Introduction to the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) Project

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Studio-Style Classes

It is known that students can learn more physics in classes where they interact with faculty, collaborate with peers on interesting tasks, and are actively involved with the material they are learning (1–5). Research on learning and curriculum development has resulted in instructional materials and teaching methods that can correct many of the shortcomings of traditional physics instruction. Careful study of these research-based introductory curricula in small classes indicates that they can significantly improve students' conceptual understanding (1,6–9). However, introductory physics instructors with large classes who want to incorporate active learning into their classrooms must typically choose between 1) hands-on activities (10) in small recitation or laboratory sections that supplement the lecture (11) and 2) interactive lecture activities for larger classes such as Peer Instruction (2,12) and interactive lecture demonstrations (13) that do not permit hands-on experiments and limit faculty interactions with individual groups. Studio-style[1] classes, where students work in teams observing and studying physical phenomena, offer faculty a third option.

Studio/workshop classes such as SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) give instructors another choice by replacing the lecture/laboratory format with 4–6 hours of activity-based instruction per week, typically in 2-hour blocks. This format has several advantages over the traditional lecture/laboratory format. Because the entire class is taught in the same room with the same students and instructors in each class, all activities, including laboratory experiments, can be arranged to build on one another in sequence for greater learning impact (14) than when some activities are taught in small sections running parallel to the lecture course. When a lab section is taught as a separate course, it is often weeks or at best a few days ahead of or behind the lecture, and for some students, the lab course is not even taken in the same term as the lecture. Additionally, even in an interactive lecture, students can avoid instructors by hiding in the middle of the row, away from the aisles. In the studio format, instructors can freely circulate and interact with any group at any time.

There are several examples of workshop/studio-style curricula in the Physics Education Research (PER) literature (15), including the Workshop Physics curriculum developed at Dickinson College (16) and the Studio Physics curricula at Rensselaer Polytechnic Institute (17) and Cal Poly San Luis Obispo (18). These curricula have the advantages described above, but are difficult to implement at large research universities because of class size limitations. The SCALE-UP project started as an effort to create studio classes for the calculus-based introductory sequence for up to 100 students, i.e., large enough to provide an effective, yet affordable, alternative to large classes taught via the standard lecture/laboratory format. (The SCALE-UP approach is now being applied to algebra-based physics as well as introductory chemistry and biology courses.)

Cooperative Groups of Students

There are many benefits to placing students into formal cooperative groups. Because they talk with each other, they are naturally more active (or interactive). Obviously, when an individual student reaches an impasse, he or she is stuck. Calling on teammates can provide additional resources and avenues to success. Seeing how others approach problems can be very valuable, especially for students whose performance is low. Also, by careful design of instruction, students can be placed into situations where they work at the upper levels of Bloom's taxonomy: synthesis and evaluation of each other's ideas. Perhaps most importantly, they learn more when they teach others.

Johnson et al. (19) present five required characteristics of successful group-based instruction. There has to be individual accountability, positive interdependence, opportunities for interaction, appropriate use of interpersonal skills, and regular self-assessment of group functioning. We have found that not incorporating all these aspects is a recipe for failure, at least as far as group functioning is concerned.

The Learning Environment

We redesigned the classroom environment to better promote active, collaborative learning. Taking a cue from a typical restaurant layout and following considerable experimentation, we use round tables with comfortable chairs placed around them. Each table seats three teams (called A, B, and C) of three students. The tables are numbered so a specific team can be identified (e.g., Group 4C), an entire table can be selected (e.g., Table 3), the entire room can be divided in half by specifying even and odd table numbers, or the room can be split into thirds by calling on all the "A groups" to do one task while the "B groups" and "C groups" work on their own activities. Each individual student has his or her own nametag so that no one can be anonymous, even in a large classroom. Laptops are used to maximize desktop space and to encourage cross-table discussions, particularly when a group is stuck and the instructors are busy with groups at other tables.

Figure 1. Seven-foot diameter table, seating three teams of three students.

Large white boards mounted on the walls (and/or smaller, portable group boards) have multiple benefits. Because students do their "thinking" on these public spaces, the instructor can more easily see how groups are progressing during an activity. In addition, students can view/critique each other's boards while working or as a tool for presentation to the entire class. A whiteboard can be seen behind the table in Figure 1.

