NSF SCALE-UP GRANT ANNUAL REPORT 1998

Summary

The goal of the Student Centered Activities for Large Enrollment University Physics (SCALE-UP) is to create and study an introductory calculus-based physics curriculum where the traditional lecture and laboratory are replaced with an integrated approach using active-learning, cooperative-group activities. The project includes development of curricular materials and a specially designed multimedia classroom. The multimedia classroom is designed to encourage students to work in groups, give each group access to networked laptop computers, and allow instructors to interact with each student group. The SCALE-UP curriculum is different from other integrated research-based introductory-physics curricula in three ways:

1. It is designed for use in larger classes (~100 students).
2. It is designed to use fewer resources per student, including instructor contact hours and physical classroom space.
3. The curriculum is designed to be modular. Instructors adopting this curriculum will have the flexibility to choose the activities that fit their student population, their resources, and/or their comfort level with active-learning activities.

The project is being conducted in three phases to study implementation of the SCALE-UP curriculum in three types of classrooms: (Phase I) a traditional lecture hall, (Phase II) a medium-sized (54 student) multimedia classroom, and (Phase III) a large (99 student) multimedia classroom. The multimedia classrooms will both be equipped with round tables to seat nine students in three groups of three. The Phase II classroom was completed in time for the 1998 Fall semester. The Phase III classroom is scheduled for completion in the second year of the grant.

A Phase I class was taught in the 1998 Spring semester. Two Phase II classes were taught in the 1998 Fall semester. The classes are evaluated through instructor journals & observer notes, diagnostic testing, student interviews, and samples of student work. While the Phase I class was more interactive than a normal lecture class, there were difficulties in implementing group activities. However, some gains in student leaning were observed. The Phase II classes have experienced success along several different avenues including the following:

- The classroom environment works very well in promoting collaborative group work and student access to technology.
- We have seen significant improvement in problem solving ability and conceptual learning.
- The majority of students seem receptive to the approach and have recognized the educational benefits of the SCALE-UP approach. Most of those making comments said they preferred this approach to lectures and they found this environment more helpful for learning physics.

Dissemination efforts have begun, including incorporation of certain aspects of the curriculum into a popular introductory textbook and expansion of our web-based homework delivery system. We are identifying difficulties with managing large classes and intend to develop means of addressing them in the remaining time of the grant. As we continue to design new materials, we will incorporate them into flexible materials that are readily accessible to other universities.

I. Participants: Who Has Been Involved?

A. WHAT PEOPLE HAVE WORKED ON YOUR PROJECT?

1. Instructors/Researchers in the Physics Education Research and Development (PER-D) Group at North Carolina State University (NCSU) — Note: * indicates people supported at least in part by the NSF scale-up award

Prof. Robert J. Beichner * (Co-PI)
Prof. John S. Risley * (Co-PI)
Dr. Scott W. Bonham (NSF SMETE Postdoctoral Fellow)
Dr. Jeffery M. Saul * (SCALE-UP Postdoctoral Research Assistant)
David S. Abbott (PER-D Graduate Research Assistant)
Rhett Allain * (PER-D GRA)
Melissa H. Dancy (PER-D GRA)
Duane L. Deardorff (PER-D GRA)

2. Computer Support in the PER-D Group

Dr. Larry Martin (Visiting faculty member at NC State): Development and Maintenance of WebAssign Homework system

Margaret Gjertsen (Administrative Staff): Hardware Support, Software Support, and Computer Networking.

3. Administrative Support

Patsy Little (Administrative Staff): Secretarial support, quarter-time

4. Other NCSU Physics Faculty and Graduate Students involved in the SCALE-UP project

Dept. Chairman C. Gould, Vice Chair R. Egler, Prof. G.W. Parker, Prof. J. Hubisz, Prof. F. Lado, Prof. J.R. Mowat, Prof. R.R. Patty, Prof. G.C. Cobb, Prof. J. Krim, Lect. E.A. Rieg, and Lect. E. Li, : These instructors and department officials allowed the students in the engineering physics classes (the same sequence as the SCALE-UP classes) to participate in pre/post course diagnostic during the 1998-99 academic year. In addition, the following instructors allowed us to record their student responses to tests and exams: Prof. G.W. Parker, Prof. F. Lado, Prof. J. Hubicz, Prof. J.R. Mowat, and Lect. E.A. Reig.

Gary Powell (GTA): In-class TA for 1st semester and 2nd semester SCALE-UP classes (Fall 1998).

B. WHAT OTHER ORGANIZATIONS HAVE BEEN INVOLVED AS PARTNERS?

1. North Carolina State University

The College of Physical and Mathematical Sciences contributed matching funds for this award. This support includes funding half of a post doc, material support, and lab equipment as well as the building and furnishing of the two experimental SCALE-UP classrooms. (The two rooms are the medium-sized classroom for 54 students we started using this fall and the full size classroom we hope to be using next fall). The furnishings of the medium-sized room include a visual (computer, videotape, and live camera display — the last replaces overhead transparencies) presentation system with two computer/video projectors, 6 six-foot diameter round tables with power and network hook-ups for laptop computers, and large white boards placed around the room. In addition, the Provost's office at NC State has been extremely helpful in getting the special classrooms designed and built.

2. FIPSE

The Department of Education Fund for Instruction for Post-Secondary Education has also awarded the SCALE-UP project a grant to be used to help defray the costs of development and implementation of the curriculum including the purchase of software, ULI computer interfaces, and sensors, and general lab equipment. The FIPSE grant is also used for administrative and travel expenses.

3. Hewlett Packard

The Hewlett Packard Corporation generously donated 39 laptop computers, 3 network servers, and 3 network printers to the SCALE-UP project. The donation of the laptops is unusual because they cost the donor more than comparable desktop computers. In fact, Hewlett Packard had several internal meetings to discuss our proposal, not on the proposal's merits but because of the request for laptop computers. A Hewlett Packard representative recently informed us that had the SCALE-UP project requested desktop computers, the proposal would have been funded with much less discussion. But as discussed in section II, the laptops are an important part of our classroom design. During a recent site visit, Hewlett Packard representatives visited our medium sized classroom and came away very satisfied with our use of their donated laptops. They were impressed at how the laptops fostered student table discussions by allowing students to talk over them, how the laptops allowed the students to do computer-based experiments in groups in fairly tight quarters, and removed themselves as a source of distraction when the instructor called for students to put their screens down.

4. Spencer Foundation

While a lot of effort has been spent developing and implementing computer-based homework delivery, collection, and grading systems, very little work has been done to explore the pedagogy of these systems. This is of great interest to us since the SCALE-UP project makes heavy use of a Web-based homework system (WebAssign) both in and out of class. The project recently received a grant from the Spencer Foundation for a project to compare the effect on student learning of well-graded written homework and WebAssign homework over the first semester of the introductory physics sequence for engineers (the same sequence as SCALE-UP). The foundation provided support for an undergraduate teaching assistant to grade the written homework. This project is discussed in more detail in section II.

C. HAVE YOU HAD COLLABORATORS OR CONTACTS?

1. Collaborators

Prof. W. Christian, Davidson College: Within the last two years, Christian has pioneered the development of graphical Java applets to make animated, web-based physics problems called

"*Physlets*." He is working with members of the PER-D group in developing, using, and evaluating this new physics teaching tool. Christian is also a pioneer in other uses of the web for physics instruction including the "Just in Time Teaching" method.

Prof. A. Titus, faculty at NC A&T University: While a member of the PER-D group at NC State, Titus contributed significantly to the development of WebAssign and the use of animated problems. He also studies the pedagogy of animated problems. He is continuing to work on these projects with several members of the PER-D group.

Senior Lect. Fellow M. Johnson, Lect. Fellow J. Tull, and Prof. R. Froh, Duke University: Members of the NC State PER-D group assisted with TA Training, teaching, and planning related to the adoption of active-learning activities in introductory physics classes at Duke University. We are also working jointly on analyzing and validating diagnostic test data from regular and innovative classes at our two schools. In addition, we are also meeting regularly to discuss development and implementation of innovative curricula (including SCALE-UP) at both institutions.

Prof. E.F. Redish, Dr. A. Hodari, Dr. B. Hufnagel, University of Maryland: Members of the PER-D group are collaborating on the collection and analysis of pre/post course diagnostic testing of undergraduate introductory physics courses nation-wide using traditional lecture and PER-based curricula, particularly from institutions with unusual student populations, historically black colleges and Universities and single sex institutions.

2. Visitors

The people in the table below came to North Carolina State University to learn about and/or contribute to the SCALE-UP Project.

NAME	AFFILIATION	VISIT DATE
Dowd, John	Univ of Massachusetts-Dartmouth	9/1/97
Hayden, Dr. Linda	Elizabeth City State University	9/6/97
Atalla, Dr.	University of Cairo	9/6/97
Lopez, Ramon	APS, Dept of Education & Outreach Programs	10/1/97
Donnelly, Denis	Siena College	10/10/97
Handler, Thomas	University of Tennessee	10/12/97
Saul, Jeff	University of Maryland	3/3/98
Johnson, Andy	San Diego State	3/18/98
Zietsman, Aletta	Univeristy of Witwatersrand	4/13/98
Thornton, Ron	Tufts University	5/1/98
Anderson, Maxine	NCSU Sociology Dept	5/6/98
Gastineau, John	Independent Consultant	5/18/98
Mark Johnson	Duke University	9/10/98
Robert Froh	Duke University	9/10/98
Don Ciaglo	Hewlett-Packard	10/21/98
Kelly Roos	Bradley University	11/16/98

3. Contacts

We are exchanging information with contacts at two schools that are using the Studio Physics approach to teaching introductory physics classes. This approach in similar to SCALE-UP in that it uses an integrated laboratory/lecture-based approach in a specially designed classroom, but differs in that the class size is typically limited to 40-50 students. However, this is similar to the intermediate SCALE-UP classes (up to 54 students) being taught in the 1998-99 academic year at NCSU until the full-size classroom is completed for the fall 1999 semester. At the 1998 Summer AAPT Conference, we discussed getting together to share our experiences and discuss issues of common concern.

K. Cummings, Rensselaer Polytechnic Institute: Development and evaluation of introductory physics curriculum for Studio Physics (Studio Physics was developed at RPI under the leadership of J. Wilson). Cummings recently showed[1] that conceptual learning gains on the FCI and FMCE in RPI studio introductory physics classes were not significantly different from what is found in traditional lecture courses. However, conceptual learning gains increased significantly when two established PER-based curricula[2, 3] were incorporated into studio physics classes at RPI. In classes using both curricula, the normalized gain on the FCI was almost three times better than the regular Studio Physics classes.

R. Knight and C.C. Hoellwarth, California Polytechnic State University (CPSU): CPSU has recently adopted the Studio Physics approach in some of their introductory physics courses. They have adopted Knight's textbook,[4] which is based on PER, and the Real Time Physics laboratory curriculum.[5] They have measured significant improvement in conceptual understanding[6] in the Studio Physics classes with no decrease in problem solving ability as measured by a common final exam for innovative and traditional lecture classes.

