

COMPREHENSIVE ANALYSIS OF A STUDENT-CENTERED ACTIVE-LEARNING
INTEGRATED STATICS AND DYNAMICS COURSE FOR
MECHANICAL ENGINEERS

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ABSTRACT

The Student-Centered Active Learning in 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 multivariable calculus, and vice-versa, as well as integrating statics and dynamics into one course. Analysis included an exploration of student study habits, multiple measures of course effectiveness, and an examination of curricular effects. Challenges of implementation are also discussed.

Study habits of students in an integrated Statics and Dynamics course were assessed through a voluntary survey in order to determine which practices are the most helpful to the students. These data indicated that there are three distinct behavior patterns for these students (Help Seeker, Supplemental Instruction Dependent, and Minimalist), which lead to different levels of conceptual understanding of the material.

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. Survey data indicate positive effects on students' use of learning resources, and anecdotal evidence demonstrates that students are continuing the patterns of peer instruction and positive interdependence in follow-on courses.

Based on these research findings, faculty development materials were generated that concisely state the pedagogical underpinnings of the method, provide evidence of success in our courses, and identify key aspects of successful implementation of SCALE-UP 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.

Mechanical Engineering students in both the old and new curricula ($n = 316$ and 366 , respectively) were tracked to glean information about the paths students take as they progress through their degree program and the effects that the new integrated course has had on these paths. For each student, the number of attempts and grades for the courses of interest were recorded. Results indicate nearly the same proportion of students pass the integrated dynamics and statics course on their first attempt as pass both the separate courses on their first attempt at Clemson University. Students in the new curriculum are less likely to quit before completing the course sequence. As expected, it takes students less attempts to pass the new course than to pass both the old courses.

Details regarding implementation of this course are discussed. Challenges to achieving success in this new course have been many and demanding. These include (1)

development of a dedicated textbook, (2) development of learning exercises to foster student comprehension, (3) reorganization of topical content including topic deletion and added emphasis on certain topics, (4) preparing faculty for change, (5) accommodating limited student maturity, and (6) dealing with widespread misgivings about the project.

DEDICATION

To my wonderful husband for his love and support and to my parents for their
lifelong encouragement.

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I would like to thank the mechanical engineering members of my committee: Dr. Sherrill Biggers, Dr. Paul Joseph, and Dr. Joshua Summers for supporting me in this line of research which is somewhat off the beaten path. Dr. Biggers has devoted a lifetime of experience towards the development of an integrated statics and dynamics course which is the basis of this research and I am grateful for his commitment to educating the engineers of tomorrow.

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1. INTRODUCTION

In 1998, a study published by Hake in the American Journal of Physics revealed that courses which made substantial use of interactive engagement methods improved students conceptual understanding of physics far more than courses which made little or no use of such methods. The study included over 6000 students and found that the difference in average normalized gain (as calculated from the Force Concept Inventory and the Mechanics Diagnostic Test) was more than two standard deviations¹. This study was a confirmation of the benefits of interactive engagement. Models like Peer Instruction² and Interactive Lecture Demonstrations³ attempt to engage students in lecture, but are not designed to facilitate interaction between individual students and faculty. Studio-style models were promising, but hard to implement in large classes. In response to this difficulty, Beichner and Saul developed an interactive learning approach that can be implemented in large classes, appropriately titled SCALE-UP, Student-Centered Activities for Large Enrollment University Physics⁴. As the approach spread to other disciplines, “University Physics” was changed to “Undergraduate Programs⁵.” The idea is that students work cooperatively on engaging activities in studio-style classrooms that allow the instructors (including graduate or undergraduate teaching assistants) to circulate around the room, engaging students and teams in “Socratic-like dialogues.” Even with large class sizes, Beichner and Saul found increased concept comprehension and problem solving abilities⁴.

In 2005, the National Science Foundation awarded a Course Curriculum and Laboratory Improvement grant to a team of investigators at Clemson University to

implement innovative student-centered changes to engineering curricula. The primary goal of the project was to adapt and implement SCALE-UP in engineering courses and then to disseminate the lessons learned to other institutions interested in implementing active-learning in their engineering curricula. SCALE-UP was implemented in a statics course, a multivariate calculus course which incorporates examples from statics, and a new mechanical engineering course integrating statics and dynamics. This thesis is a comprehensive assessment of the SCALE-UP courses, with special focus on the integrated dynamics and statics course for mechanical engineering students.

