linear increase in the length of the spring.

Fig. 2. Simple free body diagrams illustrating relationship between forces present in our model.

Fig. 2: Example of an exceptional student lab report. (Names were changed to protect anonymity.) Note from the title that the students recognized the real educational purpose of the lab, beyond a simple verification of Hooke's Law.

2.3. Real world problems

SCALE-UP implementations at NCSU and UCF have also adapted a problem-solving activity called Real World Problem Solving based on the Cooperative Group Problem Solving (CGPS) approach developed by the Physics Education Group at the University of Minnesota [see ref. 30]. Real World Problem Solving uses a problem-solving protocol based on the work of Polya.[31] The protocol is represented by the acronym GOAL: Gather information, Organize and plan, perform the Analysis, and Learn from your efforts. The CGPS group roles are used to promote better group interactions and help group decision-making. Without the groups roles, a few groups get stuck when two approaches are proposed. Some of our Real World Problems are modified from the Context Rich Problems created by the Minnesota PER group [See Ref. 30] and the Activity-Based Physics Thinking Problems created by the University of Maryland PER group.[32] Others we have created in-house. In every case we are trying to give students challenging, realistic situations that are best analyzed by working in groups and following a problem-solving protocol. Several examples of Real World Problems are given in Table 4. A student solution to an exam problem is displayed in Figure 3. Notice how much easier the problem is to grade because of the organization provided by the GOAL protocol.

As implied by the title of a frequently cited paper by Alan van Heuvelen,[33] teaching students to "think like a physicist" is an important goal. Because SCALE-UP students often use whiteboards as a public "thinking space," there are many opportunities for them to critically evaluate each other's work. We feel this is one of the most valuable aspects of our approach. A critical distinction was pointed out by Brown [see ref. 24]: "The developmental psychologist Jerome Bruner made a brilliant observation years ago when he said we can teach people *about* a subject matter like physics—its concepts, conceptual frameworks, its facts—and provide them with explicit knowledge of the field, but *being* a physicist involves a lot more than getting all the answers right at the end of each chapter. To be a physicist, we must also learn the practices of the field, the tacit knowledge in the community of physicists that has to do with things like what constitutes an 'interesting' question, what proof may be 'good enough' or even 'elegant,' the rich interplay between facts and theory-formation, and so on. Learning to be a physicist (as opposed to learning about physics)…" In the SCALE-UP setting, students have many opportunities to act as true scientists-in-training. Unfortunately, this cannot be said for most traditionally taught courses.

Table 4. Sample 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. That gets you wondering 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.

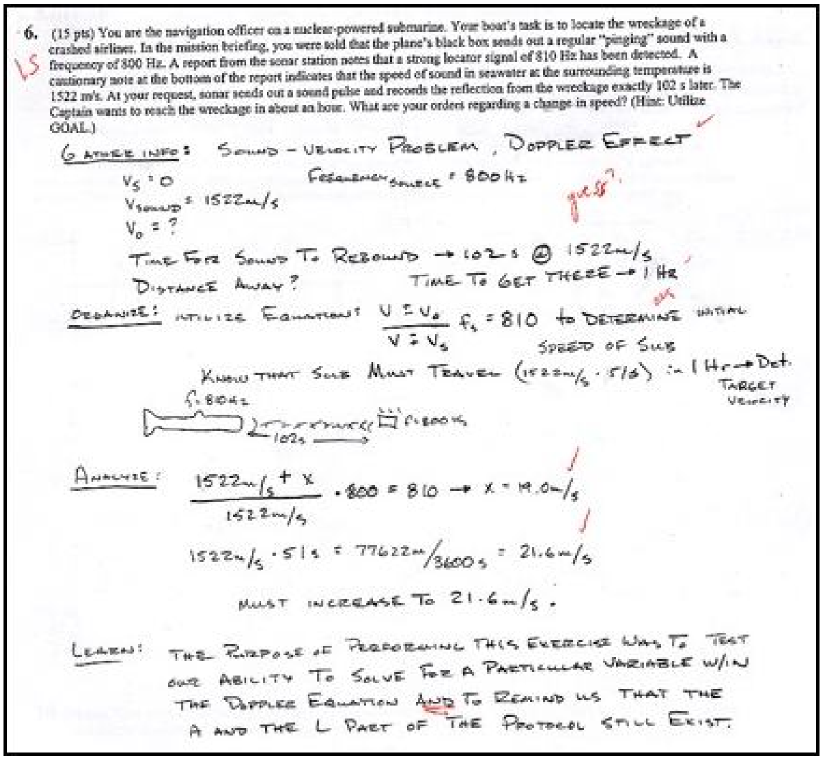
Some relate to technical jobs:

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 David 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. The seat does not touch 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. As technical advisor, 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.