II. Activities: Report of Project Activity and Findings. What Have You Done and What Have You Learned?

A. THE MAJOR RESEARCH ACTIVITIES OF THE PROJECT

1. Problem Statement & Project Goal

While several PER-based curricula have demonstrated significant improvements in students' conceptual understanding and problem solving ability,[7,8,9,10,11,12] the best results are obtained when the course components (lecture, laboratory, and/or recitation section) are well integrated and the class itself has strong underlying themes. Some of the best results have come from curricula where the course is laboratory based, i.e. all components of the course are taught in one specialized classroom and the majority of time is spent on group-learning lab activities in class. For example, students taught using Workshop Physics have demonstrated improved conceptual understanding, laboratory skills, computer skills, and understanding of the nature of science. However, this curriculum is impractical at most large undergraduate institutions because of the small class size (less than 30 students) and additional resources required by the curriculum (instructor time, computers, lab equipment).

A previously successful integrated class (IMPEC, part of the NSF SUCCEED project at NC State[13]) was taught over several years at NCSU. Although the students worked in the same room in the same groups, each component of the class (Physics, Mathematics, Chemistry, and

Engineering) was taught separately. The evaluation of the physics component showed improvements in student learning similar to the Workshop Physics curriculum (discussed above) plus significant socialization for all students and increased success for at-risk students. The typical class size was 36 students. The SCALE-UP project builds on the lessons learned from the IMPEC project.

The SCALE-UP project has two goals. The first goal is to create a scaled-up version of the Physics component of the IMPEC course that is effective for 100 students in a technology-rich classroom specifically designed for group work. The second is to create an instructor's guide of active-learning group activities that faculty at other institutions could use in their own classes. The activity guide is designed to make it easy for instructors to adopt individual activities or the entire curriculum. The guide will include some options to help the instructors fit the curriculum to their students and their institution. This activity guide would continue to evolve as more instructors adopt this approach to introductory physics.

2. Development of the SCALE-UP classroom and curriculum

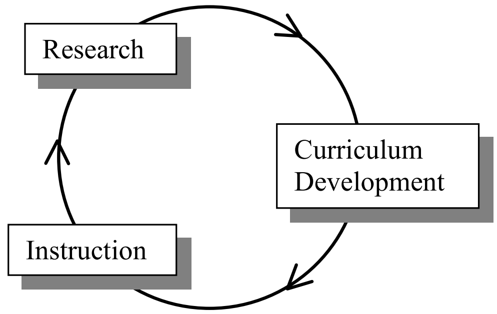
As noted earlier, the curriculum development aspect of the SCALE-UP project is taking place in three types of classrooms. In each phase, three aspects of the curriculum are evaluated: classroom management, room layout with regards to encouraging group work, and activity effectiveness. The project is designed to move from one phase to the next, as the specially designed group-learning classrooms become ready for use. We are currently in our second semester of Phase II. The activities currently being used are mostly adaptations of the IMPEC activities or simple hands-on lab activities from Phase I. However, we are also incorporating elements of University of Washington physics tutorials[14] along with new technology such as the WebAssign web-based homework system and the incorporation of Java applets.

The activities are written up for the activity guide – a comprehensive guide for instructors including pre-requisites, equipment, required time, potential problems, sample data where appropriate, and a step-by-step list of student tasks for the activity with reasons & notes for each task. The activity guide will also include an introduction to the research and philosophy behind the curriculum as well as some samples of how the activities might be incorporated into an introductory course. The samples will range from just using a few activities to occasionally supplement lecture to an almost complete active-learning curriculum. The idea is to write a curriculum that can be adopted in whole or in part depending on the needs of the instructor and the institution. The current plan is to start with a paper version of the activity guide and to later put it in HTML format for distribution on the Web or as a CD-ROM. The HTML format would allow a single version of the materials to be both Mac and PC compatible.

In developing the SCALE-UP curriculum, we are following the "wheel model" of research-based curriculum implemented by McDermott and the Physics Education Group at University of Washington.[15] In this model, the process of curriculum development has three parts:

(1) conduct systematic investigations of student views, understanding, and skills;
(2) apply the results to develop specific instructional strategies to address specific student difficulties; and
(3) design, test, modify, and revise curriculum materials in a continuous cycle on the basis of classroom experience and systematic investigations with the target population as shown in the figure below.

McDermott's iterative cycle process of research-based curriculum development



A critical part of the McDermott cycle is to focus on changes in the student. In an analogy with the study of a physical process, measurements are taken to determine the students' initial and final state to understand the transformation of student learning.

An important part of the SCALE-UP is project is to evaluate both students' reactions to the SCALE-UP class and what they are learning relative to a regular introductory course. In addition, individual activities are evaluated both for current effectiveness and with an eye to problems when we begin teaching SCALE-UP to 99 students at a time. In our evaluation of the SCALE-UP classes we use classroom observations, diagnostic testing, exams, and interviews.

To determine the initial state of the students in **both** the SCALE-UP and regular lecture classes, starting in the 1998 fall semester, **all students** in the introductory physics sequence for engineers were given diagnostic tests in laboratory or in lecture in the first week of classes. This testing is also used to see how typical the SCALE-UP students are compared with students in the regular lecture classes of the same sequence. We used various combinations of the FCI,[16] FMCE,[17] TUG-K, [18] CSEM,[19] DIRECT,[20] and MPEX[21] diagnostics. Four of these six diagnostics (FCI, FMCE, TUG-K, and MPEX are nationally recognized diagnostic tests published in the literature and three of them (TUG-K, MPEX, and DIRECT) were developed by past and present members of the PER-D group at NC State. The precourse testing is summarized in the table below:

A brief report from a preliminary analysis of the pretest data on the distribution of the most common student "misconceptions" was distributed to the instructors of the regular lecture classes in the introductory sequence. In addition, two lecture sections of the 1st semester course and the SCALE-UP class were given the Epstein Math diagnostic for mathematical thinking skills.[22]

Four methods are being used to evaluate the effectiveness of instruction in the SCALE-UP classes: observations by instructors and non-instructing observers, interviews, post-course diagnostic tests, and specially designed exam & quiz problems. Most of the instructors kept teaching journals to record their comments on student interaction with the SCALE-UP curriculum. Members of the NC State PER-D group acted as silent observers taking notes on how the activity was carried out, how much time it took, and on how well it worked. They also made comments on the teaching style of the instructors, their techniques for classroom management, and aspects of the social interaction in the classroom. In addition, a video camera records the activities of one group during each class. We have compiled 120 hours of recordings so far. We are experimenting with various combinations of recording equipment to improve

Pre-course Diagnostic Testing for all (SCALE-UP and Regular) engineering physics classes at NC State

	1st Semester course	2nd Semester course	Type of diagnostic
Fall 1998	FCI & TUG-K (N=400) MPEX (N=300)	CSEM & DIRECT (N=600) MPEX (N=350)	MC Concept Tests Cognitive Attitude Survey
Spring 1999	FMCE (N=900) MPEX (N=800)	CSEM & DIRECT (N=350) MPEX (N = 250)	MC Concept Tests Cognitive Attitude Survey

Where,

MC	=> Multiple Choice
FCI	=> Force Concept Inventory,
FMCE	=> Force and Motion Conceptual Evaluation,
TUG-K	=> Test of Understanding Graphs from Kinematics
CSEM	=> Conceptual Survey of Electricity and Magnetism,
DIRECT	=> Determining and Interpreting Resistive Electric Circuits Concept Test, and
MPEX	=> Maryland Physics Expectation Survey.

the quality of video and audio recording in class. These activities are essential for gathering information for compiling the activity guide and thinking about how these activities will work when we scale up to 99 students. This will help us learn more about how students interact with the activities and give us detailed information for improving the instructional materials.

While class observations give us considerable information on how well the activities are going, they are not informative about how the students perceive the activities. Also, the observations are not good indicators of how the SCALE-UP curriculum affects students' cognitive beliefs and attitudes. To learn more about these issues, we interviewed 7 student volunteers from the two SCALE-UP classes in the 1998 fall semester. The interviews used the MPEX survey protocol developed by Saul and Redish.[23] The protocol has proved invaluable in studying the effectiveness of research-based curricula from the students' perspective and in studying students' cognitive beliefs.

To determine if students are able to learn physics more effectively in the SCALE-UP classes, the pre-course diagnostics mentioned previously are used as post-course diagnostics to see how well SCALE-UP students improved over the semester. The same post-course diagnostics are also given to the regular classes of the same sequence for comparison with a control group. The results will show whether students who take the SCALE-UP classes develop better conceptual understanding of the basic physics concepts and develop a more sophisticated view of what physics is and how to learn it.

While the issues described above play an important role in learning, a crucial factor in the success of the curriculum is whether or not SCALE-UP students also learn problem solving at a level commensurate with (if not surpassing) regular lecture courses of the same sequence. To test this, regular and specially designed exam problems are given on exams in both types of classes. In addition, conceptual questions are given on quizzes and exams in the SCALE-UP classes to see if students can apply concepts in new contexts.

B. THE MAJOR RESEARCH FINDINGS RESULTING FROM THESE ACTIVITIES?

1. Students' Initial State

The findings from the pre-course concept tests described above were consistent with the findings in the PER literature. The pre-tests of the first semester mechanics classes showed many of the standard student preconceptions that are often resistant to instruction. Results from both force and motion concept tests, the FCI and FMCE, indicate that coming into the introductory physics sequence for engineering majors, many students (70-80%) strongly believe that force is associated with motion, not acceleration and that Newton's third law does not always hold true, particularly in collisions. In addition, 70 percent of the students who took the FMCE confused velocity and acceleration on at least half of the relevant questions (8 questions). The results for NCSU students in the engineering physics class were comparable to students taking a calculus-based introductory physics class at a liberal arts college where few of the students had physics in high school. The TUG-K test indicated student difficulties with confusing change in slope with area under the curve and seeing the graph as a picture of the motion.

The concept tests for the second semester of the sequence, CSEM and DIRECT, look at students conceptual understanding of Electricity and Magnetism and DC circuits, respectively. The results of the precourse DIRECT test indicate that the majority of students have had some exposure to circuits. Almost 70% of the students correctly answered items which compared pictures of circuits to circuit diagrams and 50% of the students correctly answered questions involving open circuits, short circuits, and complete circuits. The precourse results of the electricity and magnetism survey showed that very few students began the second semester with a good knowledge of basic electricity and magnetism concepts. This is not surprising. However, over two thirds of the students answered questions on electric and magnetic force in ways consistent with student preconceptions of Newton's third law. In addition, there are indications that many students view electric and magnetic fields as a fluid flow.

General results from both sets of diagnostic test data were passed to instructors early in the semester to give them more information about where their students were at the beginning of the semester. As mentioned earlier, data was also collected using the MPEX survey and the Epstein Math diagnostic, but this data will not be analyzed until summer of 1999.