The thesis begins with an examination of student study habits in the integrated course (Chapter 2). Using a cluster analysis of survey data, three different study habit profiles were identified, each profile leading to different levels of conceptual understanding and academic performance. This work has been peer-reviewed and can also be found in the *Proceedings of the 2007 American Society for Engineering Education Conference*.

Chapter 3 includes a multi-pronged assessment of the entire SCALE-UP project, including changes implemented in a statics course and multivariate calculus course. Assessment measures included average grades, adjusted mean grades, student attrition in each course, completion of course sequences, concept comprehension, course evaluations, and performance in follow-on courses. This work is published in the *International Journal of Engineering Education*.

Chapter 4 focuses on the curricular effects of the integrated mechanical engineering course, including trends in enrollment, 1- and 2- year retention rates, and

curricular progress. An additional benefit is that teaching dynamics concepts in the first semester of the sophomore year allows the second semester courses to put these concepts into practice

Finally, Chapter 5 is a detailed description of the implementation of such a course. Advantages, opportunities, and challenges are discussed. This chapter will be of great use to practitioners or administrators interested in making changes to their own courses. The work in Chapters 4 and 5 will be available in the *Proceedings of the 2010 American Society for Engineering Education Conference*.

Chapter 6, the closing chapter, synthesizes the conclusions of the above studies and offers suggestions for future studies.

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2. STUDENT STUDY HABITS AND THEIR EFFECTIVENESS IN AN INTEGRATED STATICS AND DYNAMICS COURSE

M. K. Orr, L. C. Benson, M. W. Ohland and S. B. Biggers, “Student Study Habits and their Effectiveness in an Integrated Statics and Dynamics Class.” *Proceedings of the American Society for Engineering Education Annual Conference and Exposition* (2008).

Abstract

Integrated Statics and Dynamics is a required five-credit course that was offered for Mechanical Engineering students at Clemson University for the first time in Fall 2006. The large-enrollment course was taught using innovative active learning techniques and new course materials. To aid in the development of the course, 211 students were asked to self-report their study habits in an eight-question survey. A cluster analysis was used to identify three study habit profiles. Knowing how students allocate their time and the effectiveness of their strategies can promote more effective guidance for students who are struggling to learn the material while managing their time, and could drive course design with proper emphasis on each aspect of coursework.

2.1 Introduction and Background

In Fall 2006, an active-learning approach modeled after Beichner and colleagues’ SCALE-UP method¹ was implemented at our institution to teach sophomore Mechanical Engineering students statics and dynamics in one integrated course. A cluster analysis of survey data allowed us to identify three patterns of study among the students; minimalist, help seeker, and SI dependent. The goal of this exploratory research is to identify study

habit profiles in order to support course development and create plausible hypotheses for further research into pedagogical innovations.

2.1.1 Course Description

Integrated Statics and Dynamics is a required five-credit course required for Mechanical Engineering students at Clemson University. The large-enrollment course is taught using innovative active learning techniques^{1,2} and new course materials³. The class meets for nearly six hours a week in a studio-style classroom with 7-foot-diameter round tables seating up to nine students. Lecture time has been transformed into studio time that allows students to work on learning exercises together in class while the instructor and several learning assistants are present to guide them. Statics is taught as a special case of dynamics. Within the first week, students are analyzing the dynamics of lifting.

Because Statics and Dynamics courses historically have high DFW rates (percentage of students receiving a grade of D or F or withdrawing from the course), the Academic Success Center provides Supplemental Instruction (SI) for these classes. A traditional class would have one undergraduate SI leader who would attend all classes and then facilitate study sessions several nights a week. Often these sessions consist of the SI leader helping the students work through their homework. Because Integrated Statics and Dynamics is a large enrollment class that meets more frequently than traditional classes, the SI system had to be modified to ease the load of the SI leaders. Multiple SI leaders served as learning assistants in each class, and a joint session was

held for all three sections several nights a week. This resulted in smaller time commitments for the SI leaders, but very large SI sessions.

