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Student-Centered Active, Cooperative Learning in Engineering*

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The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) approach to instructional design was adapted with the goal of delivering more effective statics, dynamics and multivariate calculus instruction and integrated course curricula. Inquiry-based learning exercises were designed, incorporating material from statics and dynamics into multi-variable calculus, and vice-versa, as well as integrating statics and dynamics into one course. The effectiveness of the revised course designs and activities were assessed using a mixed method approach. Student performance in these courses and in follow-on courses was used to measure improvements in concept retention. Conceptual tests (Statics and Dynamics Concept Inventories) were administered before and after semesters, and average normalized gains were compared with those for students in traditional learning environments. Open-ended questions on end-of-semester course evaluations assessed student perceptions of the course format. Results indicate increases in conceptual measures in statics with SCALE-UP, significant reductions in failure rates for students in the integrated statics/dynamics course, and reduction in time to completion of statics and dynamics courses. Additionally, anecdotal evidence demonstrates that students are continuing the patterns of peer instruction and positive interdependence, hallmarks of student-centered and active learning, in follow-on courses. Based on these research findings, faculty development materials were developed that concisely state the pedagogical underpinnings of the method, provide evidence of success in our courses, and identify key aspects of successful implementation of student-centered, active, and inquiry-based learning in engineering courses. These include effective use of learning assistants, well-designed learning activities, and formative assessment questions that emphasize learning objectives and guided inquiry. Course materials have been published, and efforts are under way to promote this as a mainstream teaching resource.

Keywords: active learning; cooperative learning; student-centered learning; second year engineering courses; integrated statics and dynamics; statics

1. INTRODUCTION AND BACKGROUND

AMONG THE goals of NSF's Engineering Education Coalitions program was to 'provide tested alternative curricula and new instructional delivery systems that improve the quality of undergraduate engineering education.' The Southeastern University and College Coalition for Engineering Education (SUCCEED) supported *Integrated Math, Physics, Engineering, and Chemistry* (IMPEC) at NC State, an effort to integrate the early engineering curriculum and make it more authentic [1, 2]. Part of the work to advance that agenda was Student-Centered Activities for Large Enrollment Undergraduate Physics (SCALE-UP) [3–6]. Beichner and others [7] showed that students benefit from the use of innovative pedagogies such as active-engagement, cooperative learning, inquiry-based learning and peer instruction even in large-enrollment courses. The SCALE-UP model has been adopted by several institutions into fields including Biology [8] and Chemistry [9, 10], but the model has had limited application in engineering. One of the authors (Ohland) became involved in the SUCCEED Coalition in 1994 and was aware of the IMPEC project and the SCALE-UP efforts that followed from it. Nevertheless, as Ohland did not have a significant role in classroom instruction until joining the Clemson faculty in 2000, that awareness had no impact until his interest in the approach was rekindled at a presentation by Jeffery Saul at a summit on campus computing initiatives sponsored by Dell Computer in 2001 [11]. Thus the ongoing research at Clemson described here has three sequential antecedents funded by the National Science Foundation: the Coalitions program, SCALE-UP, and Saul's adaptation of SCALE-UP. It is promising that the each subsequent NSF investment was less than the previous, and the impact at Clemson has been substantial.

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We have implemented the SCALE-UP model in second-year engineering courses: one section of a multivariate calculus course, one section of statics for other engineering disciplines (mainly civil engineering), and an integrated statics and dynamics course for mechanical engineers. We have examined the effectiveness of this pedagogical approach through student performance indicators, and through feedback from students and faculty.

2. LEARNING ENVIRONMENT

The courses included in this study were offered in classroom space created and equipped for instruction and learning in the SCALE-UP mode [12], featuring 7-foot round tables that can seat up to nine students each (two or three teams per table). The tables had power and wired internet to facilitate laptop use. Instructor space included an interactive pen display linked to dual projectors. White boards for instructor and student use occupied two opposing walls. Students in this study, with the exception of those who transferred in from other institutions, were acclimated to SCALE-UP through their experience in similar classrooms in their first year engineering courses. The environment and other details about the courses included in this study are summarized in Table 1.

A critical component of this environment was the teaching assistants (TAs). TAs were selected from students who had performed well in the courses in prior semesters. Other criteria included strong communication skills and, optimally, some interest in teaching as a career. Our institution has an academic support center that provided general TA training, and individual instructors also met with TAs on a regular basis to discuss the class, their understanding of the active learning exercises, and how to guide student inquiry.

2.1 Multivariate calculus

The traditional multivariate calculus course offered for engineering majors consisted mainly of lecture with out-of-class assignments for practice. The SCALE-UP multivariate calculus course incorporated statics material through Maple® tutorials, in-class team-based learning activities, team projects and a new supporting text which aligned better with the engineering courses. A graduate assistant who would usually be used for grading instead attended class to help students with learning activities. This learning assistant was equipped with a facilitator guide listing common problems students might have, as well as key questions to facilitate guided inquiry.

Additionally, five areas that overlap with statics materials were designed. First, systems of linear equations arising in statics were added to the

Table 1. Details on SCALE-UP courses included in this study, and comparable courses taught in traditional lecture format.