2. Classroom design & Course Management

a. SCALE-UP in a lecture hall

In the 1998 spring semester, we implemented our first SCALE-UP class. This was a 2^{nd} semester course taught in a standard lecture hall with 75 NC State students. We found that while it was possible to do some group activities, it was a difficult environment for active-learning group activities. In addition, starting any type of active-learning curriculum in the second semester of the introductory course is usually difficult because by then the students have already decided what is and isn't necessary for them to learn physics and they tend to view anything new as unnecessary. There were also several other difficulties. For instance, it was very difficult for the instructors to check on the student groups far from the aisle. It was also nearly impossible for more than one or two groups at a time to present and discuss their findings either verbally or visually with the rest of the class. This has been found to be a critical component of several PER-based curricula. Another difficulty was the inability to establish network connections for each student group, set up the laptop computers, or set up anything besides very simple tabletop experiments. This severely limited the types of activities that could be done; many of the IMPEC activities[24] could not be used in this environment. However, simple hands-on experiments did work well. Some of these were developed specifically for this class and some were based on activities from Chabay and Sherwood's textbook on electricity and magnetism.[25] However, even though the students seemed to learn from these activities, the instructor/observers noted a few problems. Sometimes activities designed for one day would drag on for two or three days. The class discussions were often chaotic. In addition, the instructors found it hard to get students to quiet down and stay on task. This often led to inefficient transitions between activities. In summary, the activities were not well matched for the environment of the traditional lecture hall.

However, it should be noted that there are some PER-based curricula that have been found to be effective for some aspects of student learning in this type of classroom,[26] i.e. Interactive Lecture Demonstrations[27] and Cooperative Group Problem Solving.[28] We plan to try out a modified lecture curriculum using these methods in the 1999-2000 academic year.

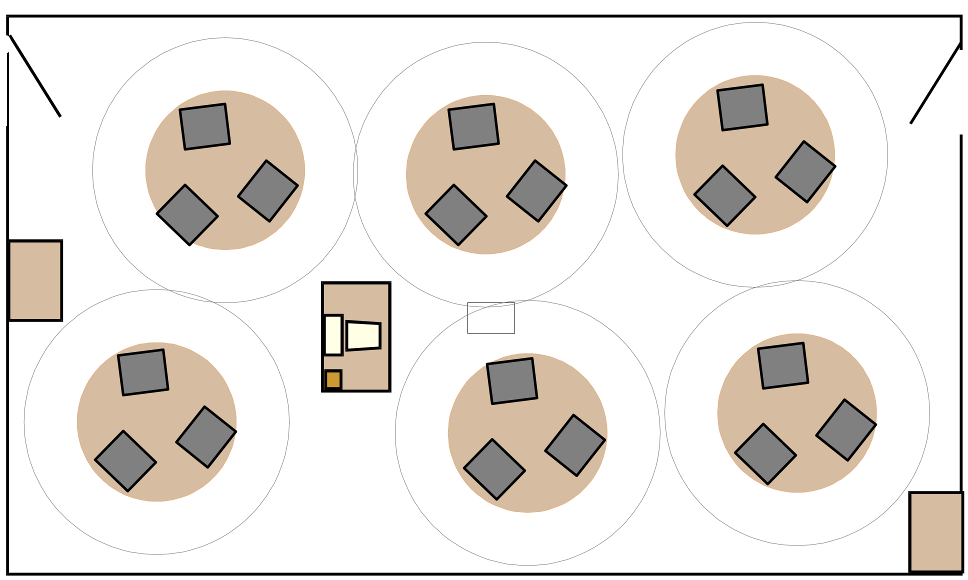
b. SCALE-UP in a medium-sized multimedia classroom designed for groupwork

In the 1998 fall semester, following the completion of the medium-sized SCALE-UP classroom (54 student capacity), we began Phase II of the SCALE-UP curriculum development project with a room specially designed for cooperative student groups working in a technology-rich environment. Diagrams and photographs of the intermediate SCALE-UP classroom are shown below. The intermediate classroom is designed to encourage students to work in groups, and it uses multimedia technology for both group work and presentations. Many visitors and faculty from other classes ask, "where is the front of the room?" since that is where they are used to seeing instructors present their lectures. However, this classroom does not have a front *per se*. The room is designed so that the instructor presents material from the small station in the middle of the room and projects from a computer, video, or camera on screens on both short walls. The design is intentional so that the instructor is in the middle of class discussions. This makes it easier for an instructor to act as moderator for a class discussion rather than the authority figure at the front of the room. (Note that the camera, clearly seen in both photographs, replaces the traditional overhead projector. In addition to duplicating the functions of an overhead projector, it can also project from any hardcopy, including books.) In addition, the walls of the room are lined with white boards. The white boards are used by both by students and instructors. At each of the six tables, there are three groups of three students each. Each student group has a laptop computer with network and Internet access.

Unlike the lecture hall discussed above, all of the IMPEC and the Phase I group activities can be implemented. The room is very conducive to group work and most PER-based curricula can be used in this environment. When given group activities with or without the computer, the student groups are working together on task most of the time. The layout of the room allows the instructors to work with any group and pass out any equipment required for class activities. The students can present their finding from their seats, from the white boards, or from the instructors' station. However, the current room is crowded as can be seen in the photograph above. Since space is at a premium, the round tables and laptops are essential elements of the SCALE-UP design at NC State. To accommodate 54 students in the limited space available (the room is only a little larger than other active-learning classrooms designed to hold 30 students), three student groups of three students each sit around six-foot diameter tables. While this is not too crowded, it is not spacious. The small footprint of the laptops is advantageous, and the laptop's short height does not diminish communication between groups across the tables. This cross table communication was one reason for the circular tables. This allows the students to share information and help each other. In addition, unlike desktop computers, the laptops can be closed during class discussions and presentations.

While the room is very conducive to the group activities that form the core of the SCALE-UP curriculum, there are some problems. For instance, there are two PER-based curricula that are effective for improving students' conceptual understanding which are difficult to implement in the intermediate classroom, University of Washington Tutorials for Introductory Physics[29] and Interactive Lecture Demonstrations (ILDs).[30] Because of the room layout and the limited space, it is difficult to carry out most demonstrations, interactive or traditional, in a way so that all students can see what is happening. The Phase III classroom is being designed with a larger central area to address this problem. The problem with tutorials is that they require instructors to coach the students in the activities through semi-Socratic dialogue.[31] This works well when the ratio of groups to instructor is five to one or less. In the present SCALE-UP classroom, the ratio is nine to one and in the Phase III classroom, the ratio will be eleven to one. We are currently experimenting with using the tutorials in two modified formats. In one format, class discussion is used to replace the instructor-group interaction group problem. In the other format, the pretest (a conceptual quiz that is a key component of the Tutorial teaching method) is used as a quiz following lecture or activities on a particular topic. Then each student hands their quiz to a another student at a different table for grading. At this point the quiz questions become the focus of a class discussion as the class goes over the quiz. As the discussion above shows, classroom management and the details of the curriculum are key factors to the success of a SCALE-UP class.

Intermediate SCALE-UP Classroom: 3 groups per table, 1 laptop for every group of 3 students



Photographs of the Intermediate SCALE-UP Classroom: (Upper) In this picture, the laptops are set up on the tables and the instructor station is clearly seen in the foreground. Note the two projectors placed back to back on the ceiling. (Lower) A typical SCALE-UP class in session.

c. Classroom management

To make any curriculum work in the classroom, it is necessary to consider more than just the room and the activities, it is also important to consider what the instructor does to implement the curriculum in the classroom. In the course of the Phase II SCALE-UP classes, we have explicitly addressed four aspects of classroom management: managing collaborative groups, assessing and reinforcing the course goals, time management, and cheating.

Managing Collaborative Groups — The functioning of the groups is a critical component in any PER-based curriculum. We have adopted several techniques from the education research literature to encourage the SCALE-UP groups to work well together. These include assigning students to groups of mixed ability, group contracts, assigning group roles to tackle open-ended tasks, and requiring the group members to evaluate the group on a regular basis. To encourage the groups to work together during group activities, the instructors only respond to questions from the group leader and the group recorder presents the group's results. To encourage the groups to look out for their weaker members, the groups are rewarded with bonus points when all the members do well on a particular activity or assessment. Recently, a student asked if he could give his bonus points to another group member.

Time management — Unlike Workshop Physics, the SCALE-UP classes cover the same course material as the regular engineering physics classes at NC State. Because active learning typically takes more time to go through material than lecturing, time management for the SCALE-UP curriculum is crucial. For example, students are required to read the text and often solve textbook problems before the relevant material is covered in class. This is encouraged by asking quiz questions on the weekly readings and homework. We found that to keep students on task in class, we generally allow only enough time for most, but not all students to finish an activity. Enough time is allowed so that a group working through the activity at a reasonable speed with minor difficulties could finish. We permit students to finish up graded activities during office hours. With limited exceptions (mainly labs), during in-class activities the student groups are given short activity segments (2-10 minutes) to help keep the class together and not let the slower groups get behind. We have found having the students discuss what they found encourages them to stay on task and to try to understand the activity better.

To reduce grading time, the *WebAssign* computerized homework system is used in all engineering physics classes. The *WebAssign* system was developed locally by members of the SCALE-UP team. Typically the system delivers the same problems to all students in a class but each student has different numbers in the problem statement. This means that students cannot just copy the final calculations from one another to answer the homework questions. The system has the capability of tailoring homework assignments for individual students. *WebAssign* also gives students immediate feedback on the correctness of their responses and makes course grade records available to each student. In addition, we are experimenting with having students grade each other's work.

Assessment and Reinforcing Course Goals — The SCALE-UP curriculum has several student learning goals beyond doing well on typical end-of-chapter problems in standard texts. PER studies have shown that many students who do well on traditional measures of student success often do not have a good understanding of basic physics concepts or the nature of what physics is and how it can be used. Often, the students don't see physics as being strongly connected to physical situations in their everyday lives. In addition, the emphasis on typical end-of-chapter problems discourages the development of expert-like problem solving skills, one of the main learning goals of the introductory physics course for engineering majors. Research has shown that to help students acquire additional knowledge and skills, the knowledge and skills must be effectively taught to the students,[32] practiced by the students during class activities including homework, and reinforced by testing.

The teaching component includes modeling the desired skills for the students, emphasizing activities that promote conceptual understanding and relating the concepts to quantitative problems, and using real world examples whenever possible. This practice component is conducted through group activities and homework. The homework consists mainly of quantitative problems distributed and graded by WebAssign (described above). Since the WebAssign homework system only looks at students' final answers, each group is also required to submit written homework solutions using the GOAL problem-solving protocol.[33] The GOAL protocol (Gather, Organize, Analyze, and Learn) is a four-step problem solving strategy is based on expert-problem strategies. In addition, we are currently experimenting with additional qualitative homework related to the *Tutorials* in the first semester class. Student notes are sampled and graded on a regular basis to encourage good note-taking skills. This has worked exceedingly well with students requesting that notes be collected because they know they've done a good job.

In addition to the homework, the course goals are also reinforced through quizzes and exams. This is important because while homework helps students practice what they learn, students quickly learn that the bottom line on their grade is how well they do on quizzes and exams. The quizzes and exams for the SCALE-UP classes are carefully constructed to reinforce the course goals. The tests and quizzes use both quantitative and qualitative physics questions, require the use of the GOAL protocol, and ask questions about various representations including graphs, diagrams, and written explanations. In addition, each quiz has a basic question on the current reading assignment to encourage students to read the book carefully.

Cheating — One problem with the current classroom is that the close quarters in the intermediate SCALE-UP classroom make it a little too conducive to group efforts during testing. The students are very close together and can look at a neighbor's paper with very little effort. This makes it very difficult to control and/or monitor cheating. Currently, the situation is remedied by having the students take exams in a lecture hall. Other approaches are being considered.

