

## **AC 2007-1563: ADAPTING AND IMPLEMENTING THE SCALE-UP APPROACH IN STATICS, DYNAMICS, AND MULTIVARIATE CALCULUS**

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# Adapting and Implementing the SCALE-UP Approach in Statics, Dynamics, and Multivariable Calculus

## Abstract

This study seeks to deliver and document more effective Statics and Dynamics instruction by implementing the Student-Centered Activities for Large Enrollment University Programs (SCALE-UP) model, in which large studio classes are taught with an emphasis on learning by guided inquiry instead of on listening. The project is also examining the benefit of integrating the content of the two traditional sequential courses and the parallel content in multivariable calculus. By tracking multiple sections taught using different approaches in different departments, the project's experimental design plans to control for each of the changes being made simultaneously to understand the benefit of each.

## Introduction

As of Fall 2006, an active-learning approach modeled after Beichner and colleagues' SCALE-UP method<sup>1</sup> has been implemented at our institution to teach sophomore Mechanical Engineering students an integrated statics and dynamics course, and one section of a statics course for Civil Engineering sophomores, as well as other engineering disciplines (except Mechanical). A simultaneous multivariable calculus was taught using the SCALE-UP method as well. Although the SCALE-UP approach has been studied in physics courses<sup>1</sup>, little has been done to validate it in engineering courses. Since this approach has shown improvement in physics courses, it is expected that engineering courses will also benefit. This research will assess the success of the SCALE-UP model in statics, dynamics and calculus courses, and will study how combining statics and dynamics as an integrated course impacts student learning and comprehension.

## The Learning Environment

Two new classrooms, equipped for instruction and learning in the SCALE-UP mode, were created for the statics, dynamics and multivariable calculus courses. The space for the engineering courses (1700 square feet) includes eight 7-foot diameter tables that can seat up to 9 students each. The space for the calculus course (1014 square feet) has four 7-foot diameter tables and a seating capacity of 36. The tables have power and wired-internet to facilitate laptop use. In both classrooms, the instructor space includes a "Sympodium" interactive digital pen display, linked to dual projectors. White boards are available for instructor and student use. A schematic and photo of the larger classroom are shown in Figure 1.

An integrated statics and dynamics course, a required course for all Mechanical Engineering majors, was offered for the first time in Fall 2006. This replaced the traditional pair of 3-credit courses, Statics and Dynamics in the ME curriculum, although the traditional courses are still offered for other majors. The course is a 5 credit-hour course and met 5 days a week. Three

meetings were standard length 50-minute classes and two were extended 100-minute classes. Almost all class meetings were a combination of lecture, discussion, and learning activities. The balance was typically 30% lecture and 70% learning activities, although some classes were closer to 100% activities. The goal of the activities was to develop skills in problem formulation, solution, and reflective evaluation. Some of the activities have been designed to allow students to discover certain fundamental principles rather than the traditional approach of being told the principles or have them derived by the instructor. Students worked on in-class activities primarily as teams with 3 students per team. Some activities, such as white-board presentations of student in-class work, involve whole tables of 6 to 9 students.

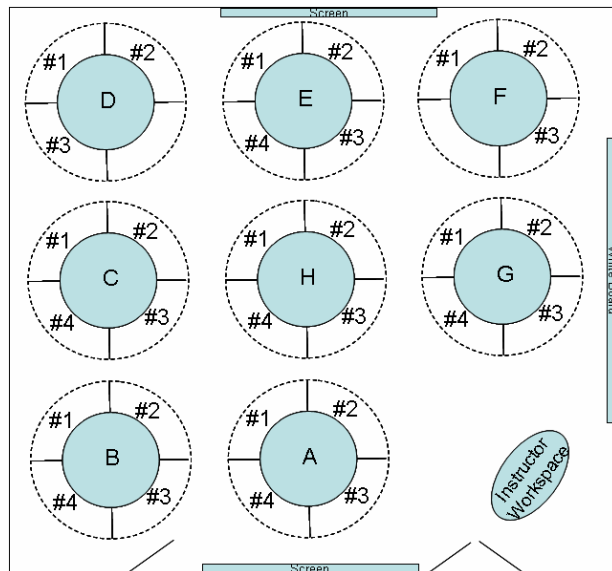


Figure 1. Schematic of SCALE-UP classroom, and photo of student-centered activity.