6. (15 pts) You are the navigation officer on a nuclear-powered submarine. Your boat's task is to locate the wreckage of a crashed airliner. In the mission briefing, you were told that the plane's black box sends out a regular "pinging" sound with a frequency of 800 Hz. A report from the sonar station notes that a strong locator signal of 810 Hz has been detected. A cautionary note at the bottom of the report indicates that the speed of sound in seawater at the surrounding temperature is 1522 m/s. At your request, sonar sends out a sound pulse and records the reflection from the wreckage exactly 102 s later. The Captain wants to reach the wreckage in about an hour. What are your orders regarding a change in speed? (Hint: Utilize GOAL.)

LS

GATHER INFO: SOUND – VELOCITY PROBLEM, DOPPLER EFFECT

$V_S = 0$ FREQUENCY$_{SOURCE}$ = 800 Hz

V_{SOUND} = 1522 m/s

V_0 = ?

yes?

TIME FOR SOUND TO REBOUND → 102 s @ 1522 m/s

DISTANCE AWAY? TIME TO GET THERE → 1 HR

ORGANIZE: UTILIZE EQUATION $\frac{V \pm V_0}{V \mp V_S} f_s = 810$ to DETERMINE INITIAL SPEED OF SUB

KNOW THAT SUB MUST TRAVEL (1522 m/s · 51 s) in 1 Hr → Det. TARGET VELOCITY

f: 810 Hz

102 s

f: 800 Hz

ANALYZE: $\frac{1522\,m/s + x}{1522\,m/s} \cdot 800 = 810 \rightarrow x = 19.0\,m/s$

$1522\,m/s \cdot 51\,s = 77622\,m / 3600\,s = 21.6\,m/s$

MUST INCREASE TO 21.6 m/s.

LEARN: THE PURPOSE OF PERFORMING THIS EXERCISE WAS TO TEST OUR ABILITY TO SOLVE FOR A PARTICULAR VARIABLE W/IN THE DOPPLER EQUATION AND TO REMIND US THAT THE A AND THE L PART OF THE PROTOCOL STILL EXIST.

Fig. 3: Example of a typical, student-written solution to an exam problem. Notice that the student recognized the true purpose of the problem, which

was to test their ability to apply the full GOAL protocol. (An earlier test had only asked students to complete the Gather and Organize steps.)

2.4. Homework

We take full advantage of the *WebAssign* web-based homework delivery system. A principal 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 encourage most of them to read the textbook before material is covered in class. 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. (Although it should be noted that some sections are now being taught using the *Matter and Interactions* curriculum[34] of Chabay and Sherwood.)

Evaluation studies at UCF found evidence that students really do read the book ahead of class when reading quizzes are used. We have observed several examples of student groups using representations such as energy bar graphs and electric field lines in activities in class without prior discussion. In one case, the class was using a new edition of the textbook and used a representation that was new to that edition, which took the instructors by surprise when half the groups used the new representation. In addition, over half of the students interviewed in focus groups at UCF commented that they get much more out of a particular class when they've done the assigned reading.

We also use *WebAssign* for follow-up homework with more challenging problems. Because we put so much emphasis on a systematic approach to solving problems, we often 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 from our large numbers of students, 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 a few papers need grading. At the next class meeting the instructor will often display actual student work that exemplifies the desired problem solving techniques while the student describes what they did. In our large room with 11 tables, if a "12" is rolled, all students get credit for the homework. This takes what could be a resented situation—having to turn in homework to the teacher—and turns it into what students view as a fun lottery. A similar scheme allows 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.

3. 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 quizzes, 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 quiz 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 72-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 and are used for weekly quizzes and Real World Problem Solving, including student presentations.

Note that the TA support for SCALE-UP is comparable or slightly less than that of typical physics labs. For example at NCSU, a lecture section of 99 students would need 4 lab sections, which would require 2 graduate TAs to teach them compared with the graduate and undergraduate TA used in the SCALE-UP classes. At UCF, 72 students would need 3 lab sections taught by 1.5 TAs, which is the same number used in their SCALE-UP classes (one of the SCALE-UP TAs at UCF is a half TA with mostly teaching and minimal grading responsibilities). The contact time for the TAs is similar to teaching a lab. Rather than teach 2 lab sections for 4-6 hours per week, SCALE-UP TAs assist in the classroom for 5-6 hours per week. Several of the TAs at UCF have mentioned that working with SCALE-UP classes helped them improve their understanding of the introductory course material.