Engaging Activities

A major advantage to having student groups working on activities is that it frees instructors from standing in the front of the room. A faculty member, graduate student, and (if possible) an undergraduate are sufficient to monitor the work of 99 students. Walking around the room and glancing at whiteboards provides considerable feedback to the teachers. Progress is ensured by engaging students in semi-Socratic dialogs (20). This type of interchange takes practice on the instructor's part and training of teaching assistants. It is especially important that teachers don't try to "show what they know" by simply telling students the right answer. This is truly a situation where the teacher is the guide at the side and not the sage on the stage.

To keep the class interesting, we have several different types of group activities: tangibles, ponderables, labs, and group problem-solving. Tangibles are short tasks where students make hands-on measurements or observations. Examples include determining the thickness of a single sheet of paper in their textbook (for practice with significant figures and estimating), calculating the number of excess electrons on a piece of transparent tape after it is pulled up from the tabletop, or determining the desired spacing of frets on a guitar. Ponderables are paper and pencil activities that may require estimating or finding values from the web, but there are no observations needed. We ask students questions such as, "How many steps does it take to walk across the country?" or "How far does a bowling ball skid before its motion is purely rolling?" These questions are hard enough that students appreciate having their teammates available to help. Labs are longer hands-on activity similar to other PER-based laboratory activities. However, we have also made substantial changes. Because we don't have to rely on labs to be the only place where students "do physics," we can concentrate on other areas such as uncertainties, hypothesis testing, and experimental design. The group problem-solving is similar to the activities developed by Heller et al. (8).

Educational Impact

We have used a wide array of quantitative and qualitative methods to evaluate the educational impact of the SCALE-UP pedagogy, particularly with regard to students' conceptual understanding, student problem-solving ability, and the quality of their overall learning experience. In addition to looking at results from SCALE-UP classes at North Carolina State University (NCSU), we have also looked at results from some of the 13 other schools that have also implemented SCALE-UP classes, particularly the University of Central Florida and the Massachusetts Institute of Technology (MIT).

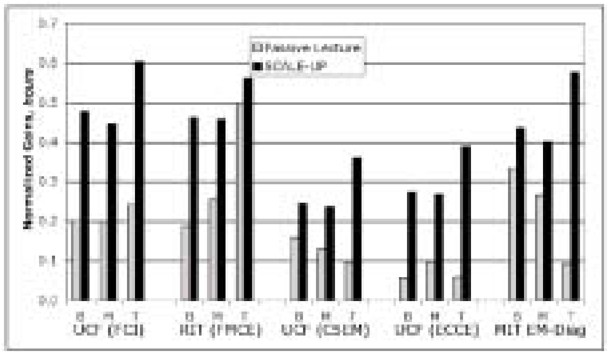

Figure 3. Students in the top third of their classes gained the most from the SCALE-UP experience. CSEM, Conceptual Survey of Electricity and Magnetism (22); ECCE, Electrical Circuits Concept Evaluation (23); EM, MIT internal E & M test; RIT, Rochester Institute of Technology; UCF, University of Central Florida.

We wanted to know if students were learning concepts, since research has shown that while student success and ability to solve traditional problems does not necessarily require real understanding, this type of understanding is needed for students to apply ideas beyond the current course. We used a variety of research-based tests. Figure 2 shows the FCI (21) results for two instructors teaching traditional and SCALE-UP mechanics. Hake's (1) national sample results are shown for comparison. It is clear the SCALE-UP students outperformed their traditionally taught peers.

A common concern of those questioning the need for reform is that a great deal of effort seems to be spent "bringing up the low-end students," perhaps to the detriment of the better students. To see if that was a problem, we examined pre-/post-conceptual test performance for the top, middle, and bottom students in the SCALE-UP classes. What we found is shown in Figure 3. The repeated patterns clearly show that the students in the top third of the class benefit the most from the SCALE-UP pedagogy. We believe this is because they are probably the ones doing most of the peer-teaching within their group. What is particularly noteworthy are the data for the top MIT students, arguably the best students in the world. Evidently, they have already gathered all they will learn from traditionally taught physics, as evidenced by the very small gain for that cohort. On the other hand, placing top MIT students in the SCALE-UP