Multivariable calculus has been offered by a co-author (Moss) since Fall 2003 using the SCALE-UP model. In this model, lecture time is reduced to about 15-20 minutes at the beginning of the class period. In addition to the traditional uses of lecture time, the instructor discussed the connections between the mathematics being learned and other engineering courses, especially statics and dynamics. The remainder of the class period was used for team-based learning activities and/or the writing of reflective journal entries and work on Maple exercises. Content in the statics and dynamics courses that overlap topics in the calculus course were identified, and incorporated into the activities and problem sets to better align these courses in Fall 2006.

Instruction was accomplished for each course section as a team of one professor, and multiple “learning assistants:” one to two graduate students, and between one and three undergraduate students depending on the size of the class. In Fall 2006, multivariable calculus had 36 students and 2 learning assistants; statics had 34 students and 2 learning assistants, and the two sections of integrated statics and dynamics had 49 and 33 students each, and 2 learning assistants each. Ideally, there would be one learning assistant for every two tables of students, not including the instructor. The instructor and learning assistants served as coaches answering questions, asking leading questions, and formatively assessing student work for the benefit of students and to inform instruction. Although the assistance of undergraduate students represented the first time at our institution for such an arrangement in the classroom, with the large number of students and

the heavy reliance on in-class learning by guided inquiry, their assistance has been a necessity and seems to be effective. Some of the undergraduate leaders also hold optional evening sessions as part of a more formal peer tutoring program on campus called “Supplemental Instruction.”

The combined statics and dynamics course content has been completely revised to present an integrated sequence of dynamics and statics rather than the standard serial approach of statics followed by dynamics. Since no text books are available that use this approach, a complete text was created that served as the students’ main reading material, available to them online. Since lectures were typically only short summaries of important points, the importance of critical reading was stressed to the students. To assist this thorough approach to reading, questions were provided for the students to answer during or after their reading. Students enter their response in a written journal. Journal questions were sometimes the subject of in-class discussion. Learning activities were developed as needed as the course was offered for the first time.

## Research Methods

In order to compare the effects of applying the SCALE-UP model to engineering and calculus courses, the following metrics were compared:

1. The percentage of students who received a D or F letter grade or withdrew from the course after the two week drop/add period, but before the midterm (DFW rate) for the same courses taught in a traditional lecture format the previous year or Fall 2006, and SCALE-UP courses taught in Fall 2006.
2. In order to measure conceptual understanding, the Statics Concept Inventory (SCI)<sup>2</sup> and the Dynamics Concept Inventory (DCI)<sup>3</sup> were administered at the beginning and end of statics courses and dynamics course, respectively. Both tests were administered at the beginning and end of the integrated statics and dynamics classes. Normalized gains were used for comparison with statics and dynamics taught separately in a traditional lecture format the previous year. Normalized gains were calculated as the points the student gained (post - pre) divided by the total number of points they could have gained. This allows reporting of gain as a percentage increase in conceptual understanding, and prevents the data from being skewed by students who scored very high on the pre- exam. This data will also facilitate future comparisons across institutions.

Some of these metrics were also used to examine the effects of integrating the statics and dynamics courses. In order to compare the DFW rates fairly for the integrated course, DFW rates for individual lecture-style classes taught in sequence in previous semesters were concatenated. A certain number of students taking Statics will pass and go on to take Dynamics the following semester, given the Statics DFW rate. Of those students, a certain number will pass Dynamics, given that course’s DFW rate. Thus the DFW rate from the beginning of the Statics course in Fall 2005 to the end of the Dynamics course in the Spring 2006 was calculated for comparison to the integrated Statics and Dynamics course taught in Fall 2006.

All protocols involving human subject data were approved by an Institutional Review Board.

## Preliminary Results

Table 1. Summary of course and grade statistics for courses taught using the SCALE-UP model and traditional lecture-style methods.

Course	Semester	Instruction Format	DFW Rate*	SCI Normalized Gain**	DCI Normalized Gain**	Number of Students
Multivariable Calculus	Fall 06	Traditional	32%	na	na	499
Multivariable Calculus	Fall 06	SCALE-UP	0%	na	na	36
Statics (ME students only)	Fall 05	Traditional	36%	22%	na	29
Statics (All disciplines except ME)	Fall 06	SCALE-UP	34%	22%	na	35
Dynamics (All disciplines)	Fall 05	Traditional	37%	10%		49
Dynamics (All disciplines)	Spring 06	Traditional	47%		14%	49
Dynamics (ME students only)	Fall 05	Traditional	14%	11%		28
Dynamics (ME students only)	Spring 06	Traditional	28%		19%	29
Separate Statics and Dynamics Courses (ME students only)***	Fall 05 + Spring 06	Traditional	54%			57
Integrated Statics and Dynamics Course	Fall 06	SCALE-UP	34%	31%	17%	82

\*DFW Rate = Percentage of enrolled students who earned a D or F, or withdrew from the course after the two week drop/add period, but before midterm

\*\*Normalized gains were calculated as the points the student gained (post - pre) divided by the total number of points they could have gained. Not all students in class took the pre- and post- tests.