4. Classroom Environment

The design of the classroom is an important consideration for teaching large studio/workshop-style classes. Since in SCALE-UP physics all classtime is held in a single classroom, the room must support both lecture and group work including experiments. Thus, studio/workshop multimedia classrooms need students to be able to do the following:

- Work in groups of 2-4 students
- Have access to computers and the internet
- Have access to equipment to perform experiments
- Participate in class discussions
- To be able to display work to peers

Because of the larger student to faculty ratio in SCALE-UP classes of 50-100 students, classroom management is greatly aided if the classroom design also encourages collaboration within groups and between groups, particularly when a group needs help and the instructors are working with other groups (a key to managing large studio/workshop classes). Also, the classroom layout facilitates distributing and collecting materials such as assignments or lab equipment, and the room has the ability to display demonstrations for set-ups that are too expensive, dangerous, or time consuming for students to do themselves.

A great deal of effort went into designing, testing, and modifying the classroom space. There were three separate phases to the process. Figure 4 shows how the development of the room evolved between 1997-2001 at NCSU. Phase 1 was located in a fairly traditional lecture hall (see Figure 4a). 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.

a) 
b) 

c) 
d) 

Fig. 4: Phases of NCSU SCALE-UP room development
(a) The Phase I SCALE-UP classroom, a lecture hall with long tables.
(b)The Phase II classroom, seating 55 before renovation.
(c)The Phase II SCALE-UP classroom, seating 54 after renovation.
(d) The Phase III classroom, seating 99 students.

The second and third phases involved a specially designed room layout to create a multimedia, collaborative classroom that can be used for group activities, class discussions, and laboratory experiments. These rooms include additional features to encourage collaboration and allow students access to multimedia technology. Figure 4b shows the Phase II room before renovation. It was a small (21 by 36 feet), crowded, traditional classroom with 55 desks. Figure 4c 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 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 4d 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 and made it difficult for students to communicate across the table. Tables should 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. 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 4d 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 many 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.)

In addition to a laptop, each group has access to lab equipment for experiments. The circular tables provide sufficient space to run all but a few of the standard and PER-based introductory physics experiments. Even the 6' tables can support force and motion experiments with low-friction carts and a 1.2 m track, typically one of the most space-demanding experiments.[35] Thus the redesigned Phase 2 and Phase 3 classrooms allow SCALE-UP classes to use almost any kind of instructional mode the instructor can think of including but not limited to lecture, Peer Instruction, class discussions, demonstrations, simulations, programming, *Excel* analysis, video analysis, and experiments with or with out MBL. It is quite possible in a single class period to have a mini-lecture, a simulation activity, a demonstration, and a short experiment. Classes can switch from a lecture or a class discussion to an experiment in a few minutes, even in the NCSU phase two classroom where no equipment could be stored in the classroom, necessitating placement of a previously prepared equipment box on each table. Since instructors can use any activity at any time, activities can be selected and ordered for greater educational impact. As one of the MIT SCALE-UP faculty, Dourmashkin says, "*Traditionally in large lectures, you do what is possible to do in front of 500 people, not because it's what you should do. Now we're asking the question: What do we really want our students to learn?*"[36]

The ceiling-mounted projectors and the document viewer (essentially a video camera on a stand) have worked well in the NCSU classrooms. The viewer's camera can be aimed at the whiteboards, zooming in for better display of student work. At UCF, a separate video camera is used to project student work or demonstrations in addition to computer displays. The classrooms shown in figure 4 also include multiple projectors so students can see what's being projected no matter where they are sitting. This works quite well but some SCALE-UP schools are redesigning their rooms so that students can easily view two different screens at the same time, for example, to be able to view the problem and its solution at the same time. Another 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.

In addition, the redesigned classrooms have been very successful in establishing the desired learning environment. The circular tables are quite effective for promoting group work and encouraging inter-group communication. 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.

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. 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. As mentioned earlier, *WebAssign* is used both during and outside of class time to present questions and problems for consideration with instant feedback for student responses. *Excel* analysis, Java applets[37] (mostly Physlets®), video analysis (using *VideoPoint*[38]) and simulations are a major part of our instructional methodology. In sections using the *Matter and Interactions* curriculum [see ref. 34], student programming in *VPython*[39] has nearly replaced simulation development using *Interactive Physics*[40] software. While students work on these activities, the instructor and assistants are able to move about the room, asking and answering questions in a semi-Socratic style [see ref. 12].