Course/Semester		Number of Students Per Section: Traditional	Number of Students Per Section: SCALE-UP	Student Majors	SCALE-UP Environment	Class Schedule
Multi-variate Calculus	Fall 05	N = 14–44 (12 sections)	N = 48	Multiple engineering majors and levels	1000 sq ft space with five tables (45 student capacity)	3 credit hours; 50-minute sessions 3 days/week
	Fall 06	N = 14–55 (17 sections)	N = 36			
Statics	Fall 06	N = 14–43 (6 sections)	N = 35	Civil Engineering sophomores; sophomores—seniors from other engrg disciplines (BioE, EE, IE)	1700 sq ft space eight tables (72 student capacity)	3 credit hours; 50-minute sessions 3 days/week or 75-minute sessions 2 days/week
	Spr 07	N = 26–42 (5 sections)	N = 36			
	Fall 07	N = 32–37 (5 sections)	N = 53			
	Spr 08	N = 21–48 (4 sections)	N = 63			
Integrated Statics and Dynamics (offered in SCALE-UP only)	Fall 06	n.a.	N = 33, 49, 62 (3 sections)	Mechanical Engineering sophomores (all ME students required to take integrated course)	Same as for Statics	5 credit hours; initially 50-minutes sessions 5 days/week, changed to 115-minute sessions 3 days/week (summer sessions: 25 four-hour sessions)
	Spr 07		N = 61			
	Su 07		N = 10			
	Fall 07		N = 58, 58, 66 (3 sections)			
	Spr 08		N = 81			
	Su 08		N = 21			

existing materials on 3D coordinate systems and vector analysis. Examples of hanging cable problems that lead to linear algebraic systems were used to apply these concepts. Lessons on matrix algebra and solving linear algebraic systems were added to this unit. A second unit was similarly designed to teach space curves, with the primary application being projectile motion. A third unit about scalar functions of several variables was designed with the primary application being maximum and minimum problems. A fourth unit on multiple integrals with the primary application being center of mass and moment of inertia used Maple tutorials for double integrals. In this case, the derivations for center of mass and moment of inertia from the Beer and Johnston statics textbook [17] were included. Additionally, and perhaps more importantly, a lesson on centroids was developed connecting the additivity property of double integrals to a method used in Beer and Johnston that decomposes a body into simple shapes. A fifth unit was incorporated concerning line integrals, surface integrals, flux integrals, Stoke's Theorem, and the Divergence Theorem.

2.2 Statics

Statics is a required course for many engineering majors. The typical course when taught in traditional format is lecturing during class period, out-of-class homework and evaluating performance primarily through exams. In the SCALE-UP format, a graduate student assigned to grade homework and undergraduate students assigned as Supplemental Instruction (SI) leaders were active in the classroom during team activities, providing timely assistance and feedback during the learning exercises. The SI leaders also held evening sessions to help students who were having difficulty mastering topics or completing homework. Attendance at the SI sessions was optional but many students took advantage of this opportunity.

Concepts taught in statics are considered to be core material for a number of civil engineering courses. Students without a good understanding of the material generally struggle in follow-on courses and are continually penalized if they have not grasped fundamental concepts [13]. It is our observation that students who struggle in statics generally have difficulty formulating a solution based on information given in a problem description and accompanying illustration. Once formulated, the mathematics is generally rather trivial in nature. Unfortunately, one of the most difficult things to teach a student is problem formulation [14]. Students study many different types of structural/mechanical systems, and the nuances of the problems can dictate the solution scheme. The ability to recognize how to mathematically model the structure is critical, so that an effective solution scheme can be developed.

Using an active learning environment to teach statics allowed students to get immediate feedback on their understanding of concepts, and rather than finding out while attempting homework problems on their own and out of class. Opportunities for students to provide peer instruction during in-class activities enriched their understanding of the material, and receiving peer instruction enabled students to benefit from hearing another perspective on the material during class periods [15]. With in-class formative assessments, the instructor had the ability to gage effectiveness of a lecture or in-class activity and better ascertain what concepts were difficult for students [3].

2.3 Integrated statics and dynamics

Integrated statics/dynamics, a required 5-credit course for all ME majors, replaced the traditional pair of statics and dynamics courses (3 credits each). This integrated course was not offered in a traditional lecture format. In fact, SCALE-UP allowed us the flexibility to integrate the two courses, which would be nearly impossible in a traditional format. Almost all class meetings were a combination of lecture, discussion, and learning activities, with a balance of typically 30% lecture and 70% activities, although some classes were closer to 100% activities. The activities sought to develop skills in problem formulation, solution, and reflective evaluation. A guided inquiry approach was used 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. In-class activities were done primarily as teams, and ongoing formative assessments ensured that each team member contributed to the outcome. Some activities, such as white-board presentations of student in-class work, involved whole tables of six to nine students. We allowed informal grouping according to the personal dynamics of the students at a given table. A ratio of one instructor (faculty and either graduate or undergraduate student teaching assistant) for every 24 or fewer students was maintained. Undergraduate student teaching assistants also participated as SI leaders, holding two or three evening sessions per week for additional instruction and help with assignments.

The course content was completely revised to present an integrated sequence of dynamics and statics rather than the standard serial approach of statics followed by dynamics. Although the integration of mechanics courses has been previously investigated [13, 16], no text books were available that integrate statics and dynamics. A complete text was created for this course, originally placed on an online course management system, although hard copies were later available and required. Having hard copies limited distractions that an open laptop can bring, and was a simpler medium for note-taking. Electronic versions of published statics and dynamics books served as optional out-of-class reading and as sources of homework problems. 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, reflection questions were provided. Questions on the reading or the classroom discussion were used to register attendance or measure comprehension with an electronic 'clicker' system. Most classes began with these questions, encouraging prompt attendance, but occasionally questions were posed at the end of class to maintain students' attention during class. Learning activities were developed throughout the course, and were refined with successive offerings.

3. RESEARCH METHODS

Project assessment followed a mixed methods approach, using mainly quantitative data comparisons between similar cohorts of students in the same courses taught either in traditional lecture format or SCALE-UP. Quantitative data included course grades, time to completion of course sequences, standardized concept inventories, close-ended questions on course evaluations, and grades in follow-on courses. Qualitative data included student responses on open-ended course evaluation questions. The data collected, organized by course, are summarized in Table 2.

Comparisons were made between *average grades* in multivariate calculus and statics classes taught in SCALE-UP format and those taught during the same time period in traditional lecture format. Average grades for the integrated statics and dynamics course were also compiled, although there was no equivalent traditional course offered for direct comparison.