3. Curriculum Development

The key part in creating an integrated active-learning classroom is the curriculum. Building on the IMPEC activities, the curriculum for the SCALE-UP project has focused on the use of computers and multimedia to help improve the students' conceptual understanding of the course material and their problem solving skills. The curriculum also includes a problem solving strategy, the GOAL protocol, and group problem solving including estimation problems. The computers are used in the following ways:

- Web delivery of student materials including "ponderables," "tangibles," laboratory activities, *Physlets*, and homework.
- Use of microcomputer-based laboratory (MBL) and video analysis activities that have been shown in the PER literature to be effective for improving student learning.

- Simulations to help students explore and understand mathematical models of physical situations.

a. Web-delivered course materials

Whenever possible in the SCALE-UP curriculum, materials are placed on the web. There are several advantages to this approach. For instance, while several computer applications have been used effectively in introductory physics classes,[34] they must be made available in public computer labs to be used by students outside of class time. This can involve installation and copyright issues on campus networks. Access through public computer labs is also impractical for many students who do not live on campus and who work part-time. However, this year at NC State, 50% of the students have access to a computer in their rooms or homes. Web-based delivery means these students have access to materials whenever they wish to, even if they live off campus, as long as they can access the Internet. Another advantage is that course materials presented on the web can be interlinked and easily modified by the course instructor. In addition, our web-based homework system, WebAssign, permits individualized assignments for students and gives immediate feedback on the correctness of their responses to multiple-choice or short answer questions. WebAssign also maintains a gradebook so students can check their grades at any time.

However, WebAssign only asks for the answer to a problem and does not look at how students solved the problem or their reasoning. There are indications in the PER problem-solving literature that this may reinforce student perceptions that only the final answer is important and devalue the reasoning process to get there. To address this issue, we are a conducting a small project funded by the Spencer Foundation to look at the pedagogical value of WebAssign homework verses traditional written homework. Two lecture sections taught by the same lecturer are being given the same homework problems, one through WebAssign and one as assigned problems in the text. The traditional homework assignments from the text are graded by a TA specially hired for the project to give students good feedback quickly.

The terms ponderables, tangibles, and *Physlets* are relatively new and need to be explained. Ponderables and tangibles are short problems that are used as group activities. Ponderables are thought problems (similar to the Concept Test problems developed by Eric Mazur[35]) that students work out on the computer or on hardcopy. Tangibles are problems where some equipment is used to help students visualize or explore the phenomenon in question. Some, but not all, of the tangible activities are really short lab activities. The term *Physlets* was coined by Christian at Davidson College to describe a class of Java applets he wrote to present physics simulations on the web either as simulations or animated problems.

We have made use of Christian's *Physlets* to design in-class problems to be used as ponderables. Although only a few have been used in the mechanics portion of the course, 75 *Physlets* have been created to illustrate principles in electricity, magnetism, and optics.[36] We have focused most of our effort on these areas because while there are already many active-learning group activities for mechanics, there are fewer such activities for topics beyond mechanics. We have also developed a new use of *Physlets* that would let students make predictions before observing a situation in the Predict-Observe-Explain (POE) style of activity prevalent in the PER literature.[37]

b. Laboratory activities

MBL, video analysis, and simulations are used along with more traditional laboratory apparatus to let students study physical situations. PER has shown that MBL and video analysis activities can be very effective for improving student understanding of graphical representations and the connection between a graph and the physical situation, particularly for graphical representations of physical parameters such as force, energy, velocity, and acceleration.[38] However, computers are used in activities only when there is an advantage to doing so. If the point of an activity can be made just as well and just as easily without using computers, then more traditional tabletop experiments are used. Simulations using *Interactive Physics* (first semester mechanics course) and *Physlets* (second semester E & M, optics, and modern physics course) are used both to help students develop conceptual understanding and to give students practice in mathematical modeling.

For some lab activities in mechanics, the lab might consist of three different activities so that each group at a table is working on a different activity at any given time. During the lab, each group will rotate through all three activities. For example, in a lab on constant acceleration, students did experiments on fan carts with motion sensors, analyzed video clips of a volleyball serve, and created a projectile motion simulation using Interactive Physics. This type of laboratory has significant learning and logistical advantages. It lets students explore the same idea in multiple contexts, lets them analyze these situations with a variety of tools, and allows inclusion of activities when there is enough equipment for six groups but not eighteen groups. This last advantage is particularly helpful for including activities that require expensive equipment like the charge-to-mass ratio experiment.

By having the laboratory as part of the integrated class, the laboratory activity is then synchronized with the rest of the course. In addition, the laboratory classes become part of the shared experience of the class rather than a related adjunct to it. Discussing related situations/problems both before and after the lab can reinforce this integration. Laboratory skills are tested throughout the groups by following the lab with a lab practicum where every student must demonstrate specific skills and an understanding of the underlying physics.

c. Activity guide

The activity guide is coming along slowly. Only 10% of the activities are currently written up. However, in addition to the instructor notes on what is and isn't working, all classes are being videotaped and there is one non-instructing observer taking detailed notes on each class. Our plan is to finish the first semester activity guide in time for use during the 1999 fall semester. The second semester activity guide will be completed in the 1999 fall semester.

4. Evaluation of the SCALE-UP Curriculum

As discussed earlier in Section II, four methods are being used to evaluate the effectiveness of instruction on student learning in the SCALE-UP project: pre/post course diagnostic testing, analysis of exams & quizzes, classroom observations, and interviews. A PER assessment specialist was hired as a post-doctoral associate before the 1998 fall semester to manage the course evaluations for the SCALE-UP classes. The preliminary findings are listed below.

Initially, we thought that the IMPEC classes could be used as a standard of what was possible for NC State students in the engineering physics sequence using an integrated active-learning curriculum. However, now there is evidence to suggest that both the population and the experience may have been sufficiently different as to make direct comparison difficult. First, all the IMPEC students were volunteers. These volunteers had significantly higher pre-course FCI scores than the SCALE-UP students and the students in the regular lecture courses. While normally a difference of 5-6% points does not seem like much, The IMPEC scores are at least 5 standard errors above what would be expected for a random sample of NCSU students in this sequence. Second, observers and instructors in the 1998 fall SCALE-UP classes noted that the student groups took longer with the activities and were off task more often than the IMPEC students. They also observed that while the IMPEC students interacted well with each other in and out of class, the SCALE-UP groups did not achieve a similar degree of socialization. However, in the IMPEC classes, the same students worked in the same groups for four different classes. They also had a Listserve to communicate questions and ideas to everyone electronically. This summer we will be looking at how to duplicate the IMPEC experience more fully in the SCALE-UP classes.

a. Conceptual understanding diagnostic tests

The following diagnostic tests were used during the fall 1998 semester for pre/post evaluation of instruction: FCI, TUG-K, CSEM, DIRECT, and MPEX. Due to logistical difficulties we were only able to collect post-course test data from a small fraction (~15%) of the students enrolled in the regular lecture course of the introductory physics sequence during the 1998 fall semester. Similar difficulties prevented us from collecting any post MPEX data. While the poor participation rate allows some analysis to be done of the concept test data, the low post-course turnout raises the possibility of sample bias and threatens the validity of the conclusions drawn from the data on the 1998 fall regular lecture classes. We have changed our procedures for post testing and are confident for our post-course testing sample will include a much larger fraction of the students in the regular lecture sections.

First Semester Mechanics class — Two concept tests were used to measure the improvement in students' knowledge of basic physics concepts in this class: the Force Concept Inventory (FCI)[39] and the Test for Understanding Graphs in Kinematics (TUG-K). The FCI, developed by Halloun, Hestenes, Wells, and Swackhammer,[40] is the most commonly used physics conceptual evaluation test in the United States today.[41] It is designed to measure students' belief in Newtonian laws of motion vs. the student's common sense beliefs. The TUG-K, developed by one of the SCALE-UP PIs, looks at student understanding of graphical representations of position, velocity, and acceleration vs. time. Both tests have questions that are explicitly designed to trigger and identify specific common sense beliefs identified by the research literature.

In his recently published study of FCI results from over 6500 students, Hake found that the figure of merit for gains in students' conceptual understanding in a class was the average fraction of the possible (fractional) gain h, where h is defined as follows,[42]

$$h = (\text{class post-test average} - \text{class pre-test average}) / (100 - \text{class pre-test average})$$

Hake collected FCI data to see if PER-based curricula are more effective for teaching Newtonian mechanics than traditional lecture methods. He found the following result:

Traditional Classes (14 classes, N = 2084 students) $h = 0.23 \pm 0.04$ (Std. Dev.)

PER-based Classes (48 classes, N = 4458 students) $h = 0.48 \pm 0.14$ (Std. Dev.)

where *h* is averaged over classes, not students. The average fractional gain of the PER-based classes is twice as great as the average gain for traditional lecture classes. Note the narrow widths and large separation of the two distributions. Based on Hake's work, the fractional gain is considered the best measure of improvement in student understanding of basic concepts on pre/post diagnostic tests. The FCI results from the regular, IMPEC, and SCALE-UP classes is shown below:

FCI test data for first semester mechanics classes from the engineering physics sequence

Class	Normalized Gain h
Regular F 97 *	0.21
IMPEC Sp 96	0.42
IMPEC Sp 97 *	0.55
SCALE-UP F 98	0.42

* - These classes were given FCI v. 2; some schools experience a 5-6% drop in scores for calculus-based introductory physics courses using v. 2 for pre-course testing.

The SCALE-UP and the IMPEC classes have twice the normalized gain of the traditional lecture class. The following four points should be noted. First, these results are not just due to instructor effects since the same instructor taught the regular class, the IMPEC classes in 1997, and the SCALE-UP class in 1998. Second, despite differences between the SCALE-UP class and the IMPEC classes, the normalized gain for the SCALE-UP class is comparable to the normalized gain for the first IMPEC class. Third, the standard error of the mean for all four normalized gains is 0.05 ± 0.01, i.e. the distributions are fairly narrow. And last, the normalized gain results for IMPEC, SCALE-UP, and regular lecture course are consistent with the results of the Hake Study. These results indicate that the SCALE-UP students improved their understanding of the basic concepts of force and motion much better than traditional students and as well as one of the two IMPEC classes.

The results were very different for the TUG-K test. The results are shown below. The normalized gain for the SCALE-UP class is not statistically different than the normalized gain for the regular lecture classes. The IMPEC class has twice the fractional gain of the other two classes. The standard error of the mean for all three measurements is 0.01 ± 0.01. This result indicates that the SCALE-UP students showed the same amount of improvement in their understanding of kinematics graphs as the regular lecture students and much less improvement than the IMPEC students.

TUG-K — SCALE-UP gain comparable to regular lecture instruction, but not as good as IMPEC

Class	Normalized Gain h
Regular classes	0.40
IMPEC	0.89
SCALE-UP F98	0.42

Second Semester E & M, Optics and Modern Physics class — Here as well, two diagnostics were used as pre/post course tests to measure improvements in students' understanding of basic concepts: the Conceptual Survey of Electricity and Magnetism (CSEM)[43] and the Determining and Interpreting Resistive Electric Circuits Concept Test (DIRECT).[44] These two diagnostics are relatively new (CSEM is still under development) and not as well established as the TUG-K and FCI.