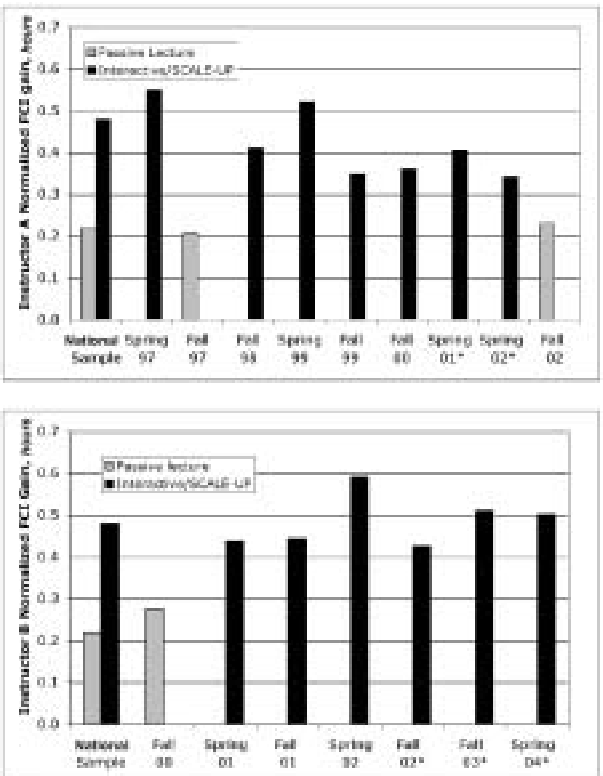

*Figure 2. Normalized gains on the FCI for students of two different instructors. Classes with * had ~99 students. Classes without * had ~54.*

environment resulted in a huge gain, so there was obviously more to be learned.

The physics and engineering departments were especially interested in knowing if SCALE-UP students could still do typical exam problems, so we randomly sampled problems from a mechanics test and gave them to our students. The results are shown in Figure 4. The NCSU SCALE-UP students performed significantly better on most problems. While Electricity and Magnetism exam differences were not as striking as the mechanics results, the SCALE-UP students outperformed their peers when the material was covered for approximately the same amount of time in both SCALE-UP and traditional classes. In general, the SCALE-UP students do as well or better on common exam problems than their peers in lecture/laboratory classes.

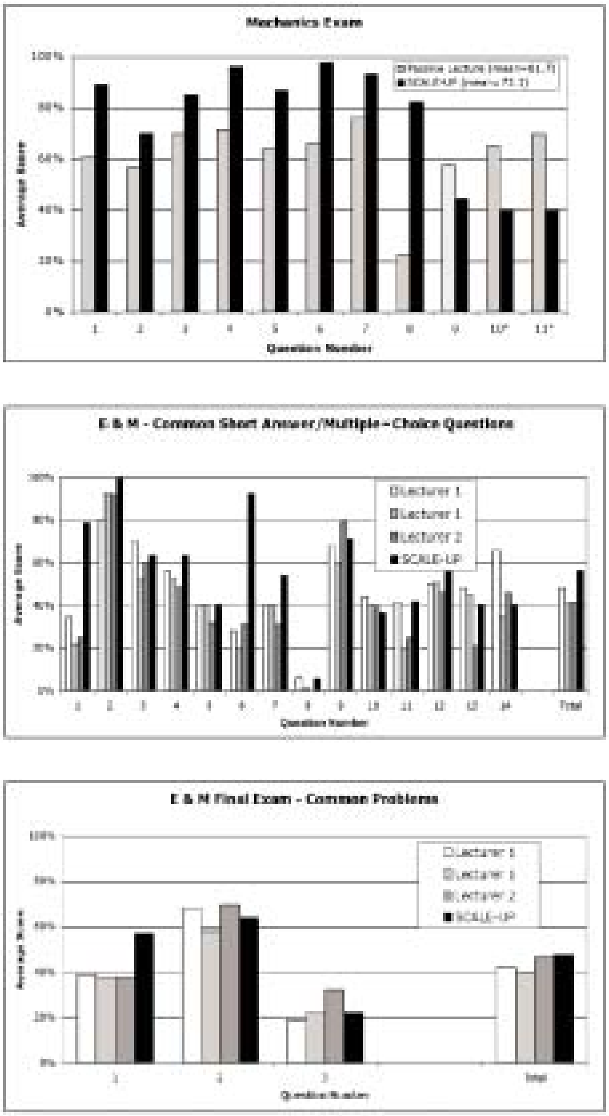

Figure 4. Comparison of traditional and SCALE-UP students using randomly selected questions from traditional exams. For the Mechanics Exam, item 9 values are not significantly different at the 0.05 level. Items 10 and 11 were not covered in the SCALE-UP class.