Fully randomized studies were not feasible because students self-selected their course sections in multivariate calculus and statics. It is possible that over time word got out that the sections taught by certain instructors were 'different' and this may have affected which students signed up for the course. So, in order to account for differences in student achievement prior to entering the multivariate calculus or statics course, *adjusted mean grades* were estimated using the students' GPA prior to taking the course as a covariate. Analysis of covariance allowed us to predict what the average grades would be if all students in all sections had the same incoming GPA. This is referred to as the adjusted mean because it has been corrected to remove variance associated with differences in student prior achievement (as measured by GPA). Partial η^2 is a measure of effect size that estimates the fraction of the variance explained by the intervention. Large effect sizes indicate strong relationships between variables. Effect sizes can be characterized as small when partial $\eta^2 = 0.01$, medium when partial $\eta^2 = 0.06$, or large when partial $\eta^2 = 0.14$ [22].

Student attrition in courses in this study were calculated as the 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 (DFW rate). Because the integrated statics/dynamics course was not offered in a traditional lecture format, the DFW rate in the separate course sequence was concatenated using data from two previous semesters. The concatenated DFW rate was calculated by multiplying the percentage of students who passed statics by the percentage that passed dynamics and then subtracting from 100. In addition, *completion of course sequences* for students in the integrated statics/dynamics course compared to the separate course sequence, determined by looking at the number of semesters that students took to complete both statics and dynamics, and the percentage of students successfully completing both.

Concept comprehension was assessed through

Table 2. Summary of data gathered for each of the courses involved in this study

Semester	Student Performance	Concept Inventories	Course Evaluations	Follow-On Course Grades
Multivariate Calculus (for engineering majors)	Traditional vs. SCALE-UP: • Course grades • Adjusted mean grades • DFW rates			
Statics (for non-ME majors)	Traditional vs. SCALE-UP: • Course grades • Adjusted mean grades • DFW rates	Traditional vs. SCALE-UP: Statics Concept Inventory (pre-post)	Traditional vs. SCALE-UP	Strength of Materials; Dynamics: • Adjusted mean grades (non-ME majors)
Integrated Statics and Dynamics (for ME Majors)	SCALE-UP integrated Statics/ Dynamics: • Course grades • DFW rates • Time to completion Traditional sequential Statics and Dynamics: • Concatenated DFW rates • Time to completion	Statics Concept Inventory Dynamics Concept Inventory (pre-post)		Strength of Materials: • Adjusted mean grades (ME majors)

tracking of average normalized gains on standard concept inventories covering Statics and Dynamics. The Statics Concept Inventory (SCI) [18] was given online outside of class to both the statics and integrated statics/dynamics classes. The Dynamics Concept Inventory (DCI) [19, 20] was given on paper during class for the integrated statics/dynamics class only. These were administered during the first week of class and at the end of the semester. Average gain and average normalized gains were calculated according to Hake's definition [21], with all scores and gains reported as percent correct. That is, the average gain was calculated as:

$$\langle G \rangle \equiv (\text{average post} - \text{score for the course}) - (\text{average pre} - \text{score for the course}) \quad (1)$$

and the average normalized gain:

$$\langle g \rangle \equiv \frac{\langle G \rangle}{100\% - (\text{average pre} - \text{score for the course})} \quad (2)$$

Only pre-scores of students who also took the post test were included in the analysis.

Course evaluations for statics were compared for ten semesters prior to the implementation of SCALE-UP (Fall 1999–Spring 2003), and four semesters after its implementation (Fall 2006–Spring 2008). Responses to open-ended questions for students in SCALE-UP and traditional environments were coded, and frequencies of responses relevant to the instructional method were summarized.

Student performance in *follow-on courses* was compared for SCALE-UP versus traditional format statics, and for separate statics and dynamics versus integrated statics/dynamics. The approach described previously to calculate adjusted mean grades (estimates of the average course grade under the condition that all students have the same incoming GPA prior to entering statics or integrated statics/dynamics) was used in these comparisons. For the integrated course, we included a wider historical comparison group, since there was not a concurrent traditional format course for comparison; all students in the comparison group for this course were ME majors.

4. RESULTS

4.1 Student performance

Figure 1 shows the average grades by section for each course in multivariate calculus and statics. Average grades for the integrated statics and dynamics course are also given, although there is no equivalent traditional course. Also note that the multivariate calculus instructor began using SCALE-UP in Fall 2005, while the statics instructor used the approach for the first time in Fall 2006.

As shown in Table 3, the adjusted mean grades were higher for SCALE-UP than traditional classes in all cases for multivariate calculus and statics. However, the difference was not statistically significant for statics classes in the Fall semesters of 2006 and 2007; in the Spring Semesters of 2007 and 2008 for statics, the teaching approach (SCALE-UP or traditional) accounted for 4.2% and 5.5% of the variance in final grades, respectively. In multivariate calculus, the improvements were significant with medium effect sizes of 8.3% and 12.7%.

Similarly, the SCALE-UP method showed positive effects in multivariate calculus and statics in terms of the DFW rate when compared with traditional teaching methods during the same semesters (Fig. 2). The DFW rate was remarkably low in the calculus course, and the statics course showed a decreasing trend over time. The integrated statics and dynamics course did not show any clear trends over time, but the DFW rate appears to be lower in the summer sessions, which also have much smaller enrollments.

There was evidence that the integrated statics/dynamics course increased the rate of student success in these subjects based on a reduction in the DFW rate, compared with a concatenated DFW rate for individually taught statics and dynamics courses for previous semesters. (The concatenated DFW rate was calculated by multiplying the percentage of students who passed statics by the percentage who passed dynamics and then subtracting from 100.) The DFW rate for the integrated course taught in Fall 2006 was 34%, versus 54% for the concatenated statics and dynamics courses in Fall 2005/Spring 2006. However, it should be noted that the DFW rate might have been artificially higher for the sequential courses, as students had twice as many opportunities to withdraw than for the integrated course (two semesters versus one). It should be noted that Clemson's DFW rates in early courses were potentially inflated by an academic redemption policy that allows students to expunge a certain number of D or F grades after successfully retaking the course.

4.2 Completion of course sequences

Using historical data, we found that a larger percentage of ME students completed the SCALE-UP integrated statics/dynamics class with a C or better than completed the traditionally taught separate statics and dynamics courses (Table 4). The students took an average of 1.30 semesters to complete the integrated course and 2.49 semesters to complete the traditional 2-course sequence. Additionally, 63% of ME students passed the integrated course with a C or better on their first try, compared to 55% who completed both traditional statics and traditional dynamics with a C or better on their first attempt [23].