5. Dissemination

5.1. 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.*[41] 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 library of detailed lesson plans. (An example is given at the end of this chapter.) These activities are designed to be modular and somewhat interchangeable so that faculty can pick and choose both which activities and how many activities to implement in their classroom. Many activities can be implemented in lecture either as ponderables or as interactive demonstrations. Each activity in the library is 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 continue 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 online [see ref. 18]. All of the questions associated with labs, in-class activities, quizzes, and tests used in *WebAssign* are available for other teachers.

5.2. Visits and workshops

We have had more than 40 visitors each academic year, including faculty from quite a few foreign countries. Members of the project staff have given many colloquia as well as consulted with architects and planning teams at other institutions. We continue to give half-day introductory workshops at several AAPT meetings and also two-day workshops for faculty from adopting schools.

5.3. Secondary implementations

There are now over 50 secondary implementations of SCALE-UP classes at colleges and universities across the country. Some, like UCF, follow the details described here closely and use many of the activities developed at NCSU. Others, like MIT's TEAL Project use the SCALE-UP approach and the SCALE-UP classroom design, but have modified the classroom management techniques and developed their own group activities to suit their own situations. For example, when moving from pilot projects to full implementation, some schools decide not to use some of the SCALE-UP techniques for creating structured cooperative groups such as group contracts and group roles. (Observations found that this strengthened the table groups but weakened the smaller 3-4 student groups except when they were doing experiments.) Based on our experience with SCALE-UP and other PER-based curricula, we find that the less structured the student activities, the more structured the student groups need to be. The common elements of these secondary implementations are the following:

- A classroom renovated to emphasize group work with 2-3 groups of 3-4 students each per table
- the majority of class time is spent on learning physics through activities done by groups of 3-4 students each,
- the activities tend to be short (5-20 minutes) and followed by a class discussion,
- the activities are based-on or at least informed by PER,
- all components of the class are tightly integrated, and
- the instructor is more of a coach or a guide rather than the source of knowledge.

Not surprisingly, most of these are common elements of PER-based curricula in general.

SCALE-UP Physics classes are taught with class sizes ranging from 25-100 students. At UCF, MIT, and RIT, some SCALE-UP university physics classes are taught by regular department faculty and TAs who are not PER specialists and were not part of the development team at their school. While many of the SCALE-UP faculty at these schools attended our 2-day implementer's workshop, they and the TAs attend preparation meetings during the semesters where the pedagogy and the activity details of the next day or week of classes are discussed. In some cases, the faculty and the TA do the activity in groups like students to better understand how to teach it. They also discuss the main student learning difficulties and what questions are useful to address them.

5.4. Implementation challenges

Implementing SCALE-UP with non-PER Faculty

The first step in implementing SCALE-UP classes is getting individual faculty and departments to accept a new way of teaching introductory classes. Some faculty don't see the need to change and some don't want to spend time learning a new way to teach a course, particularly when they have years of experience teaching it as a traditional lecture course. Small departments (1-5 faculty) find adopting SCALE-UP by consensus easier (in part because they already teach both lecture and laboratory components and there is more emphasis on teaching) while larger departments (20 or more faculty) are often willing to allow a small group of motivated faculty freedom to experiment with sections taught in parallel with regular lecture/laboratory sections. At RIT and MIT, the latter led to full implementation of all but honor sections.

The second step is finding faculty to teach SCALE-UP classes. Many faculty with a strong interest in teaching are interested in trying something new with the potential to improve student learning. For these faculty, the main obstacle to teaching SCALE-UP is time. In studies of non-PER faculty teaching SCALE-UP classes for the first time at UCF and RIT, these faculty need 8-13 hours of preparation time to teach 4-6 hours per week, roughly 2 hours of preparation for every hour of class. Some faculty, even those who have attended a 2-day workshop and expressed a strong interest in teaching a SCALE-UP are reluctant to make that much of a time commitment. What is interesting is that some of them later spend at least that much time developing new courses. This suggests that the key may be in getting these faculty to see teaching a SCALE-UP class as teaching a new class rather than a new version of a familiar class. Note that by the 2nd year, the preparation time typically drops to 1 hour of preparation for each class hour. At NCSU, preparation time has dropped to 1 hour per week to teach 4 hours in class, for one of the original implementers.