2.1.2 Cluster Analysis

Cluster analysis is the process of uncovering natural groupings in data⁴ by clustering objects (students in this case) according to attributes (the students' study habits in this case). Each survey item is essentially a dimension in space and a student's responses to the survey questions are her coordinates. These coordinates can be used to calculate the Euclidian distances between students. Although many variations are possible, there are two major types of clustering; hierarchical and partitioning. A typical agglomerative hierarchical clustering algorithm computes the distance between every pair of objects and then groups the two closest. This process is repeated until all the objects are grouped together. The result is a multi-level hierarchy of groups. K-means clustering is a common partitioning method. The objects are randomly partitioned into K clusters and the centroid or average of each cluster is computed. Each point is then reassigned to the cluster with the closest centroid. The centroids are recomputed and the process is repeated.

2.2 Methods

An integrated Statics and Dynamics course was developed, and is a requirement for students majoring in Mechanical Engineering. There were three sections of the course each semester with enrollments ranging from 33 to 66 students per section. In the Fall semesters of 2006 and 2007, all students in the course were given a voluntary survey

consisting of 8 questions during the last week of class. The surveys were administered by a teaching assistant while the instructor was not in the room. Students were asked only to write their student number on the survey. Two hundred and eleven students completed the survey; 169 students selected at least one of the multiple choice answers for each of the questions. Write-in answers were also accepted, but they were not used in this analysis. All methods were approved by the Institutional Review Board; confidentiality of student identities and survey responses was maintained throughout the study.

2.2.1 Coding

Quantitative analysis of the survey responses varied depending on the format of the question. The first survey question was regarding homework, with 6 close-ended and one open-ended response choices:

- a) I did the homework for this class (circle all that apply)
- b) by myself
- c) with help from my team or table
- d) with help from classmates not at my table
- e) at SI
- f) with help from the instructor
- g) during class
- h) other:_____

Since the students were asked to circle all that apply, each choice (a-f) was scored separately with a 1 if it was circled and a 0 if it was not.

The remaining questions were scored by ranking the choices. This was done for clustering purposes so that the value for someone who “always or almost always” does the homework is closer to someone who “usually” does the homework than to someone who only “occasionally” does the homework. For simple interpretation, the highest values are associated with those habits traditionally considered the most prudent. For example, in question 2 shown below, choice a) always or almost always was assigned 4 points while answer d) never or almost never was assigned 1 point.

- a) I did the homework
- b) always or almost always
- c) usually
- d) occasionally
- e) never or almost never
- f) other: _____

The remaining questions were scored in a similar manner. The questions and point values are given in the appendix. The survey given to the students did not include point values. Question 5 regarding journal questions was not used for clustering the data because of ambiguous wording, and because completion of the journal questions was required for the 2006 class but optional for the 2007 class.

The dependent variables used in the study were incoming GPR, course grade, and grade differential, as well as pre-scores, post-scores, raw gains, and normalized gains on the Statics Concept Inventory⁵ (SCI) and the Dynamics Concept Inventory⁶ (DCI). A grade differential was calculated as the difference between the course grade and the

previous semester GPR. This normalized differences between incoming GPR for different clusters. Raw gains are calculated as post-score minus pre-score. Normalized gains are calculated by dividing the raw gain by the maximum possible gain (points possible minus pre-score).

2.2.2 Cluster Analysis

Twelve dimensions were used for the cluster analysis. Six were the binary items from question 1, and six were ordinal scores from questions 2, 3, 4, 6, 7, and 8. Since the scales varied the scores were standardized to have a mean of zero and a standard deviation of 1. Both hierarchical and K-means methods were used to cluster the students using MATLAB⁷. Since K-means groupings can vary due to random starting points, 100 replicates were used to find the best solution for 2,3,4,5, 6, and 12 clusters. However, the chosen solution was consistently found with as few as 10 replicates.

Based on average silhouette values, the 3-cluster K-means grouping was selected (average silhouette value 0.3365). Cluster 2 of the chosen decomposition was very consistent. It appeared in hierarchical groupings as well as K-means groupings of various sizes. Analysis of variance ($\alpha=0.05$) was used to determine whether at least one of the groups was different for each independent and dependent measure. Ten of the 12 dimensions used for clustering showed significant differences.

2.3 Results

2.3.1 Clusters

Table 2.1 gives the mean values of responses to the survey questions for each group. Brief descriptions of each groups study habits are below. Due to the binary nature of question 1, the averages for items 1a through 1f also represents the proportion of students who reported each behavior.