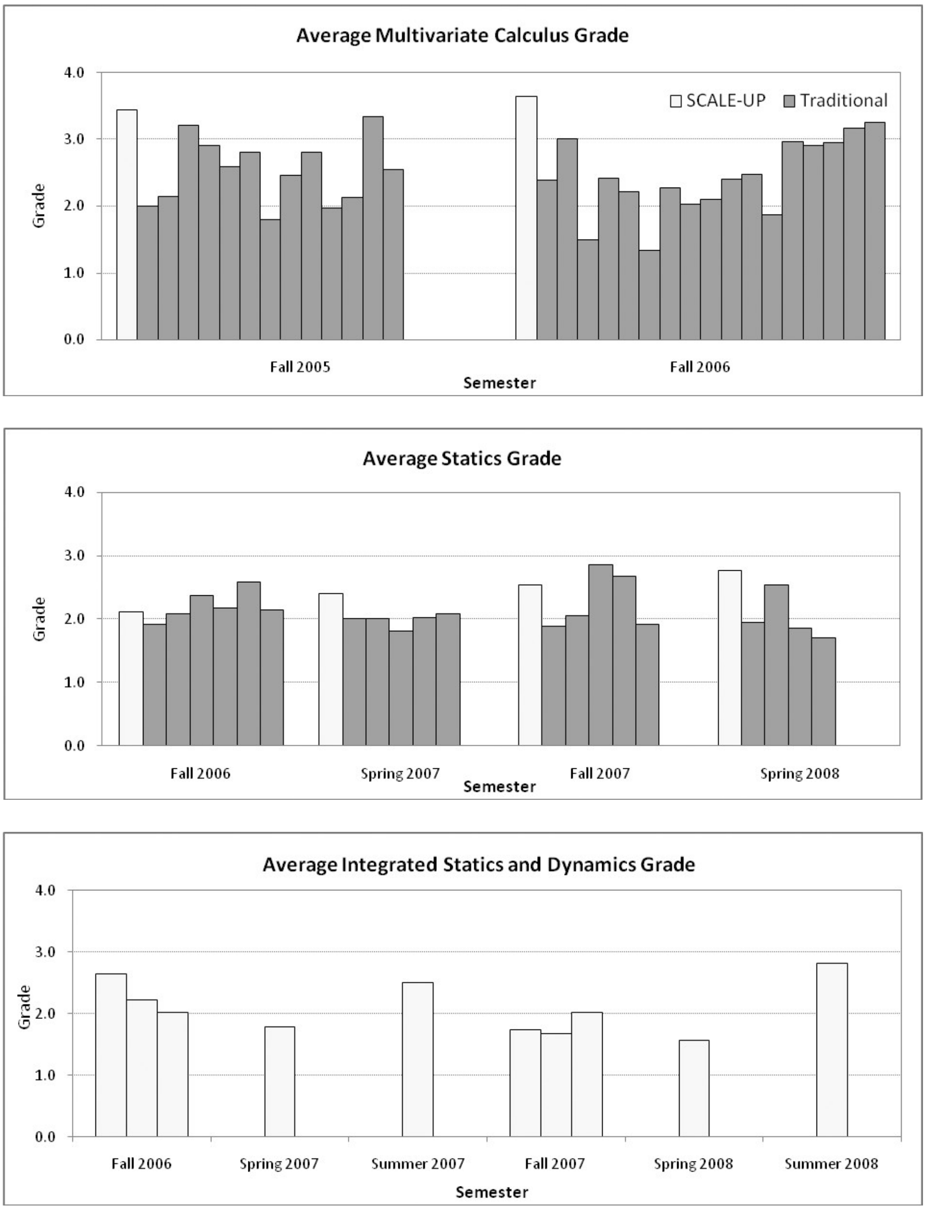

Fig. 1. Course grades for courses taught in SCALE-UP and traditional formats in multivariate calculus, statics for non-ME majors, and integrated statics and dynamics for ME majors (offered in SCALE-UP only). Course grades are reported on a 4.0 scale (A = 4, B = 3, etc.) Where there are multiple sections of the same course, the sections are ordered from smallest to largest enrollment.

Table 3. Adjusted mean course grades after controlling for incoming GPA in Multivariate Calculus and Statics. Course grades are reported on a 4.0 scale (A = 4, B = 3, etc.) The adjusted means are estimates of the average follow-on course grade under the condition that all students have the same incoming GPA; partial η^2 indicates the effect size of SCALE-UP on follow-on course grades

	Multivariate Calculus			**Statics (for Non-ME majors)**		
	Fall 2005	**Fall 2006**	**Fall 2006**	**Spring 2007**	**Fall 2007**	**Spring 2008**
SCALE-UP	N = 46 3.409 (s.e. = 0.167)	N = 34 3.778 (s.e. = 0.173)	N = 33 2.235 (s.e. = 0.187)	N = 30 2.547 (s.e. = 0.181)	N = 48 2.554 (s.e. = 0.141)	N = 62 2.575 (s.e. = 0.124)
Traditional	N = 231 2.499 (s.e. = 0.074)	N = 386 2.374 (s.e. = 0.051)	N = 153 2.185 (s.e. = 0.086)	N = 154 1.991 (s.e. = 0.080)	N = 152 2.292 (s.e. = 0.079)	N = 114 2.082 (s.e. = 0.091)
p	<0.001	<0.001	0.800	0.006	0.107	0.002
partial η^2	0.083	0.127	0.000	0.042	0.013	0.055