A graduate student in the PER-D group at NC State developed the DIRECT diagnostic as a Ph.D. project. As the name implies, it is designed to look at students' conceptual understanding of DC resistive circuits. This test has been validated and tested for reliability. The results are as follows:

DIRECT results: Both the Phase I and II scale classes show some improvement than the regular lecture classes. Note that here, the result from the regular classes is averaged over 6 sections.

Class	Normalized Gain h
Regular F 98	0.10
SCALE-UP Sp 98	0.16
SCALE-UP F 98	0.17

The SCALE-UP classes had significantly higher gains than the average of the regular classes. However, because of sampling problems the result from the regular classes should be viewed with caution. Note that Phase I and Phase II SCALE-UP classes did about the same. This indicates that the DC circuit activities worked equally well in both formats. However, the normalized gains indicate there is much room for improvement and DC circuits are only a small part of the second semester curriculum.

The CSEM is being developed to provide an instrument that measures student understanding of a broader range of concepts from the second semester curriculum. The developers of the CSEM agreed to let us use the beta version to evaluate the second semester SCALE-UP course. The results are shown below. While the SCALE-UP class achieved a larger normalized gain than the regular class, the difference is small and again the normalized gain shows significant room for improvement.

CSEM: The SCALE-UP class again has the higher normalized gain, but the difference and total are small.

Class	Normalized Gain h
Regular F 98	.14
SCALE-UP F 98	.21

b. Exams

Exam scores for a course do not reveal much about students learning unless there is some basis for comparison, either with pre-course results for the same class, exam results for a similar class whose population is similar,[45] or where the problem difficulty is established in some other way. For example, if the students are shown to do well (> 60% correct) on a problem that physics graduate students find challenging, then the result demonstrates student mastery of that problem.

In the 1998 fall semester, two methods were used to compare exam results for the SCALE-UP classes with the regular classes in the introductory physics sequence for engineering majors. Because of the unusual structure of the NC State exams, it is worth describing them here. Each of the four regular exams consists of 15 multiple choice questions and a five-part written response problem. The final exam consists of 40 multiple-choice questions which are a combination of qualitative and quantitative problems. The same exams are given to all lecture sections at a common time. Since the SCALE-UP project decided to use exams to reinforce goals beyond what was asked of students in the regular classes, it was decided that this structure was too rigid to use. The instructors of the two SCALE-UP classes used two different approaches for comparison with the regular classes. The instructor of the first semester class used some multiple choice problems and parts of the long problem while the other instructor adopted only the long problem to a strict multi-part GOAL format. The latter instructor gave the same final exam to his SCALE-UP class that was used in the regular lecture classes. The results were mixed and we have instituted changes in testing procedures to improve our ability to compare student learning in the two formats. This includes negotiating to change the format of the regular final exam to permit specially designed problems that would test students' understanding of the physics and their problem solving ability. The results from the 1998 fall semester are as follows:

First Semester Mechanics class — On two of the regular exams, eleven of the thirty multiple-choice questions from the common exam for the regular lecture classes were used on the SCALE-UP exams as well. Eight of the problems dealt with force and energy while the other three were basic questions on center of mass, angular velocity, and torque. The last two topics were not covered in class but were given as reading assignments with homework. The SCALE-UP students did significantly better on the eight force and energy problems (88% vs. 61% and significantly worse on the other three (41% vs. 64%). For the final exam, the SCALE-UP final consisted of the FCI and 20 of the 40 multiple-choice problems that made up the final exam for the regular lecture sections. The average scores for the twenty problems for the SCALE-UP (N=45) and regular classes (N=488) were not significantly different (71% vs. 72%) even though only five of these problems addressed force or energy.

Second Semester E & M, Optics, and Modern Physics class — Comparison of exams in this class was more difficult because of the differences in format and grading for the regular lecture and SCALE-UP classes. Each SCALE-UP test had more qualitative problems and a long problem with the GOAL protocol with no multiple-choice questions. When both classes used a common long problem, the analysis showed that the SCALE-UP students used different approaches and made very different mistakes. The results were not comparable. Since the same final exam was given to both types of classes, a valid comparison analysis was possible. Overall, the regular students barely scored significantly better[46] than the SCALE-UP students (63 ± 1% std. error vs. 56 ± 3% std. error). An item analysis showed that the SCALE-UP students scored at least 10% better on four of the 39 exam items and at least 10% worse on 18 items. However, an examination of the questions the SCALE-UP students scored at least 10% less on indicated that a large part of the problem was an inability to adjust to the multiple choice format with three formula sheets which they had not seen before the final weeks of the semester.

c. Classroom Observations

In each SCALE-UP class there are two facilitators, an instructor and a TA. Both keep notes on what goes on the classroom. In addition to the instructors, there is a member of the Physics Education Research & Development Group observing the class. In most cases the observers do not interact with the class at all; they pick a vantage point and stay there, silently taking notes. A protocol was developed to help the observers focus on the following points:

- How the instructors manage the class and interact with the students
- Whether the students are engaged by the class activity and able to work through it with a minimum of help from the instructors.
- Determining how long each activity lasts and whether it would be suitable for use when SCALE-UP is used in a class with 99 students.

Both the instructors and observers have compiled extensive logs on which aspects of the SCALE-UP project are working well in the Phase II classroom and which aspects need more work. A brief summary of their comments from the SCALE-UP implementation in the 1998-1999 academic year on classroom design, classroom management & instruction, and student behavior is given below. In addition, a summary of student comments follows.

Both the observers and the instructors agree that most aspects of the Phase II classroom are working well. The use of technology appears to be effective; the equipment is functioning properly and does not distract the students. The projected display is clearly visible from the opposite side of the room even with the lights on. The round tables make group and table discussions much easier than a traditional lecture hall with the same capacity. However, there are some problems with the classroom design that need further work. For example, the classroom is too crowded; there is not enough room for instructors to roam freely or for the students to easily access the white boards. Also, during class discussions, it is often difficult to hear individual student responses to instructor problems. In addition, observers have commented that the handing out of equipment for lab activities can be very disruptive. A large part of this difficulty is due to the lack of equipment storage space in the Phase II classroom. The Phase III classroom will have cabinet space to store equipment for each table. The last major problem we found with the room design is that demonstrations are hard to see; although, small demonstrations can be effectively shown on the two screens using the camera projection system.

One of the biggest challenges in implementing an active-learning classroom is developing the classroom management techniques to keep students engaged and on task. This aspect of classroom management is vital to the success of the project. We've seen a variety of responses to different kinds of activities and we are analyzing our data to determine how to maximize student attention. The observers have noted that the most common off-task activities are working with the Interactive Physics simulation program and doing WebAssign homework assignments. By studying the comments from the instructors and the observers, we have been able to learn which techniques are working. For example, the observers have noted that during the harder activities some groups will flounder and perhaps give up until the group received help from one the class instructors. (There is a lead instructor and a TA in each class.) We have found that holding students accountable for the in-class activities helps to motivate them to stay on task. One technique for this is to call on students by name after a group activity and ask the students to explain what they found or ask for verbal feedback for a class activity. To help the instructors learn students' names quickly, both classes have students make and use large (4" x 11") name tags which sit on the table. The observers have commented that this has the additional effect of "personalizing the class environment and makes for a friendly atmosphere." Another technique for keeping students attentive in class is the collection and grading of students' class notes. This acts as an incentive to pay attention in class and help students develop better note-taking skills. Even with these techniques, students can easily get off task during class activities, particularly when they have computers connected to the Internet. One way to keep them from drifting off task is for the instructor to give time expectation cues. For example, "You have 5 minutes to come up with an answer to this problem. If the cue is timed so that most but not all of the students can finish, this keeps the class focused to the task on hand and improves their attention to the class discussion that follows.

Another big challenge is the design of active-learning activities and the encouragement of cooperative/collaborative groups. Although the student groups and the active-learning activities appeared to be working well in the 1998 fall semester, the observers commented that during the activities few of the group discussions focused on the subtleties of the key concepts in the course. To address this, the two current SCALE-UP instructors have found different ways to adapt materials from McDermott *et al.*'s *Tutorials in Introductory Physics*. One is using conceptual quizzes with in-class student grading and the other is adapting the Tutorial Worksheet activities as in-class group activities. Observers have noted that both methods are promoting more student discussion of the material but observers have noted that for the latter activity careful classroom management is needed to keep students on task and to see the point of the activity. Another technique we have borrowed from the PER literature is the use of group roles to promote better group interactions and problem solving. The group roles are organizer/manager, checker/recorder, and skeptic. The observers noted in the 1998 fall semester that although group roles were introduced in the beginning of the semester, few of the student groups paid attention to the group roles. The observers believe this was because there was little follow up and little accountability for the group roles. To encourage the group roles, the students are asked to rate each group member's performance in their role for graded assignments and the groups are given 5 extra points on exams if the average score for the group is least 80% on the exam.

There are also comments that the SCALE-UP curriculum is influencing student behavior. The observers made the following comments:

- Class attendance is high, students have more incentive to come to class. [Instructors note that typical attendance is least 80%.]
- Students openly ask questions when they do not understand.
- Students are generally attentive and respect the instructors.
- Students discuss predictions and results within their groups.
- Discussions of problem solutions often include frequent interaction and input from students.
- During the five-minute break in the middle class, many students continue to work at their tables.

d. Student Comments

Student comments are solicited regularly during the course. At various times during the SCALE-UP class, the students are asked to make comments to the instructors regarding what is and isn't working for them in the course as well as what they plan to work on to improve. One thing that is clear from these comments is that students do not believe they learn well from open-ended activities that require planning and thinking. This is consistent with findings of cognitive attitudes of freshman and sophomore undergraduates in the education research literature.[47] They tend to prefer working out solutions to typical end-of-chapter problems, which form the bulk of their homework assignments.

In addition, the NC State Physics department collects course evaluations from the students at the end of the semester. The course evaluation form has nineteen multiple-choice items and room for written responses to the following three questions: (1) How would you describe this course to other students? (2) What do you like best about the instruction? (3) What do you like least about the instruction? Over 80% of the students in each class completed the end-of-semester evaluation. At least two-thirds of these students included written responses to the three questions. The responses of students who included written comments were rated as "favorable" if most of the comments about the course indicated that the student liked the SCALE-UP approach and "unfavorable" if most of the comments indicated that student did not like the SCALE-UP approach. If a student's written responses could not be rated as favorable or unfavorable, they were rated as "mixed." Approximately half the students in each class who included written responses were rated as favorable. A summary of the ratings is shown below. By looking at both the multiple-choice and written responses, it is possible to draw some insight on student perceptions of both classes

What we found was that most of the students in both 1998 fall semester SCALE-UP classes liked the SCALE-UP approach and found it more helpful for learning than traditional lecture courses. A small fraction of students disliked the approach and believed they were not able to learn effectively from it. A very common student complaint even from students who liked the SCALE-UP approach was that the workload was too large.

Summary of written student comments on end of semester course evaluations. Percentages are the fraction of students who filled out evaluation forms.

	F98 1st semester SCALE-UP course	F98 2nd semester SCALE-UP course
% of students whose comments towards the SCALE-UP class were rated as "favorable"	32 %	42 %
% of students whose comments towards the SCALE-UP class were rated as "mixed"	11 %	33%
% of students whose comments towards the SCALE-UP class were rated as "unfavorable"	22 %	11 %
% of students who did not include written comments	35 %	14 %

e. Interviews

MPEX Interviews: MPEX interviews were conducted with 7 students in the 1998 fall semester SCALE-UP classes. These interviews have been transcribed and will be analyzed in summer 1999.