The next step is helping faculty teach their first SCALE-UP classes. From our own experience and from working with non-PER faculty at the secondary implementations, teaching a SCALE-UP class as lead instructor for the first time can be a very daunting, uncomfortable experience, even for those who have taught interactive engagement activities in lecture, lab, or discussion sections. Most faculty do not start to feel comfortable with the new teaching format until sometime in their 2nd term teaching a SCALE-UP class. The main challenge faced by first-time SCALE-UP faculty is that it is very different from a traditional lecture class. Coaching student groups through activities and guiding class discussions require different skills than lecturing. For example, a good lecture requires faculty to make a good presentation, highlight key points, use relevant examples, and keep students' attention. A good SCALE-UP class is more like teaching a lab section where it is important for instructors to know the activity, know where students can go wrong and how to steer them back, how to keep the students engaged, and what questions to ask them to see if they understand. Time on task no longer depends on the instructor's presentation but on how the students go through the activity. In addition, SCALE-UP instructors need to know how to lead class discussions so that the students present the key points and to keep the class together. Some faculty are surprised that the format also encourages students to ask more questions. (At NCSU, an evaluator, who had previously taught physics there, was quite surprised at the number and depth of questions being asked by students in class.)

The lead instructor must time the activities so that most but not necessarily all students finish each activity, keep students attention and coach the class discussion to cover key points and common difficulties, and keep the student groups engaged. The instructors (faculty and TAs) need to learn to work together so that every table is visited at least once during all but the shortest activities. However, the classroom design helps keep students engaged by making it easy for them to work together and by making it clear on the first day as they walk in that this is a different learning environment. It also helps that with multiple groups at each table, the groups help each other when instructors are busy helping students at other tables. Class observations at NCSU and UCF find few if any students off task during activities; although sometimes instructors will have the whole class close their laptops if they find someone off task using the computer before their group has finished an activity. At RIT, computers are only passed out when they are needed to run an experiment or a simulation. Several other methods have been developed to help keep students groups engaged and on-task. One example is to call on students or groups who are off-task to present their results to the rest of the class and gently question them to see what they have done or learned from the activity before going on to another group (NCSU and

UCF). Another is to collect worksheets for grading from random members of a group (RIT).

At first, some instructors find they are only be able to do 2-3 activities in a two-hour class. These instructors may find it necessary to lecture more to maintain the pace of coverage. With more experience, most instructors can manage to complete 4-5 activities in a two-hour class. Time pressure can make it tempting to cut an activity short or tell students the answers. However, more experienced SCALE-UP instructors learn it is better to cut activities rather than cut them short and have students miss the point. And while it is tempting for instructors to present “the answer” for each activity to the students, the students learn more when they present their results.[42]

One additional challenge non-PER faculty have teaching a SCALE-UP class for the first time is that, like with other PER-based curricula, it may take teaching an activity a few times before faculty understand why an activity is designed a particular way. First time SCALE-UP faculty sometimes find it hard not to tinker with the activities before they have actually used them with students. The new faculty who spent the most time on preparation were the ones who tinkered with the activities the most before implementing them. This can cause problems as they often don’t understand what makes the activity work and they sometimes make changes based on assumptions of how they think students will react that may not be accurate.

At UCF, RIT, and MIT, although three different techniques were used to help non-PER faculty adopt a SCALE-UP approach, each approach had common elements. At each school, weekly instructor meetings were held to go over materials provided by the development team and how to implement them as intended. Instructors were then advised to use the materials as they saw fit.[43] At UCF, materials were provided a few days before they were to be used. The non-PER faculty discussed changes with the PER group before implementing them.

From our experience at these schools, it is recommended that faculty intending to teach SCALE-UP classes observe several classes before trying to teach it. Weekly instructor team meetings to practice and discuss how to teach activities as intended are also recommended. This way, new SCALE-UP faculty can be introduced to the how and the why of SCALE-UP activities while still having the freedom to tweak them.

Developing a SCALE-UP classroom

While small SCALE-UP classes can be taught in regular large rooms, larger SCALE-UP classes need to be designed to facilitate group work and encourage groups to help one another when an instructor is not available.[44] Although operating expenses for

SCALE-UP classes are comparable to regular lecture/laboratory sections, the initial capital expense for SCALE-UP classrooms for large classes is much larger. Outfitting each group for a two-semester introductory sequence can cost $4,000-5,000 per group (including tables, chairs, and computers). This does not include the cost of renovating the space. Surprisingly, most of the schools adopting SCALE-UP were able to find internal funds to create SCALE-UP rooms such as start-up funds, educational improvement awards, or dean's initiatives. Some schools used CCLI grants from NSF as leverage to build their SCALE-UP classrooms. One school was able to obtain funding from their dean by showing pictures of SCALE-UP rooms to other departments and asking them, how would you like to teach in a room like this? Four departments requested a SCALE-UP room from their dean and the room was online in less than one year. In another case, the majority of funding came from a private foundation.