A very coarse but still useful measure of educational impact is overall pass/fail rate. While not entirely comparable because requirements for traditional and SCALE-UP courses differed, we feel justified in this analysis because other performance measures for SCALE-UP classes are as good or better, and also demands were much higher on the SCALE-UP students. Figure 5 shows failure rate ratios, calculated by dividing the percentage failing traditional courses by the percentage failing in SCALE-UP. This is over a five-year timespan, from 1997 to 2002, and incorporates data from over 16,000 NCSU students. (A student was said to fail the mechanics course when he or she received a grade lower than C–, since that level of performance barred the student from the E&M course. The second semester course was failed with a grade below D–.) The results for African Americans and females are particularly interesting, with traditional class failure rates, respectively, nearly four and five times larger than those seen in SCALE-UP classes. We attribute their success to the social interactions common in the SCALE-UP environment, where risk-taking is encouraged.

We wanted to assess students' attitudes about the class, but this is a difficult task. A rough measure is to compare attendance rates for students of the same teacher (R.J.B.) when teaching both traditionally and in a SCALE-UP mode. The attendance requirements were identical: students could attend if desired, but there were no direct grade penalties for low attendance. Table 1 shows that not only was attendance

Table 1. Attendance Rates for Students of the Same Instructor, With the Same Attendance Policy

	Lecture/lab	SCALE-UP
Number of classes	3	6
Number of students	263	342
% Attendance	75.2	90.3
Standard deviation	24.0	11.6

better in SCALE-UP classes, but the spread of attendance rates was lower. The traditional sections always had a few people who rarely attended, driving up the standard deviation values. This was not the case in SCALE-UP.

Quotes from interviews also provide insight into how students viewed the SCALE-UP classes. It is interesting to compare the impressions students have of their peers in the following two quotes:

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

The real test of an educational reform is student performance in later classes. We found that SCALE-UP Mechanics students do significantly better in their E&M course (whether the later course is taught traditionally or in the SCALE-UP mode). We found their performance slightly, but significantly, worse than that of traditional students in Engineering Statics courses. This caused us concern until we realized that a substantially larger fraction of students are passing SCALE-UP sections. Those students would have never been admitted to the engineering course if they had taken a traditional physics course and failed. To see if this might be the case, we used SAT scores as a way of identifying students at risk of failure in traditional physics. As we expected, there was no difference in passing rates for those students with math SAT scores above 500. But of those students whose math SAT was less than 500, 83% of the SCALE-UP students passed Engineering Statics compared with only 69% of the traditionally taught students. So physics is no longer the "filter" it used to be. What's more, students who probably would not have progressed toward an engineering degree with traditional physics instruction are succeeding in their later courses.

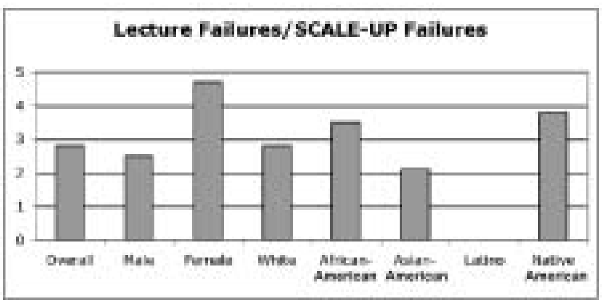

Figure 5. Ratio of failure rate percentages. Overall, students were nearly three times as likely to fail in a traditionally taught section than an equivalent SCALE-UP section of the course. The Latino ratio could not be calculated because no Latino students have failed in a SCALE-UP section.

Acknowledgments

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Assistance is available to any who are considering adopting this approach by sending an e-mail to beichner@ncsu.edu or by visiting http://scaleup.ncsu.edu.

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23. David Sokoloff's Electric Circuits Concept Evaluation is available from the Workshop Physics website: http://physics.dickinson.edu/~wp_web/wp_resources/wp_assessment.html#ECCE

Endnote

1. Jack Wilson coined the term "studio physics" for his classroom at Rensselaer Polytechnic Institute.