Physlet Interviews: *Physlets* are Java applets that are used to create animated physics problems that can be delivered over the world-wide web. These *Physlet* problems are more like laboratory or simulation problems than traditional end-of-chapter problems. They are sometimes used to illustrate abstract concepts that are difficult to demonstrate through experiments. Although *Physlet* problems are used extensively in the electricity, magnetism, and optics curriculum of SCALE-UP, not much is known about the pedagogy of this new class of problems. Up to now, we have observed students working *Physlet* problems in the SCALE-UP classes and have conducted *Physlet* problem solving interviews with a few student groups from the traditional lecture classes to look at how students solve and learn from these problems. In the coming year, we hope to use this type of interview to see how SCALE-UP has improved students' problem solving and measurement skills. So far, the interviews have shown that while the *Physlet* problems do encourage students to consider the physical situation described in the problem and the underlying concepts, the problems do not encourage students to adopt a more expert-like strategy for solving them.

C. THE RESEARCH TRAINING YOUR PROJECT HELPED TO PROVIDE

Training of graduate students

All four graduate students in the Physics Education Research & Development group are actively involved in all aspects of the SCALE-UP Project including writing and evaluating the curriculum including participating in all planning and preparation meetings for SCALE-UP. They design assessment protocols, conduct diagnostic testing, interviews, and classroom observations, and analyze the results. In addition, they act as substitute instructors in both the SCALE-UP and regular lecture classes in the introductory physics sequence. As part of our collaboration with Duke University, two of the graduate students helped implement and teach McDermott *et al*.'s *Tutorials in Introductory Physics* curriculum.[48]

In addition to the PER-D graduate students, other physics graduate students have and will participate in the SCALE-UP classes as facilitators for group activities. One graduate TA served as facilitator and substitute lead instructor for both SCALE-UP classes in the 1998 fall semester. This experience introduced him to the current thinking in physics education and gave him broad exposure to two different ways to introduce active learning activities in large classes. He was also actively involved with both classes and made several suggestions to improve the curriculum. One of these was that he would have gotten even more out of the experience and been more effective with more preparation. Based in part on his comment, we have implemented planning and preparation meetings to go over the curriculum, the learning objectives, and the anticipated student difficulties for the coming week.

The weekly planning and preparation meetings can be an essential part of helping faculty prepare to teach the SCALE-UP classes and providing teacher training for graduate teaching assistants. These meetings are based on the training meetings developed for the *Tutorial* curriculum.[49] The meetings have four objectives: to review the past weeks activities, to go over student responses to conceptual questions to see how they are thinking about the material, to go over the classroom activities for the coming week and think about potential student difficulties with the activity, and to think about how the instructors can address student difficulties and misconception. This type of meeting changes the focus of teaching from how material is presented to what students need to do to learn it.

D. ANY OTHER EDUCATIONAL AND OUTREACH ACTIVITIES?

1. Contributed and Invited Talks at Conferences

(Note: Only presentations and posters related to the SCALE-UP project have been listed.)

a. "How WebAssign and Physlets affect the teaching and learning of physics: A case study with SCALE-UP," J.S. Risley (contributed talk, AAPT Winter Conference, Anaheim CA., January 1999).
b. "Progress report on the Student Centered Activities for Large Enrollment University Physics (SCALE-UP) project at North Carolina State," D. Abbott, R. Beichner, J. Risley, J. Saul, S. Bonham, M. Dancy, D. Deardorf and R. Allain (contributed talk, AAPT Winter Conference, Anaheim CA., January 1999).
c. "Group problem solving using multimedia-focused problems," S. Bonham, D. Abbott, J. Risley, R. Beichner, and W. Christian (contributed talk, AAPT Winter Conference, Anaheim CA., January 1999).
d. "Group problem solving using multimedia-focused problems," S. Bonham, D. Abbott, J. Risley, R. Beichner, and W. Christian (contributed talk, North Carolina Section AAPT Conference, Asheville NC, November 1998).
e. "Webassign and grants to high school teachers in North Carolina," J. Risley and L. Martin (contributed talk, North Carolina Section AAPT Conference, Asheville NC, November 1998).
f. "WebAssign," J. Risley (keynote address, International Conference on Multimedia in Physics Teaching and Learning, University of Sciences and Technology of Lille, Lille, France, September 1998).
g. "New teaching environments at NC State," R. Beichner (invited talk, AAPT Summer Meeting, Lincoln NE, August 1998).
h. "Do multimedia-focused problems meet the needs of learners or are they just another way to torture students?," A. Titus, & R. Beichner (invited talk, AAPT Summer Meeting, Lincoln, NE, August 1998).
i. "Physics education research using web-based assessment systems," S. Bonham, A.Titus, R.J. Beichner, and L. Martin (contributed talk, AAPT Summer Meeting, Lincoln NE, August 1998).
j. "Motivating and evaluating students using web-based technology," A.P. Titus and L.W. Martin (contributed talk, AAPT Summer Meeting, Lincoln NE, August 1998).
k. "Introduction to the Physics Education Research and Development Group at NC State," J. Saul, R. Beichner, S. Bonham, A. Titus, M. Dancy, R. Allain, D. Abbott, and J. Risley (contributed poster, Physics Education Research Conference, Lincoln NE, August 1998).
l. "Physics education research with web-based assessment and testing systems," S. Bonham (contributed poster, Physics Education Research Conference, Lincoln NE, August 1998).

m. "Integrating video and animation with physics problems," A. Titus (contributed poster, Physics Education Research Conference, Lincoln NE, August 1998).

2. Workshops and Exhibits

a. "WebAssign," J. Risley and P. Gjertsen (exhibit, AAPT Winter Meeting, Anaheim CA, November 1998).
b. "WebAssign," J. Risley, L. Martin, A. Titus, and P. Gjertsen (exhibit, North Carolina Section of the AAPT, Ashville NC, November 1998).
c. "WebAssign," J. Risley, L. Martin, P. Gjertsen (exhibit and workshop, NC Science Teachers Association, where Greensborough, NC, November 1998).
d. "WebAssign," J. Risley and P. Gjertsen (exhibit, National School Board Meeting Association, where Nashville, TN, October 1998).
e. "WebAssign," J. Risley, L. Martin, and P. Gjertsen (exhibit, Educomm meeting, Orlando Fl, October 1998).
f. "SCALE-UP," J.M. Saul and D. Deardorff (exhibit, North Carolina State University Educational Technology Exposition, Raleigh NC, September 1998).
g. "WebAssign," J. Risley, L. Martin, and P. Gjertsen (exhibit, North Carolina State University Educational Technology Exposition, Raleigh NC, September 1998).
h. "Video capture and analysis in physics courses," P.W. Laws, P.J. Cooney, R. Beichner, and R. Teese (workshop, AAPT Summer Meeting, Lincoln NE, August 1998).
i. "WebAssign," J. Risley and P. Gjertsen (exhibit, J. Risley, A. Titus, and P. Gjertsen, AAPT Summer Meeting, Lincoln NE, August 1998).
j. "WebAssign for high schools," J. Risley, L. Martin, and P. Gjertsen, (workshop, North Carolina High School Teachers, Raleigh, NC, June/July 1998).
k. "WebAssign," J. Risley and P. Gjertsen (exhibit, NSTA Meeting, Las Vegas NV, April 1998).

3. Seminars and Colloquia

Faculty:

John Risley:

a. "WebAssign," seminar presented at Renssellaer Polytechnic Institute, Troy, New York in May 1998.
b. "Teaching physics with computers," colloquium presented at University of Tennessee in Feb 1998.

Robert Beichner

a. "SCALE-UP," a colloquium at Drexel University, Philadelphia, PA in March 1999.
b. "SCALE-UP Project," a panel presentation at the FIPSE Annual Project Director's Meeting, Washington, D.C. in October 1998.
c. "NC State's Physics Program: A Case Study," a seminar at the Revitalizing Undergraduate Physics Conference, Alexandria, VA. in October 1998.
d. "SCALE-UP," a colloquium at University of North Carolina, Charlotte, NC in September 1998.
e. "Using Technology to Establish Learning Environments," Presentation for the Preparing the Professorate Program, North Carolina State University, Raleigh, NC, in January 1999.

f. “Linking Technology to Pedagogy,” Presentations for the Faculty Center for Teaching and Learning, North Carolina State University, Raleigh, NC, in June & July 1998.
g. “Using Technology to Help Students Learn,” Hewlett Fellows Presentation, North Carolina State University,” Raleigh, NC in March 1998.

Postdoctoral Research Associates:

Scott Bonham

a. “Enabling physics education reform, computers and world wide web,” Colloquium presented at University of Northern Iowa, Cedar Falls, IA in March 1999.
b. “Enabling physics education reform, computers and world wide web,” Colloquium presented at Texas Tech University, Lubbock, TX in February 1999.

Jeff Saul

“The role of the hidden curriculum or what physics education research can teach us about the introductory physics course.” Colloquium presented at Duke University, Durham, NC in August 1998.

III. Products: Describe tangible products of this work

A. WHAT HAVE YOU PUBLISHED AS A RESULT OF THIS WORK?

1. Journal Publications

a. “Case study of the physics component of an integrated curriculum,” R. Beichner, L. Bernold, E. Burniston, P. Dail, R. Felder, J. Gastineau, M. Gjertsen, and J. Risley, *Phys. Ed. Res. Supplement to Am. J. Phys*., in press.

b. “Writing web-based predicton-observation questions,” S. Bonham and L. Martin, submitted to *Computers in Education* (1999).
c. “GOAL-Oriented problem solving,” R. Beichner, D. Deardorf, and B. Zhang, submitted to *Phys. Teach*., (1998).
d. “Using Physlets to teach electrostatics,” S.W. Bonham, J.S. Risley, and W. Christian, submitted to *Phys. Teach*. (1998).
e. “Education research using web-based assessment systems,” S.W. Bonham, A. Titus, R.J. Beichner, and L. Martin, submitted to *J. Res. Comp. Ed*. (1998).
f. “What physics education research can teach us about the introductory physics course: A response to ‘Innovations in physics teaching, a cautionary tale,’” J.M. Saul, E.F. Redish, and R. Beichner, in preparation for submission to *Phys. Teach*. (1999).
g. “The role of the hidden curriculum: An evaluation of research-based approaches to the introductory physics course,” J.M. Saul and E.F. Redish, in preparation for submission to *Phys. Ed. Res. Supplement to Am. J. Phys*. (1999).

2. Books or other non-periodical, one-time publications

a. *Physics for Scientists and Engineers, 5th ed.,* R. Serway & R. Beichner, in progress (Saunders, Philadelphia PA, 2000).
b. *Instructor’s Manual to Accompany Physics for Scientists and Engineers, 5th ed.,* (see Ref. a.) R. McGrew, C. Teague, and J.M. Saul, in progress (Saunders, Philadelphia PA, 2000).

c. *Study Guide Student Solutions Manual to Physics for Scientists and Engineers, 5th ed.,* (see Ref. a.) by J.R. Gordon, R. McGrew, and R. Serway, in progress (Saunders, Philadelphia PA, 2000). D. Deardorff, an NSCU PER-D Ph.D. student, is contributing the GOAL solutions for all 44 chapters.