The common elements of the SCALE-UP rooms are having at least one computer for each group of students, lab equipment for each group, an instructor station with projector so that students can see the screen wherever they sit, and ample white boards. They also have 2-3 groups per table, although this is less necessary in small SCALE-UP classes. At UCF, small SCALE-UP classes (25 students each) were offered in a traditional lab room at first until space could be renovated for a larger SCALE-UP room. (Using existing furniture and equipment can greatly reduce costs.)

Because the large start-up cost was likely to be an obstacle to other schools adopting SCALE-UP, the NCSU group looked at ways to reduce costs. One way is to use more low-tech activities. Another way is to have three-part lab experiments, where one group at a table does an actual experiment, one group does a simulated experiment, and the third group does a video experiment or paper and pencil activity. The groups rotate through each of the three experiments so each group does each activity.

Student and Faculty Acceptance

Overall student acceptance has been mostly positive. End of term evaluations are typically as good or better than those of regular lecture/laboratory sections. End-of-term evaluations and small focus group interviews at NCSU, RIT, and UCF found while almost all students felt the SCALE-UP classes were more work, more than half (typically 2/3) believed it was worth it because they felt they learned more. For example, in one large focus group of NCSU students in a second semester SCALE-UP class conducted by an outside evaluation team, the twelve students stated they felt they were learning the material at a deeper conceptual level and there was much less rote memorization on their part. Despite the fact that all 12 students had taken their first semester physics class in the lecture format and that they all felt that SCALE-UP required about 3 hours more effort per week, only 2 of the 12 preferred the lecture format. When asked about why they preferred lecture, one stated that he thought he could get an "A" in the class with less effort. The other had difficulty expressing the reasons for his preference. The others preferred SCALE-UP and thought the extra time was worth it because they were learning the material so much better.

The student reaction to TEAL (MIT's SCALE-UP project) has been more mixed although the student reaction appears to be more positive over time. Although the project has been able to document improved learning and reduction of failure rates, the main challenge at MIT is a student culture that dislikes courses where you have to come to class. Similar attitudes have been observed in other studies of studio physics classes for students, like pre-medical majors, who are often very successful with passive lecture instruction. They, like the NCSU student above, feel they can get a better grade with less effort in a lecture format.[45] MIT continues to make adjustments to their TEAL classes to improve student acceptance.

Faculty acceptance varies between generally positive at small schools or small teams in large departments to more of a fifty-fifty mix for full implementation in large departments. At MIT, a recent faculty vote on continuing with TEAL classes decided to stay with the program primarily because the students were getting more out of it than the lecture/recitation classes it replaced. At RIT, the faculty voted in favor of full implementation but initially went with a modified SCALE-UP format with 2 hours of lecture and 5 hours of workshop (a lab for doing SCALE-UP activities) per week. After two years, the lecture sections were found to be ineffective and were dropped. The main faculty concerns for those who are willing to try something new are the time commitment, how can you teach without lectures, and is this really a good thing to do for our best students. One of the more interesting reactions from a non-PER faculty member teaching a SCALE-UP class resulted from his becoming much more aware of how students were thinking and their difficulties. He was no longer able to ignore his students' learning difficulties and was spending much more time thinking about how to address them.

5.5. 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. Other schools have plans or are in the process of expanding into biology, astronomy, physical oceanography, physical geology, and mathematics.

6. Educational Impact

A great deal of research has been done while iteratively refining the SCALE-UP pedagogical approach, classroom layout, and activities. Besides hundreds of hours of classroom video and audio recordings, we have conducted numerous interviews and focus groups, carried out many conceptual learning assessments (using nationally-recognized instruments in a pretest/posttest protocol), and collected portfolios of student work. We have data comparing over 16,000 students over more than five years of instruction in traditional and SCALE-UP settings. A sample of our results is shown in Figures 5 to 7 and Tables 5-6.