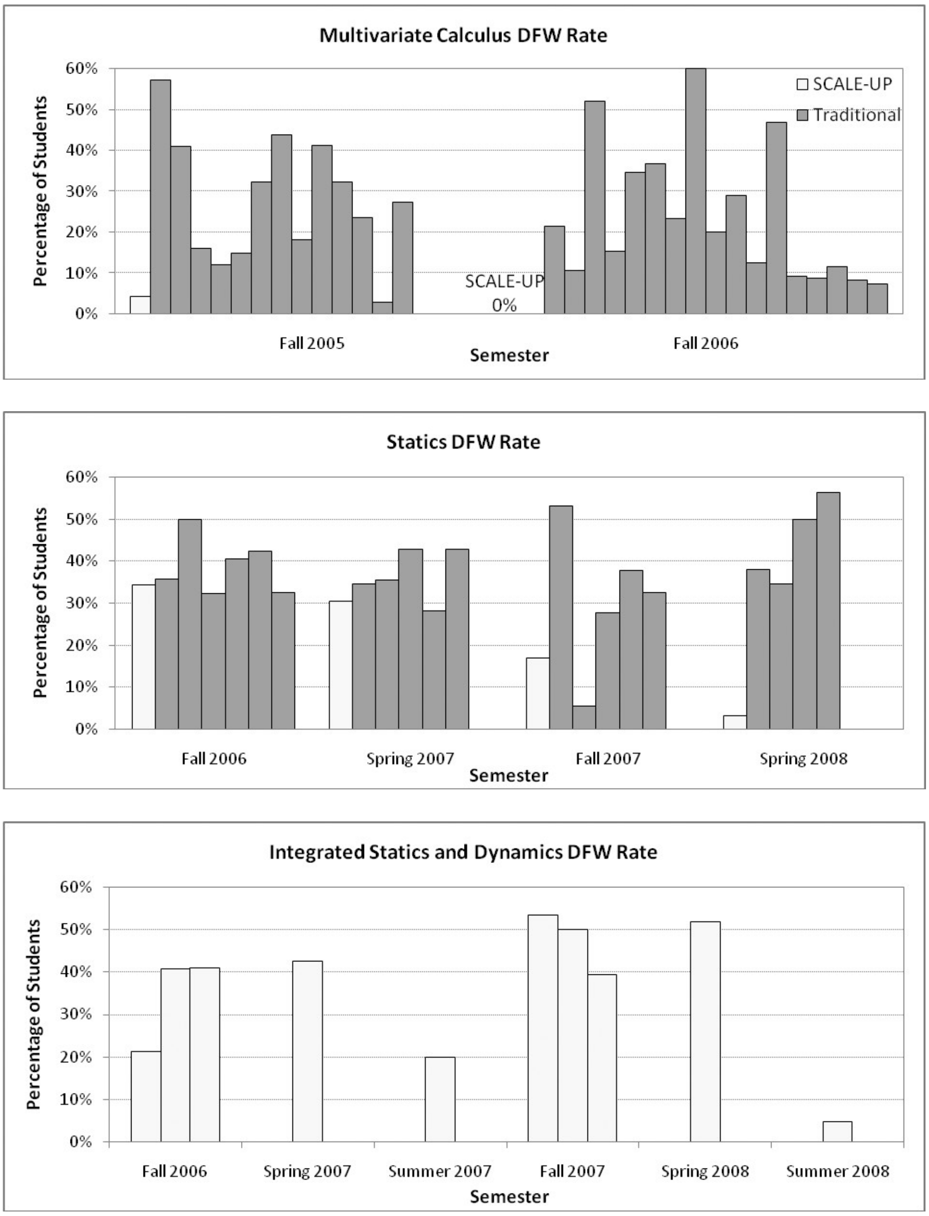

Fig. 2. Student attrition, reported as a percentage of students earning a D or F, or withdrawing from SCALE-UP statics (DFW rate) over four semesters. Where there are multiple sections of the same course, the sections are ordered from smallest to largest enrollment.

Table 4. Completion rate and time to completion of the statics/dynamics course sequence

	SCALE-UP Integrated Statics and Dynamics	Traditional (Separate) Statics and Dynamics (historical data)
Sequence	One 5 credit-hour course	Two 3 credit-hour courses
N	280	773
Percent of students completing the sequence (C or better)	86%	72%
Average time to completion	1.30 semesters	2.49 semesters
Percent of students completing the sequence on their first attempt	63%	55%

4.3 Concept comprehension

Our results showed slightly improved concept comprehension based on increases in normalized gains on the Statics Concept Inventory for students in SCALE-UP statics versus traditional lecture-style instruction (0.21 vs. 0.20), despite the surprisingly high pre-scores of the traditional class. The high scores of the traditional class could be due to the paper format of the test, which may have encouraged students to take it more seriously. However, the paper and online versions of the test have essentially the same questions and the same mode was used for both the pre and post by individual students. The

Table 5. Average gain and average normalized gains for Statics Concept Inventory (SCI) and Dynamics Concept Inventory (DCI), for students in statics, dynamics, and integrated statics/dynamics. Scores are reported in percent correct; gains are reported as percent; normalized gains are reported as a ratio of average gain to possible percent gain. These results were calculated according to Hake's method for analyzing concept inventory results [16]

Statics Concept Inventory								
Course (Engineering Majors)	**Semester**	**Environment**	**Pre SCI (%)**	**Post SCI (%)**	$\langle G \rangle$ **(%)**	$\langle g \rangle$	**n**	**Test Format**
Statics (all)	Fall 2005	Traditional	31%	45%	14%	0.20	35	paper
Statics (all except ME)	Fall 2006–Spring 2008	SCALE-UP	21%	38%	16%	0.21	95	online
Integrated Statics/Dynamics (ME)	Fall 2006–Spring 2008	SCALE-UP	27%	44%	17%	0.23	248	online
Dynamics Concept Inventory								
Course (Engineering Majors)	**Semester**	**Environment**	**Pre DCI (%)**	**Post DCI (%)**	$\langle G \rangle$ (%)	$\langle g \rangle$	**n**	**Test Format**
Dynamics (all)	Spring 2006	Traditional	28%	37%	9%	0.13	40	paper
Integrated Statics/Dynamics (ME)	Fall 2006–Spring 2008	SCALE-UP	31%	41%	10%	0.14	335	paper

normalized gains on the SCI for the integrated course were higher than observed at the completion of separate statics course (0.23 vs. 0.20), and the DCI gains were slightly higher than those observed at the completion of the separate dynamics course (0.14 vs. 0.13). These results are summarized in Table 5.