B. WHAT WEBSITES OR OTHER INTERNET SITES HAVE YOU CREATED?

In connection with the SCALE-UP project, we created four main websites: one for each of the current SCALE-UP classes, one for the Physics Education Research & Development group, and one for WebAssign. The websites for the SCALE UP classes are designed primarily for the students in the courses. The sites include links to the course syllabus, a course calendar with access to in-class activities, homework assignments, and practice tests, a link to the student groups including access to each group's required Web project, and a link to the WebAssign sites. The PER-D group website has pages on group projects including physlets and the SCALE-UP project. The site includes copies of paper, abstracts, and presentations disseminated by the group. The SCALE-UP project pages are designed for people interested in learning more about the SCALE-UP project. In addition, starting in the 1999 fall semester, the site will offer detailed information on the SCALE-UP curriculum, including the activity guide and research summaries. These pages will be geared towards physics instructors who are either considering or have already decided to adopt the SCALE-UP curriculum. These pages will be accessible with a password to prevent student access.

The physlet and WebAssign sites both have general information pages that describe what these Web-based programs can do and offers several examples. The WebAssign site also contains extensive documentation for instructor and student use and provides access for users at other schools.

C. WHAT OTHER SPECIFIC PRODUCTS (DATABASES, PHYSICAL COLLECTIONS, EDUCATION AIDS (TECHNOLOGY, COMPUTER MATERIALS, PHYSLETS), SOFTWARE, INSTRUMENTS, OR THE LIKE) HAVE YOU DEVELOPED?

1. Incorporation of Active-Learning Activities and Physics Education Research into a Mainstream Text

The fifth edition of Serway and Beichner, *Physics for Scientists and Engineers* incorporates several aspects of the SCALE-UP project including Tangibles (Quick Quizzes), Ponderables (Quick Labs), and the GOAL protocol. In addition, the instructors' manual will include PER summaries and suggestions for incorporating PER-based activities in large classes. We see this popular text as a means of "mainstreaming" some of the results of physics education research.

2. Physlets

We have developed over 100 Physlet problems on a wide range of topics in introductory physics including mechanics, electricity, and magnetism. The Physlet problems are part of the WebAssign problem database and are available for use to any physics instructor with access to WebAssign.

3. Interactive Physics Activities

The Interactive Physics (IP) program is an easy-to-use mechanics simulator that allows students to build and analyze visual representations of mathematical models. The program allows students to vary position, velocity, acceleration, and forces and will graph them vs. time over the course of the simulation. It's ease of use and visual display makes IP useful for demonstrations and student group activities. We have developed 50 Interactive Physics activities for mechanics. We also have many activities where the students themselves generate their own simulations. These have proven to be both popular and effective.

4. SCALE-UP Activity Guide

As described previously, the activity guide is a complete introduction and how-to guide for the SCALE-UP curriculum. The guide is a compilation of results of physics education research, active-learning group activities, and suggestions for teaching the calculus-based introductory physics sequence. The guide is designed so that instructors can use just a few active-learning group activities to supplement traditional lecture instruction or they can make these activities the focus of the curriculum. Although the first draft of the guide is being written in Word 97, the later drafts will be written in HTML and made available on CD-ROM and at the SCALE-UP Website.

5. WebAssign

The WebAssign web-based homework system allows instructors to easily construct, deliver, grade, and modify homework assignments for students. WebAssign allows problems to have multiple-choice, numerical with units, and essay responses as answers. All problems, student responses, and grades are stored in a database on the server. For problems with numerical answers, WebAssign can randomize the physical parameters of the problem within specified ranges so that each student receives their own version of the problem. The system currently contains over 20,000 problems from most of the standard Algebra- and Calculus-based texts. The WebAssign system is currently being used by 10,000 students at 50 colleges, universities,[50] and high schools nationwide. The program is being offered free of charge to all high schools in North Carolina. WebAssign has also been featured in a recent article in *The Chronicle of Higher Education*[51] and on *NBC Nightly News*.[52]

IV. Contributions: Explain ways in which you work, your findings, and specific products of your project are significant –-how they have contributed or been applied:

A. TO THE DEVELOPMENT OF YOUR OWN DISCIPLINE

1. Researched-based curriculum development

In the last ten years, there have been several curricula developed applying the results of physics education research.[53] Evaluation studies have shown that students taught with these curricula can show greater gains in problem solving ability,[54] conceptual understanding,[55] and/or cognitive attitudes[56] than students taught with traditional lecture instruction. However, the most successful curricula are those like Workshop Physics in which cooperative-group activities replace lectures as the primary mode of instruction. Until recently, there have been three problems with widespread adoption of active-learning group activities to replace lecture at undergraduate institutions. One problem is the difficulty of implementing cooperative group activities in large classes (50 or more students in a class). Another problem is that these curricula are sometimes too inflexible to adapt to local circumstances or to be adopted in part. The last problem is to design activities that allow large numbers of students to work in groups but allow instructors to interact with each group. In addition, the activities must challenge the students' common sense beliefs to promote conceptual change and improvements in problem solving ability. The SCALE-UP curriculum and activity guide addresses all three of these difficulties. The curriculum consists of active-learning activities designed for use with up to 50-100 students. The activities are designed to be modular so they can be used in different combinations depending on the equipment available, characteristics of the student population, and the fraction of active-learning activities the instructor wants to incorporate in the class. **Instructors can adopt the entire curriculum or just some activities.**

In addition to the features described above, the full SCALE-UP curriculum is the first to focus on improving student conceptual understanding, problem solving, cognitive attitudes, and socialization as primary course objectives. This is achieved through the use of ponderables (conceptual quizzes, estimation problems, and more traditional problems) and tangible activities, the GOAL protocol, and modified McDermott *Tutorials*. In addition, we have pioneered the development of three-part labs where at any time each student group at a table works on one of three different but related activities. These three part labs make use of string and sticky tape experiments, MBL experiments, video analysis, and simulations. Each group goes through each of the three activities and looks for common elements. This format allows for better use of limited equipment and allows students to see concepts applied in multiple contexts.

2. Classroom management for using cooperative group in large classes

Most PER-based interactive curricula make use of group activities that can be done either in recitation sections or small classes where instructors can interact with the groups and provide guidance during the activity. Some PER-based activities such as Mazur's *Concept Tests*[57] and Thornton and Sokoloff's *Interactive Lecture Demonstrations*[58] are designed for use in larger lecture sections but they do not allow for instructors to interact with most of the student groups. The SCALE-UP classroom is designed to overcome this limitation of group activities in lecture. However, while the classroom layout for the modified SCALE-UP rooms encourages students to work together groups and allows for instructors to interact with each group, it also presents new challenges for classroom management. These challenges include presenting material to students in a room with no "front," presenting demonstrations, keeping students on task in the classroom, and interactive classroom discussion. The last is an important point since studies of the Studio Physics curriculum at RPI showed that this component was critical to helping students achieve the learning objectives from the group activities.[59] The techniques being developed in SCALE-UP to address these issues will be critical to the success of schools adapting SCALE-UP or a Studio Physics approach to teach the introductory physics sequence.

3. Research on student learning

In addition to the effort to evaluate the effectiveness of SCALE-UP through diagnostics, exams, and interviews, we are also incorporating conceptual quizzes and making use of noninstructional observers to evaluate which activities balance ease of use with student learning gains. By using the iterative approach described earlier, we should be able to develop activities that students can complete with support from their classmates at the table and minimal interaction with the instructors, but also promote learning gains in conceptual understanding and problem solving. We are also looking at how to help students integrate these two learning goals.

B. TO OTHER DISCIPLINES OF SCIENCE AND ENGINEERING

The IMPEC project showed that the teaching methods used in SCALE-UP can be used for introductory classes in other disciplines, namely chemistry, engineering, and math. The methods can also be used in Astronomy and Computer Science classes as well as in upper division classes in all these fields. In addition, the IMPEC project showed that by using an integrated approach, teaching the course using similar types of group activities, and tying in the physics being taught with these other disciplines, what students learn in physics class can be used outside of the specific domain in which it was learned.

1. Tie-in of SCALE-UP course with parallel math course

The IMPEC project showed that an active-learning physics curriculum in a technology-rich environment that encourages students to work in groups can be very effective when integrated with other science and math classes taught in a similar format. In IMPEC, this was found to be particularly true when students get more opportunities to work in the same groups. We have worked out an agreement with the Mathematics Department at NC State to have one calculus class set up so that students in the first semester SCALE-UP course will be able to work in the same groups in both classes. Both classes are taught in the SCALE-UP room. We plan to look at improving the integration of the two classes over the next year.

2. Discussions with the College of Engineering

We are also having conversations with the College of Engineering on how a SCALE-UP approach can be used in their upper division courses. They are very interested in using computer-based group activities in these classes. In the past we had collaborated on the pilot to the SCALE-UP curriculum. Now they plan to reintroduce some of our findings back into the other freshman courses for engineers.

C. TO EDUCATION AND DEVELOPMENT OF HUMAN RESOURCES

1. Teacher training and preparation for SCALE-UP Instructors as professional development

There are three aspects that are relevant to the project. First of all, we have been visiting and supporting visits from instructors interested in applying some or all of the SCALE-UP curricular materials at their institutions. We are also in the planning stages for nationally offered workshops that directly address the issues involved with active learning by large numbers of students.

During our training meetings we are helping instructors learn more about their students' difficulties and how to address them with instruction. We have tried to hold these meetings on a weekly basis whenever possible. Another part of these meetings includes evaluating the previous week's instruction. This type of reflective teaching is a proven way to improve instruction.

Last, but certainly not least, we hope that we are providing a better educational experience for the students. This is our primary goal and guides all our efforts.

D. TO PHYSICAL, INSTITUTIONAL, OR INFORMATION RESOURCES FOR SCIENCE AND TECHNOLOGY

We have developed three major resources in this area: the Phase II multimedia classroom, WebAssign, and the mainstream introductory physics text.

The design of an effective classroom that can support this type of instruction is an important component of the project. We believe we have made significant progress toward a learning environment where large numbers of students can be actively involved. We are making these room layouts and wiring considerations available to others. Of course, other departments on campus are also using the classroom. The instructor of an upper-division marketing class that used the room without laptops commented to the university on the design of the current Phase II classroom. He said that it was "fabulous" and expressed disappointment that he was unable to use the room in the current semester. He found that the room design allowed him to

- Easily divide the class into teams for group work
- Provide a more conversational teaching environment that elicits more active class participation
- Enables the use of the Internet as a teaching tool
- Make his presentations more visual by presenting material from a computer

Furthermore, he found that the room layout did not create as much of a divide between the instructor and the students as a tradition al classroom. He concluded by saying that classrooms like this will become more and more essential for teaching.

WebAssign is an information resource that is proving to be very popular, both on campus and nationally. We are exploring additional ways to take advantage of this type of technology in instructional settings, including new ways of using Physlets–both for in-class and out-of-class activities, and expanding the automatic grading features.

The Serway and Beichner textbook will reach hundreds of thousands of students around the world. Several of the new features in this revision are directly extracted from the curricular reforms championed in the project.