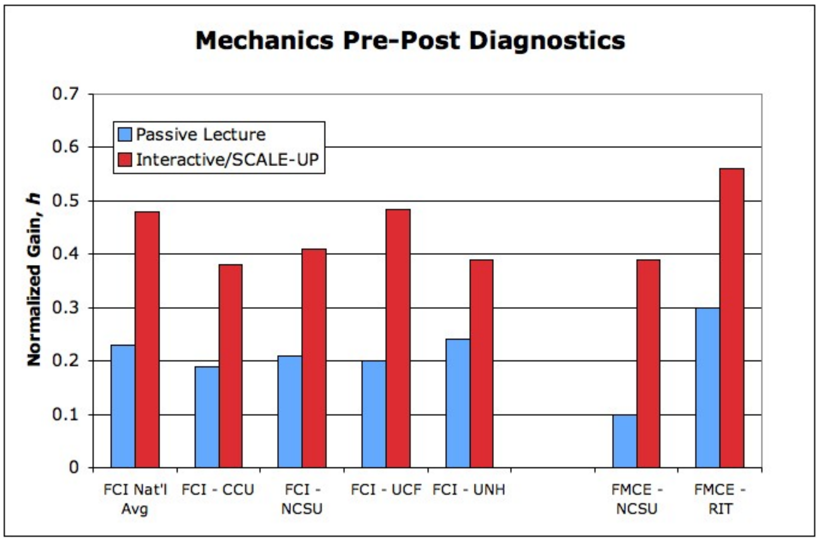


Fig. 5: The SCALE-UP class demonstrated better improvement in conceptual understanding than Lecture/Laboratory classes by achieving higher normalized gains for the Mechanics semester pre/post force and motion concept tests at Coastal Carolina University (CCU), North Carolina State University (NCSU), University of Central Florida (UCF), University of New Hampshire (UNH), and Rochester Institute of Technology (RIT). FCI is the Force Concept Inventory developed by Hestenes, *et al.* [46] FMCE is the Force and Motion Conceptual Evaluation developed by Thornton and Sokoloff. [47] The FCI national average is from Hake's 6,000 student study comparing Interactive Engagement classes with traditional Lecture/Laboratory classes. [48]

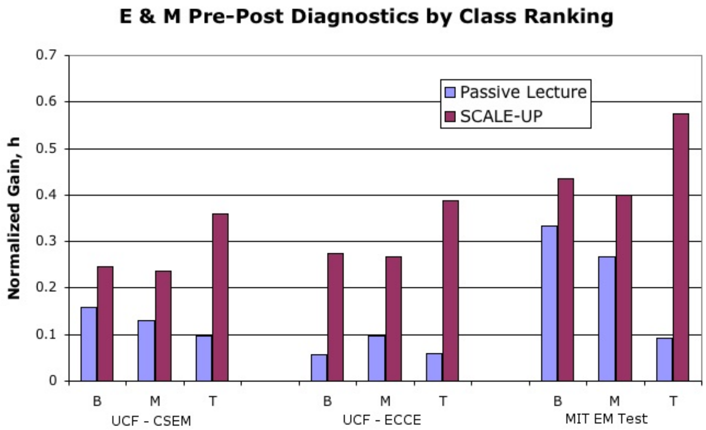


Fig. 6: Students in the top third of their classes gained the most from the SCALE-UP experience in improving their conceptual understanding, possibly because they were teaching their peers. CSEM is the Conceptual Survey of Electricity & Magnetism developed by Maloney, *et. al.,*[49] ECCE is the Electric Circuit Conceptual Evaluation developed by Thornton and Sokoloff.[50] The MIT E & M test was developed at MIT for their SCALE-UP implementation.[51]

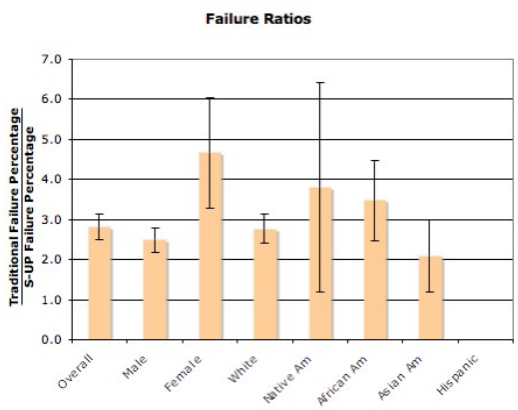


Fig. 7: Ratio of failure rate percentages for NCSU physics classes found by dividing the percentage of students failing in Lecture/laboratory sections divided by the percentage failing in SCALE-UP sections. Here, failing means receiving a grade lower than C – in the mechanics course or less than a D – in the E & M course, the grades needed to receive credit for taking the course. The Hispanic rate cannot be calculated because no Hispanic students have failed in an NCSU SCALE-UP section. Error bars represent standard error of the mean. More details are provided in Table 6.

Table 5. Pre, Post, and Normalized Gain Force Concept Inventory (FCI) results for regular Lecture/Laboratory classes, Honors Lecture classes, and SCALE-UP classes at UCF. The second column gives the number of classes and the average class size after midterm withdrawals. Honors classes are offered to students in the honors college taking an honors section. The proportion of physics majors is the same as in a regular class. Note that the SCALE-UP classes start within 1 σ of the regular classes and end within 1 σ of the honors sections.