At the beginning of Fall 2008, students in a junior-level civil engineering structures course completed the SCI to see whether having SCALE-UP statics would have continued effects on statics comprehension (Table 6). Typically, students in this class would have completed statics during the Fall 2007 semester and would have taken structural mechanics (mechanics of materials) class in the Spring 2008 semester. Although the students who completed SCALE-UP statics averaged higher scores than the students in traditional statics, the difference was not statistically significant (p = 0.203). This is not surprising given the small sample sizes.

4.4 Course evaluations

Course evaluations for statics were compared for ten semesters prior to the implementation of SCALE-UP (Fall 1999–Spring 2003), and four semesters after its implementation (Fall 2006–Spring 2008). Responses to open-ended questions for students in SCALE-UP and traditional environments were coded, and frequencies of responses relevant to the instructional method are summarized in Fig. 3. Results indicate positive student perceptions of the SCALE-UP approach for the majority of students responding to these questions (78%), and of peer instruction, or team-based activities in class (61%). It should be noted that in this course, teams were formed by the instructor with the goals of not isolating under-represented minority students and providing a balance of academic performance among team members. Typical responses coded as 'yes,' 'no' or 'ambivalent' for these two questions are:

Table 6. Comparison of statics concept inventory scores at the beginning of a structures course for students who took SCALE-UP vs. traditional statics. Cohen's d indicates the effect size of taking SCALE-UP statics as opposed to traditional statics in standard deviation units

Statics Class	**Statics Concept Inventory Scores at the Beginning of Follow-on Structures Course**
SCALE-UP	N=14 Score = 44% correct (s.e.=4.3%)
Traditional	N=69 Score = 38% correct (s.e.=1.8%)
P	0.203
Cohen's d	0.376

- In general, was SCALE-UP an effective method for teaching statics? (N=91)
  - Yes: 'I felt that the learning activities kept me focused during class, and helped me to understand the concepts more thoroughly.'
  - Yes: 'I think the active learning environment was really helpful after I got over the initial "I don't want to look stupid in front of other people" stage.'
  - No: 'This method was not beneficial to me. Most of the time, my group was unsure where to even begin the problem, and we'd be sitting there wasting time until an instructor could come over and point us in the right direction to get started.'
  - No: 'I'd prefer a more standard learning environment to the active one.'
  - Ambivalent: 'It's ok. It was a good idea but I feel it all depends on if you have good team members on your team who are willing to work with you. My first team worked out really well, but my second team didn't help me out as much and as a result, my grade really suffered.'

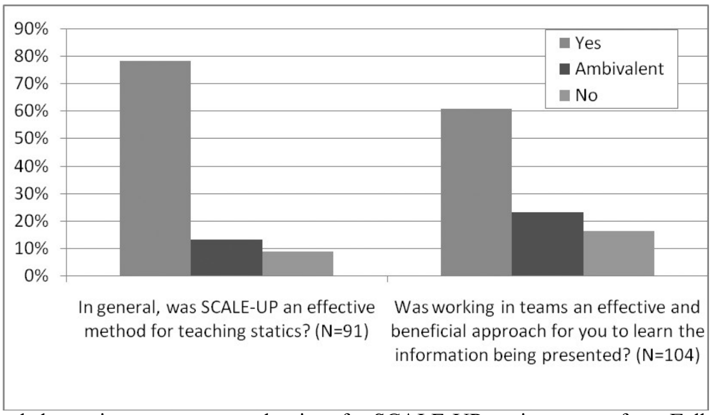

Fig. 3. Responses to open-ended questions on course evaluations for SCALE-UP statics courses from Fall 2006 – Spring 2008 (n = 154 evaluations; not all students responded to all questions), reported as percentages of responses that were coded as 'Yes,' 'Ambivalent,' and 'No.'

Table 7. Responses to Likert scale questions (1 = strongly disagree; 5 = strongly agree) on course evaluations for students in statics, and results of t-tests between means (p-value). Both SCALE-UP and traditional sections were taught by the same instructor. Number of responses, mean and standard error (S.E.) in SCALE-UP and traditional environments are reported; Cohen's d indicates the effect size of SCALE-UP on the difference between the variables. Statements that showed significant differences between groups (p<0.05) are shaded

	SCALE-UP?	**N**	**Mean**	**S. E.**	**p-value (Cohen's d)**
The instructor clearly communicated what I was expected to learn.	yes	153	4.25	0.061	0.02
	no	158	4.03	0.058	(0.26)
The instructor made the relevance of the course material clear.	yes	154	4.19	0.061	0.20
	no	157	4.06	0.063	(0.15)
The course was well organized.	yes	155	4.40	0.064	0.33
	no	158	4.26	0.062	(0.11)
There was a positive interaction between the class and instructor.	yes	155	3.91	0.075	0.30
	no	158	3.75	0.078	(0.12)
The instructor's teaching methods helped me understand the course material.	yes	154	3.90	0.083	<0.01
	no	158	3.55	0.076	(0.33)
The instructor's verbal communication skills helped me to understand the course material.	yes	155	3.97	0.075	<0.01
	no	157	3.66	0.073	(0.34)
The instructor clearly explained what was expected in assignments and tests.	yes	155	4.12	0.068	<0.01
	no	157	3.80	0.069	(0.38)
The instructor kept me informed about my progress in the course.	yes	152	4.15	0.074	<0.01
	no	158	4.44	0.060	(–0.36)
The feedback I received on assignments and tests gave me the opportunity to improve my performance.	yes	155	3.94	0.079	<0.01
	no	156	3.62	0.069	(0.35)
Overall, the instructor is an effective teacher.	yes	155	4.21	0.069	0.07
	no	157	4.00	0.066	(0.21)
The instructor's grading procedures gave a fair evaluation of my understanding of the material.	yes	153	4.05	0.076	0.63
	no	158	4.01	0.065	(0.06)
How much work did you put into this course relative to your other courses?	yes	153	4.62	0.050	<0.01
	no	158	4.33	0.061	(0.41)
How difficult was this course for you relative to you other courses?	yes	155	4.34	0.061	0.19
	no	158	4.22	0.063	(0.15)