\*\*\*This includes data for two sections taught by the same instructor. DFW rate for the sequential Statics and Dynamics courses was calculated by concatenation of DFW rates for the separate courses.

## Discussion

This study is a work in progress, thus this paper constitutes only an interim report, not final results. However, several key observations and significant findings were made, resulting in subsequent course improvements and topics for future investigations.

Based on the comparison between the SCI scores for the separately taught statics courses in traditional and SCALE-UP models (22%), a collaborative learning environment did not result in gains in conceptual understanding of topics. However, the fact that the conceptual understanding measures held up compared to past scores gives some confidence that the grading standard was not relaxed from previous semesters. Moreover, the percentage of non-Civil and Mechanical Engineering students taking this course increased in Fall 2006, making this potentially significant given that the student population is less “mechanics” oriented. Student performance data needs to be further studied to come to a conclusion about this.

Comparing the concatenated DFW rate for the sequential statics and dynamics courses (54%) to the DFW rate for the integrated statics and dynamics course (34%), the combination of content integration and SCALE-UP approach produced a improved retention rate. However, it should be noted that the DFW rate may be artificially higher for the sequential courses, as students have twice as many opportunities to withdraw than for the integrated course (two semesters versus

one). The normalized gains on the SCI for the integrated course were higher than observed at the completion of the separate statics course (34% vs. 22%), and the DCI gains were only slightly lower than those observed at the completion of the separate dynamics course (17% vs. 19%). These results are encouraging for several reasons including: (1) the instructors were using SCALE-UP for the first time and are still learning how to use it effectively, (2) the students were learning dynamics a semester earlier than with the sequential approach, and (3) some students were predisposed to the opinion that the 5-credit course was an experiment doomed to fail, and likely withdrew in anticipation of a return to separate courses. A surprisingly large number of those students who officially withdrew from the course continued to regularly attend the class. It was particularly encouraging to observe such students helping each other, with effectiveness, during the in-class activities. It is also interesting to note that the time devoted specifically to statics topics in the 5-credit integrated course amounted to the equivalent of about 1.5-credits, yet students in this course showed gains in their SCI scores equal to or better than students in the 3-credit statics course. These initial results give some confidence that focusing immediately on dynamics with statics viewed as a special case, and achieving this in one semester, does not seem to be detrimental to statics conceptual understanding, in spite of the fact that less time overall was spent on statics alone. DCI gains were slightly lower for the students in the integrated course compared to students in the 3-credit dynamics course, indicating that there was a slightly negative effect on conceptual understanding of dynamics in the integrated course. As these courses develop and instructors become more proficient at implementing the SCALE-UP model, it is anticipated that students may benefit from the combined effect in which an understanding of dynamics helps comprehension of statics concepts, and vice versa. The introduction of a new course (integrated statics and dynamics) along with a new teaching method (SCALE-UP) concurrently does not allow us to quantify the contribution of SCALE-UP methods to the success of the course. However, it would be difficult, if not impossible, to effectively use a traditional lecture approach to the combined 5-credit course. The role that SCALE-UP methods play in the success of the combined course will become clearer as instructors become more experienced and proficient at applying the model.

In the combined statics and dynamics course in Fall 2006, student attitudes toward in-class work improved significantly through the semester as they became more accustomed to the team-based active learning approach. Student comments at the end of the semester about the teaching methods and the course activities were generally very favorable. Some commonly listed suggestions for improvement have been incorporated into the course this semester, for example, modifying the written journaling assignments so they form the basis of in-class quizzes on reading material, reducing the number of physical activities, and increasing the amount of time spent by instructors working problems on the Symposium, focusing on a cognitive apprenticeship approach<sup>4</sup> (disclosing all of the thought processes going on during problem solution). Other changes for making the classroom more student-centered include alternative questioning strategies to encourage student participation<sup>5</sup>, and the use of a laptop/web-based system (*MessageGrid*)<sup>6</sup> for efficient real-time assessment of student learning. This will make it practical to record a significant number of both individual and group answers to in-class questions on out-of-class reading mentioned above, and in-class discussion and activities. The SCALE-UP model increased the importance of undergraduate peer instruction in these engineering courses. Participation in student-lead Supplemental Instruction evening study sessions has been high, and feedback has been extremely positive. Whereas normal evening