Type of Class	***number/avg. size of classes***	***FCI avg. Pre (%) & Std. Error (%)***	***FCI avg. Post (%) & Std. Error (%)***	***Normalized gain, h***
Lec/Lab (Reg)	13 / 70	42.6% ± 3.3%	54.3% ± 4.1%	0.204
Lec/Lab (Hon)	2 / 19	65.3% ± 5.5%	71.4% ± 5.7%	0.176
SCALE-UP (all)	6 / 47	40.5% ± 3.5%	69.2% ± 6.0%	0.483
SCALE-UP (n > 60)	3 / 62	39.9% ± 4.8%	68.6% ± 5.8%	0.477

Table 6. Numbers of students and failure rate with uncertainty for students in calculus-based NCSU Physics 1 (Mechanics) and Physics 2 (E & M, Optics & Modern Physics). Ratio of failure rate percentages for NCSU physics classes found by dividing the percentage of students failing in Lecture/laboratory sections divided by the percentage failing in SCALE-UP sections. Here, failing means receiving a grade lower than C – in the mechanics course or less than a D – in the E & M course, the grades needed to receive credit for taking the course. The Latino rate cannot be calculated because no Latino students have failed in an NCSU SCALE-UP section. Uncertainty is calculated from binomial probability for passing or failing and then using propation of uncertainty for the ratio to calculate the standard error of the mean. The last column is the statistical significance of the ratio. This is calculated by subtracting 1 from the ration (a ratio of 1 indicates the failure rates are the same) and dividing by the standard error. *Note that the failure rates for Native American, Asian American, and Hispanic students in SCALE-UP classes are not statistically different (< 2.0 σ) from lecture instruction.

Group	***# of Students (Lec/Lab)***	***# of Students (SCALE-UP)***	***Failure Rate Ratio***	***σ (Std. Err.)***	***Stat. Sig. (σ)***
Overall	14804	1150	2.8	0.3	5.7
Male	11473	888	2.5	0.3	4.9
Female	3331	262	4.7	1.4	2.6
White	12009	922	2.8	0.4	4.8
*Native American**	*109*	*23*	*3.8*	*2.6*	*1.1*
African American	1361	114	3.5	1.0	2.5
*AsianAmerican**	*1026*	*65*	*2.1*	*0.9*	*1.2*
*Hispanic**	*299*	*25*	*No failures*	*–*	

Our comparison findings can be summarized as the following:

- Conceptual understanding is increased
- The top third of the class show the greatest improvement in conceptual understanding.
- Ability to solve problems is as good or better
- Attitudes are improved
- Class attendance is higher, typically > 90%
- Failure rates are drastically reduced (typically 50%), especially for women and minorities [see Figure 7 and Table 6]
- Performance in the second semester physics class is improved, whether taught traditionally or in SCALE-UP
- Failure of at-risk students in a later Engineering Statics class is cut in half

Many of these findings have also been observed at the secondary implementation sites in their introductory physics classes. They report a 2-3x improvement in normalized gain on pre/post conceptual learning assessments such as the Force Concept Inventory, the Force and Motion Conceptual Evaluation, Conceptual Survey of Electricity and Magnetism, and the Electric Circuit Conceptual Evaluation [see Figures 5 and 6]. This is similar to the results found in Hake's study of interactive engagement classes vs. traditional lecture instruction. On common problems on a final exam at UCF, the SCALE-UP students outperformed their peers in parallel lecture sections on the problem where the topic was covered with multiple activities and performed comparably when topic coverage was less than that in the lecture sections, typically a mini-lecture and a short ponderable. The secondary implementations also report greater than 90% attendance, and 40-60% reductions in failure rates in their pilot SCALE-UP classes compared with traditional lecture/laboraory classes in their program. These findings and the associated research methodologies will be discussed in detail in a later publication. Dori and Belcher describe similar studies carried out in their SCALE-UP adaptation at MIT.

7. Conclusion

In summary, we have found ways to maintain an active learning environment, even with large numbers of students. Collaboration is possible (and desirable) in these large classes and provides many of the benefits normally seen only in smaller classes. While learning a great deal about the importance of careful design of classroom settings, we have been able to help students add new 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, in terms of conceptual understanding and demonstrating problem solving ability as good or better than their peers in lecture sections. Other universities are adopting and adapting our curriculum and learning environment and we have established a website for materials distribution.

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