  – Ambivalent: 'I'd say it was helpful, but not significantly. If anything, the change of pace was nice.'
- Was working in teams an effective and beneficial approach for you to learn the information being presented?
  – Yes: '[Working activities with my team was] very beneficial because we were able to try and do problems on our own while the concept was fresh in our mind.'
  – Yes: 'EXTREMELY beneficial to work with a person with the same level of understanding.'
  – No: 'I would rather the instructor work more example problems. Also, I wish we were at least told what the correct answer was supposed to be for the in-class activities because many times, my group would solve the problem but not know if the answer we got was correct.'

Table 8. Adjusted mean (standard error) grades in follow-on courses after controlling for incoming grade point average (GPA). Course grades and grade point averages are reported on a 4.0 scale (A = 4, B = 3, etc.) Data were compared using analysis of covariance. The adjusted means are estimates of the average follow-on course grade under the condition that all students have the same incoming GPA; partial η^2 indicates the effect size of SCALE-UP on follow-on course grades.

	Non-ME		ME
	Strength of Materials	**Dynamics**	**Strength of Materials**
SCALE-UP	N = 54 2.199 (s.e. = 0.119)	N = 43 1.743 (s.e. = 0.179)	N = 182 2.817 (s.e. = 0.072)
Traditional	N = 337 2.309 (s.e. = 0.048)	N = 240 2.088 (s.e. = 0.076)	N = 818 2.503 (s.e. = 0.034)
p	0.393	0.078	<0.001
partial η^2	0.002	0.011	0.016

– No: 'I would have rather [had] more time for lecture because it seemed like he didn't have enough time to get through everything.'
– Ambivalent: 'I don't think it was bad for most people, but I'm really not a morning person and found it difficult to hold a polite conversation with anyone in my group, and wound up working by myself often.'
– Ambivalent: 'It helped somewhat.'

Results of comparisons of responses to close-ended questions on course evaluations in statics are summarized in Table 7, and show significantly higher ratings for the SCALE-UP statics classes for items directly related to the instructional method, such as the perceived student workload, the effectiveness of instructor's teaching methods, and the effectiveness of feedback on students' performance. The effect size of these differences was calculated using Cohen's d (the difference between two means divided by a standard deviation).

4.5 Follow-on courses

Long-term effects were assessed by tracking student performance in follow-on courses and correcting for the student's incoming GPA within the statistical analysis (Table 8). For ME students, integrated statics/dynamics is a prerequisite for a three credit-hour strength of materials course. For non-ME students, statics is a prerequisite to both a two credit-hour dynamics course and a four credit-hour strength of materials course.

Only the SCALE-UP statics/dynamics course had statistically significant effects on follow-on course grades. The partial η^2 value of 0.016 indicates that 1.6% of the variance in strength of materials grade is explained by the treatment variable, SCALE-UP statics/dynamics vs. traditional statics. This is typically considered a small effect size [22]. The data showed that the SCALE-UP approach used in the ME course has a measurable positive effect on student performance in the follow-on course. The related improved preparation has been reported anecdotally by instructors of this strength of materials course when comparing current ME students to those they encountered in the past.

5. DISCUSSION

In mechanical engineering, students adapted well to the new instruction mode although there was noticeable resistance in the first semester. This resistance seemed be centered between two types of students. One was a subset of the better than average students who, based on feedback on course evaluations, saw in-class peer learning as a hindrance to their progress. However, another subset of the very best students seemed to enjoy the approach and were seen tutoring other students with excitement. A second small group of students included the weakest students who came to the course with limited math and problem solving skills, and preferred a 'cookbook' approach, mimicking the instructor's solutions to problems. Others in this group simply preferred not to work during class, but would rather just watch and listen.

Increasing the length of the classes during the second semester of this study (115 minutes) seemed to create a much better learning atmosphere. Because of the active learning, the classes did not seem to be excessively long to most students. The extremely long classes established during the following summer session (4 hours and 15 minutes) were even more effective. In the two summer sessions taught to date, the success rate has been 88% and most of those taking the summer course were weaker students repeating the course. One especially persistent student who had been unsuccessful in four prior attempts earned a B in the summer. With an active learning, team-based approach, the disadvantages common to long class sessions seemed to disappear, and in fact became advantages. Longer classes seemed to foster establishment of stronger teaming relationships and sense of camaraderie. Time was available to work some significant problems and to allow students to focus deeply on the subject at hand.

The positive results regarding the integrated statics/dynamics course are encouraging for several reasons: (1) the instructors were using SCALE-UP for the first or second time and are still learning how to use it effectively, (2) the students were learning dynamics a semester earlier than with the old sequential approach, and (3) some students in the early part of the project 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.

Some difficulties exist in the implementation of this study. Students in statics self-selected to some degree, choosing a SCALE-UP section over other traditionally-taught sections that were available. (In integrated statics/dynamics, all students in ME were required to take it.) It could be that these self-selecting students have had enough experience in the SCALE-UP format (two first year courses and at least one calculus course) that they chose that learning environment, knowing that they prefer the support system incorporated into the SCALE-UP approach (SI, TAs, instructors, in-class learning activities, peer instruction, etc). Our data from follow-on courses for non-ME students shows that these students do not have a significant advantage (and in some cases, may actually have lower grades) than students who were taught statics in traditional lecture format.