Supplemental Instruction sessions might attract 10 to 20 percent of the students on a given night, approximately 40 to 50 percent of students from the combined statics and dynamics course were typically attending during Fall 2006. The reasons for the increase in students' utilization of peer instruction for SCALE-UP courses will be investigated as survey and interview data is analyzed.

It should be noted that the comparison between the separate and integrated statics/dynamics courses includes data for only one instructor. This eliminated the effects of different teaching styles and grading practices. As the project continues, data analysis will be expanded to include more instructors implementing the SCALE-UP model in engineering courses, and more student performance data generated in follow-up courses.

Conversely, although DFW data for the Multivariable Calculus course (traditional and SCALE-UP) are reported, there are several factors that confound this data and limit a direct comparison. The two versions of the course have different student populations, and are not taught by the same instructors. Students self-select the section taught using the SCALE-UP model, as it has been taught this way for 3 years and has gained a reputation as being a more challenging yet rewarding course. Students understand before classes begin that this is a reduced lecture class which involves group learning activities, and are generally more motivated than students in other sections. In fact, the actual content is somewhat different for the two courses, as the SCALE-UP version uses laptops and software to allow 3D visualization of concepts. Finally, the traditionally taught course data includes multiple sections, and the SCALE-UP data is for one section only. As with the engineering courses, as more sections open up with more instructors implementing the SCALE-UP model, an expanded data set that includes previously taught courses using a traditional lecture format with the same instructor will perhaps allow more direct comparisons between teaching methods.

It is apparent that there are many complex and confounding factors contributing to these preliminary results, including changing student populations, changing teaching methods, and some alterations in course content. A more thorough inspection of the data, with subsets to reduce confounding factors, will allow for more relevant comparisons in future data analyses.

## Dissemination

This research has gained exposure at our institution, as it has built on the success of the precursors to the study, namely multivariable calculus. The SCALE-UP approach was adopted in one section of this course in Fall 2003 as a pedagogical experiment. Based on success of this one course section, beginning in Fall 2006, all freshman Calculus I courses were taught using the SCALE-UP model, in order to address high DFW rates. Historically, the DFW percentage was 44%, and had seen a sharp increase prior to Fall 2006 in most freshman calculus classes. The current DFW rate for all these courses, which includes nearly 800 freshmen, has dropped to approximately 22% in that program, which is encouraging our faculty to adopt the SCALE-UP approach permanently as part of our academic culture. Our research is an outgrowth of the way students are taught in the first year calculus, and we have had some success in expanding the use of these advanced teaching methods on campus. A campus-wide workshop, organized by our institution's faculty development program, will allow faculty to explore the applicability of SCALE-UP in other disciplines. This has the potential to impact the way that all students are



educated at our institution, not just engineering students. It will certainly impact the way statics and/or dynamics is taught.

### Conclusions and Plans for Continuing Research

College teaching hasn't changed much since the amphitheater was invented; lecture is still the most common approach to teaching. The SCALE-UP model promotes teaching in a student-centered environment, where the professor's role in the classroom is more of a facilitator and coach than that of an orator. It has been proven effective in physics instruction, and the preliminary results of this study indicate that it has the potential to increase the rate of student success in engineering courses (including a parallel multivariable calculus course) as well.

Future efforts in this study will focus on tracking student performance in follow-on junior and senior level courses in ME and CE, and expanding our data collection and analysis as more instructors implement the SCALE-UP model in statics and dynamics. In addition, results of a study habits survey, and interviews with a sample population of students of varying performance (including students who withdrew from the courses) at the end of the integrated course will be compiled and analyzed. Integrated course comparisons will be expanded to include data normalized by GPR to offset any changes in departmental GPR requirements. Mathematics course comparisons will be expanded to include data for instructors who have taught multivariable calculus using both traditional and SCALE-UP methods.

Student performance on Force Concept Inventory (FCI)<sup>7</sup> will be examined in addition to the SCI and DCI in the Statics and Dynamics course. GPR at the start of the class and pretest scores on the concept inventories will be used to determine if the populations are significantly different, and normalize this difference if necessary.

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