E. OR TO COMMERCIAL TECHNOLOGY, THE ECONOMY, COST-EFFICIENT ENVIRONMENTAL PROTECTION, SOLUTION OF SOCIAL PROBLEMS, OR ANY OTHER ASPECTS OF THE PUBLIC WELFARE BEYOND SCIENCE AND ENGINEERING.

In the IMPEC project the success rate for at-risk student populations improved dramatically. Significantly larger fractions of African-American and women passed the course with a "C" or better compared with the students in the regular classes. The numbers are currently too small to make similar statistically significant claims for the SCALE-UP classes, although as the project progresses, this should not be a problem.

V. Future Plans

A. SCALE-UP CURRICULUM DEVELOPMENT

1. Summer 1999

Completion of first full draft of SCALE-UP Activity Guide for 1st semester introductory physics for engineers and scientists (Vol. I: Mechanics) in time for fall 1999 semester

Publication of *Physics for Scientists and Engineers, 5th ed.,* R. Serway & R. Beichner, in progress (Saunders, Philadelphia PA, 2000). This textbook is designed to complement curricula with active learning activities for cooperative groups. Publication also includes an instructor manual with PER summaries and a Student Solution and Study Guide with several examples of the GOAL problem solutions in each chapter. The first volume is due out in May 1999.

2. Fall 1999 – Spring 2000

The second volume of the textbook (covering the second semester of the SCALE-UP curriculum) should be published by Fall 1999.

First full draft of SCALE-UP Activity Guide for 2nd semester introductory physics for engineers and scientists (Vol. II: E&M, Optics, & Modern Physics) is scheduled for completion by Jan 2000

More research and development of Phase I SCALE-UP activities for use in lecture classrooms

SCALE-UP classroom for 99 students + 3 instructors is scheduled for completion in fall 1999. The first full-size SCALE-UP implementations (99 students) will commence after completion of the room. Additional instructors will begin teaching using the SCALE-UP format in the new room including physics faculty from outside the group.

B. SCALE-UP DISSEMINATION & SECONDARY IMPLEMENTATIONS

1. First SCALE-UP Workshops will be held in the 1999-2000 academic year at regional and national AAPT meetings

2. Continue five-part program of implementation support for institutions adopting the SCALE-UP curriculum

a. Bring interested faculty to NC State to observe the curriculum in operation.

b. Invite them to attend an Implementation Planning Workshop

c. Conduct site support visits by NSCU SCALE-UP project staff

d. Expand the SCALE-UP website to provide a means for all implementers of SCALE-UP to share information. The website will have both public and password protected sections.

e. Offer a follow-up Workshop/Conference for implementers to share their SCALE-UP experiences and discuss evolution of the curriculum.

REFERENCES

[1] K. Cummings, " 'Studio Physics' at Rensselaer: Where we are, and where we may be headed," *AAPT Announcer* **28** (2), 82 (1998, abstract only); K. Cummings, J. Marx, D. Kuhl, and R. Thornton, "Innovations in Studio Physics," submitted to the *Physics Education Research Supplement of AJP* (1999).

[2] P. Heller, T. Foster, and K. Heller, "Cooperative group problem solving laboratories for introductory courses," in *AIP Conference Proceeding No. 399 The Changing Role of Physics Departments in Modern Universities: Proceedings of the International Conference on Undergraduate Physics Education*, edited by E.F. Redish and J.S. Rigden (AIP Press, Woodbury NY, 1997), 913-934; P. Heller, R. Keith, and S. Anderson, "Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving," *Am. J. Phys.* **60** (7), 627-636 (1992); P. Heller and M. Hollabaugh, "Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups," *Am. J. Phys*. **60** (7), 637-644 (1992);

[3] D.R. Sokoloff and R.K. Thornton, "Using interactive lecture demonstrations to create an active learning environment", *Phys. Teach*. **35** (6), 340-346 (1997).

[4] R. Knight, *Physics: A Contemporary Perspective* (Addison Wesley, Menlo Park CA, 1997).

[5] D. Sokoloff, P. Laws, and R. Thornton, *Real Time Physics* (John Wiley and Sons, New York, 1999).

[6] As measured by fractional gain on the FCI

[7] R.R. Hake, "Active-engagement vs. traditional methods: A six thousand student study of mechanics test data for introductory physics courses," *Am. J. Phys*. **66** (1), 64-74 (1998).

[8] R.K. Thornton and D.R. Sokoloff, "Assessing student learning of Newton's laws: The Force and Motion Concept Evaluation and the evaluation of active learning laboratory and lecture," *Am. J. Phys*. **66** (4), 338-351 (1998).

[9] L.C. McDermott, "Millikan Lecture 1990: What we teach and what is learned – Closing the gap," *Am. J. Phys*. **59** (4), 301-315 (1991).

[10] L.C. McDermott, "Bridging the gap between teaching and learning: The role of research," in *AIP Conference Proceeding No. 399 The Changing Role of Physics Departments in Modern Universities: Proceedings of the International Conference on Undergraduate Physics Education*, edited by E.F. Redish and J.S. Rigden (AIP Press, Woodbury NY, 1997), 139-166.

[11] E.F. Redish, J.M. Saul, and R.N. Steinberg, "On the effectiveness of active-engagement microcomputer-based laboratories," *Am. J. Phys*. **65** (1), 45-54 (1997); J.M. Saul, *Beyond Problem Solving,: Evaluating Introductory Physics Curricula Through the Hidden Curriculum*, Ph.D. Dissertation, University of Maryland, 1998 (unpublished).

[12] See Ref. 2.

[13] R. Beichner, L. Bernold, E. Burniston, P. Dail, R. Felder, J. Gastineau, M. Gjertsen, and J. Risley, "Case study of the physics component of an integrated curriculum," *Phys. Ed. Res. Supplement to Am. J. Phys*., in press.

[14] L.C. McDermott, *Tutorials in Introductory Physics* (Prentice Hall, Upper Saddle River NJ, 1998).

[15] See Ref. 10.

[16] D. Hestenes, M. Wells, and G. Swackhamer, "Force Concept Inventory," *Phys. Teach.* **30** (3), 141-158 (1992).

[17] See Ref. 8.

[18] R.J. Beichner, "Testing student interpretation of kinematics graphs," *Am. J. Phys.* **62** (8), 750-762 (1994).

[19] T.L. O'Kuma, C.J. Hieggelke, D. Maloney, A. van Heuvelen, "Developing conceptual surveys in electricity and magnetism, *AAPT Announcer* **28**, 81 (July 1998, abstract only); C. Hieggelke and T. O"Kuma, "The impact of physics education research on the teaching of scientists and engineers at two-year colleges," in *AIP Conference Proceeding No. 399 The Changing Role of Physics Departments in Modern Universities: Proceedings of the International Conference on Undergraduate Physics Education*, edited by E.F. Redish and J.S. Rigden (AIP Press, Woodbury NY, 1997), 267-287;

[20] P.V. Engelhardt, *Examining Students' Understanding of Direct Current Electrical Circuits Through Multiple-Choice Testing and Interviews*, Ph.D. dissertation, North Carolina State University, 1997 (unpublished).

[21] E.F. Redish, J. M. Saul, and R.N. Steinberg, "Student expectation in physics," *Am. J. Phys.* **66** (3), 212-224 (1998).

[22] J. Epstein, "Report on basic skills test given to various student populations," (unpublished, 1993).

[23] See Ref. 11

[24] See Ref. 13.

[25] R. Chabay and B. Sherwood, *Electric and Magnetic Interactions* (John Wiley & Sons, New York, 1995).

[26] See Ref. 1.

[27] See Ref. 3.

[28] See Ref. 2.

[29] See Ref. 14.

[30] See Ref. 3.

[31] See Ref. 14.

[32] G.J. Posner, K.A. Strike, P.W. Hewson, and W.A. Gertzog, "Accommodation of a scientific conception: Towards a theory of conceptual change," *Sci. Educ.* **66** (2), 211-227 (1982).

[33] R. Beichner, D. Deardorf, and B. Zhang, "GOAL-Oriented problem solving," submitted to *Phys. Teach*., (1998).

[34] For example: Videopoint and Videograph, EM field, M.U.P.P.E.T., CUPLE, EM-Field, Excel, Mathematica, and many others.

[35] E. Mazur, *Peer Instruction: A Users Manual* (Prentice Hall, Upper Saddle River NJ, 1997).

[36] Scott Bonham has led the group in the development of Physlets for the SCALE-UP project. Samples of these Physlets can be viewed at "http://www4.ncsu.edu/unity/users/s/swbonham/www/Physlets.html".

[37] R. White and R. Gunstone, *Probing Understanding* (The Falmer Press, New York NY, 1992).

[38] R.K. Thornton and D.R. Sokoloff, "Learning motion concepts using real-time microcomputer-based laboratory tools," *Am. J. Phys*. **58** (9), 858-867 (1990); Also see Refs. 3, 8, 11, & 18.

[39] D. Hestenes, M. Wells, and G. Swackhamer, "Force Concept Inventory," *Phys. Teach.* **30** (3), 141-158 (1992).

[40] See Ref. 3.

[41] Over six thousand students participated in a study of FCI results by Hake. See Ref. 7.

[42] Hake found that unlike average post score, the average fractional gain h did not correlate with the average pre-test average. This makes h a more useful measure for comparing classes with significantly different pre-course scores. See Ref. 7.

[43] See Ref. 19

[44] See Ref. 20.

[45] Classes whose populations do not exhibit statistically significant differences in general characteristics. In this case, the pre-course diagnostic test data showed no such differences between the SCALE-UP and regular classes

[46] Using a t-test comparison of two means, the difference is significant at the $\alpha = 5\%$ level.

[47] W. F. Perry, *Forms of Intellectual and Ethical Development in the College Years* (Holt, Rinehart, and Wilson, NY, 1970); M.F. Belenky, B.M. Clinchy, N.R. Goldberger, and J.M. Tarule, *Women's Ways of Knowing* (Basic Books, New York NY, 1986); D.P. Maloney, "Research of problem solving: physics," in *Handbook of Research*

on Science Teaching and Learning, edited by D.L. Gabel (Macmillan Publishing Company, New York, 1994), 327-354. Also see Ref. 21.

[48] See Ref. 14.

[49] T. O'Brien Pride, S. Vokos, and L.C. McDermott, "The challenge of matching learning assessments to teaching goals: An example from the work-energy and impulse-momentum theorems," *Am. J. Phys*. **66** (2), 147-157 (1998).

[50] Including the Georgia Institute of technology, Duke University, Rensellaer Polytechnic Institute, and North Carolina State University.

[51] L. Guernsey, "Textbooks and tests that talk back," Chron. Higher Ed., Feb 12, 1999.

[52] Broadcast nationally on Feb. 19, 1999.

[53] P.W. Laws, *Workshop Physics Activity Guide* (Wiley, New York NY, 1997), for example; Also see Refs. 2, 3, 4, 5, 14, & 25.

[54] See Refs. 2 & 49.

[55] See Refs. 6, 8, & 11.

[56] See Ref. 21.

[57] See Ref. 35.

[58] See Ref. 3.

[59] Sister M.A. Cooper, An Evaluation of the Implementation of an Integrated Learning System for Introductory College Physics, Ph.D. dissertation, Rutgers – The State University of New Jersey, 1995 (unpublished).