A prior study of the effectiveness of student study habits in the integrated statics/dynamics courses was conducted using a cluster analysis of survey and interview data [24]. Three study habit profiles and patterns of resource use were identified (Help Seekers, Supplemental Instruction Dependent, and Minimalists) which lead to different levels of conceptual understanding of the material. Help Seekers utilize every resource available to them, and performed moderately well on concept inventories and earned grades in line with their incoming GPA's, despite the difficulty of the course. Supplemental Instruction Dependent students relied almost exclusively on the student-led sessions to get homework done and spent little time studying on their own. Minimalists started and finished with higher concept inventory scores, although their grades were similar to the Supplemental Instruction Dependent group. They read the book more frequently than the other students, but utilized other resources less. The students self-selecting to take statics in SCALE-UP format may be Help Seekers, who utilize any and all resources available to help them master the material. Further research using qualitative methods such as interviews and/or open-ended surveys will seek to determine what factors contribute to students' selection of certain course sections, whether these students do indeed fall into the 'Help Seekers' category, and how these patterns of behavior contribute to their experiences in follow-on courses.

Effect on student performance in follow-on courses indicates a positive trend for students coming from the integrated statics/dynamics course, but not for the statics course in civil engineering. Feedback from students indicates a positive attitude towards the SCALE-UP environment as shown in course evaluation and survey data reported above. Other faculty members have reported that students are continuing to work in 'SCALE-UP' mode even in traditional lecture-style classes. One instructor in civil engineering gave an account of how, when students turned and talked to each other during his lecture, he was at first disturbed by their behavior, until he realized that they were working out details of what he was teaching. He ended up adapting his lecture format to allow time for students to discuss the material with each other during class. One instructor in mechanical engineering stated that students in a 4th semester fluid systems class, having taken SCALE-UP statics/dynamics, seemed unusually mature and ready to work on in-class activities on the first day of class. Another instructor of the same class confirmed that the quality of questions and comments coming from his students seemed much more mature than in the past.

In addition to student performance data, comments and responses to questions on course evaluations are further evidence that the SCALE-UP approach is effective in engineering courses. For example, more students in SCALE-UP found the feedback helpful to their learning. As discussed below, ongoing formative assessments are a key component to the success of the approach. Some of the negative comments and attitudes of the students towards the SCALE-UP approach such as those reported from course evaluations above have been taken into account as our team developed materials to guide faculty in applying the method to new or existing courses. For example, concerns about 'wasting time' waiting for guidance from an instructor TA can be addressed by proper scaffolding of the materials in the mini-lectures, by effective training and use of TAs, and by acclimating students to the 'student-centered' environment. It is understood that there will always be a certain level of student dissatisfaction in this environment, as it requires students to do more work in class, and places the responsibility of working through problems on them rather than the instructor. It is no surprise that significantly more students in SCALE-UP versus traditional statics thought that they worked harder in this class than in other courses.

6. RECOMMENDATIONS FOR IMPLEMENTING SCALE-UP

Our goal in disseminating the findings of our study is to streamline the process of adapting the method to new and existing courses, thus improving undergraduate STEM education. Our research team has developed materials on adapting SCALE-UP that form the basis of a workshop that we have offered at several institutions. The workshop materials are available on our project web site [23], and include the following.

- An overview of SCALE-UP
- A workshop for calculus instructors
- A workshop for engineering instructors
- A workshop for a general audience
- A workshop on creating learning activities and facilitator guides for learning assistants

We have identified the following components as essential to the successful implementation.

- Student-centered learning; students responsible for mastery of course material
- Mini-lectures (scaffolding), interspersed with learning activities
- Learning activities that engage students in the learning process
- Learning activities that enable social interactions
- Formative assessment in class by instructor and learning assistants during learning activities to provide timely assistance and evaluation
- Infrastructure that enables social interactions

In a student-centered course, the supporting material for each instructional objective does not have to be written on the board. In an active learning mode of instruction, the lecture is interspersed with activities which can be quite varied. SCALE-UP is a specialized active learning format. The key to SCALE-UP is the social interaction among students, instructor, and learning assistants. Faculty must be willing to lecture less and see the benefit of having students be more active in the classroom. The instructor and learning assistants formatively assess student learning by listening to student conversations and by watching students work. They serve as facilitators of guided inquiry by asking students leading questions when they get stuck and by assessing student skills. The instructor no longer has to wait until the first exam to determine who is 'getting it.' Formative assessment informs instruction by revealing gaps that need to be addressed. Traditionally, students solve sets of problems for homework and this work is often done alone. A SCALE-UP course brings problem solving into the classroom as a team activity.

The creation of SCALE-UP course materials can be time intensive, especially the first few times that the course is taught. This includes the development of instructional objectives and the design of mini-lectures, learning activities, and learning activity facilitator guides. Mini-lectures must focus on the big ideas; learning activities typically take key problems and break them into multiple parts; and learning activity facilitator guides include formative assessment tools such as guiding questions and skills to be assessed. After a set of activities and facilitator guides are created, modifying them based on experience can be done efficiently. In addition, instructors need to be organized prior to each class period so that they (and TAs) are prepared to guide student learning.

7. CONCLUSIONS

Based on results of our study, we have successfully adapted SCALE-UP in second-year engineering and mathematics courses. Adapting the SCALE-UP approach in our classes has allowed the successful integration of course materials from what are traditionally separate courses, which otherwise would have been overwhelming for students in a tradition (mainly lecture) environment. Our results have demonstrated some gains in concept comprehension based on increases in normalized gains on the Statics Concept Inventory for students in SCALE-UP statics/dynamics versus traditional lecture-style instruction. We have also seen drops in the DFW rate (students earning a D or F, or withdrawing from a course) over the four semesters included in our study for SCALE-UP statics and integrated statics/dynamics compared to traditionally taught courses. We observed improvements in the time to completion and completion rate for students completing the integrated statics/dynamics course compared to students in traditionally taught separate statics and dynamics courses. We have evidence that students passing integrated statics/dynamics are more successful in follow-on courses, while student passing SCALE-UP statics were not significantly different in their likelihood of being successful in follow-on courses than their counterparts in traditional classes. Feedback from students and faculty indicate a positive attitude towards the SCALE-UP environment, and most students have found the peer instruction and in-class activities helpful to their learning experience. Future directions for this research will explore how students have changed in their development as a community of learners, how students might use online activities, and how faculty adapt from traditional instructional methods to this more active, student-centered method.

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