Table 2.1 Average survey response values by cluster (followed by standard deviation). Means with common super scripts are not significantly different based on ANOVA and Fisher's Least Significant Difference Test (alpha = 0.05)

Cluster	1a. Did HW alone**	1b. Did HW with help from team or table**	1c. Did HW with help from other classmates**	1d. Did HW at SI**	1e. Did HW with help from the instructor**	1f. Did HW during class**	2. Homework Frequency**	3. Reading Frequency**	4. Reading Depth	6. SI Attendance**	7. Time spent on course**	8. Attention in class
1.Minimalist	0.73 ^a (0.45)	0.42 ^a (0.50)	0.21 ^a (0.41)	0.06 ^a (0.24)	0.00 ^a (0.00)	0.08 ^a (0.28)	2.98 ^a (0.87)	2.96 ^{ab} (1.38)	3.25 (1.21)	1.83 ^a (1.06)	3.25 ^a (1.33)	3.13 (0.76)
2.Help Seekers	0.76 ^a (0.44)	0.82 ^b (0.39)	0.76 ^b (0.44)	0.88 ^b (0.33)	1.00 ^b (0.00)	0.29 ^b (0.47)	3.76 ^b (0.56)	3.53 ^a (1.01)	3.88 (1.17)	3.47 ^b (1.18)	4.65 ^b (1.11)	3.35 (0.70)
3.SI Dependent	0.45 ^b (0.50)	0.54 ^a (0.50)	0.70 ^b (0.46)	0.95 ^b (0.21)	0.00 ^a (0.00)	0.10 ^a (0.30)	3.83 ^b (0.38)	2.64 ^b (1.29)	3.41 (1.20)	4.08 ^c (1.08)	4.47 ^b (1.40)	3.22 (0.71)

** At least one group is significantly different based on ANOVA (alpha=0.05)

Cluster 1 (48 students): Minimalists - Most students in this group did not take advantage of Supplemental Instruction (SI). They also reported spending the least amount of time outside of class, doing the least amount of homework, and were the least likely to seek help from their classmates.

Cluster 2 (17 students): Help Seekers - Everyone in this group reported seeking help from the instructor on homework. No one in the other groups reported seeing the

instructor for homework help. This group used every resource available to them. They sought help from peers and SI, and also worked on their own. They reported the most frequent reading and the most hours spent studying outside of class.

Cluster 3 (104 students): SI Dependents - Members of this group were the least likely to do the homework on their own. They reported the highest attendance at SI sessions and 95% reported doing homework at SI. They also reported doing the most homework, but the least reading.

2.3.2 Performance

Table 2 shows each group performance in the class and on the concept inventories. Significant differences were noted in six of the eleven categories. The three groups had similar incoming GPA's (semester GPR from previous semester) and SCI pre-scores. The Minimalists had the highest DCI pre-score, followed by the Help Seekers. The SI Dependent group scored the lowest on the DCI pre-test.

Table 2: Average performance by cluster (followed by standard deviation).

Cluster	Incoming GPR (4 point scale)	Course Grade (4 point scale)	Grade Differential**	SCI Pre-Score (out of 27)	SCI Post-Score** (out of 27)	SCI Gain*	SCI Normalized Gain**	DCI Pre-Score** (out of 29)	DCI Post-Score** (out of 29)	DCI Gain	DCI Normalized Gain
1.Minimalist	3.06 (0.86)	2.23 (1.37)	-0.78 ^a (1.15)	7.58 (3.61)	13.68 ^a (4.46)	6.55 (4.76)	32% ^{ab} (24%)	10.39 ^a (3.19)	13.52 ^a (4.35)	3.16 (3.59)	17% (20%)
2. Help Seekers	2.95 (0.86)	2.88 (1.17)	0.05 ^b (0.91)	6.50 (2.07)	13.40 ^{ab} (6.14)	7.80 (6.63)	38% ^a (33%)	9.56 ^{ab} (2.68)	12.73 ^{ab} (4.93)	3.20 (3.82)	17% (21%)
3. SI Dependent	3.01 (0.75)	2.28 (1.01)	-0.76 ^a (0.92)	6.43 (3.40)	11.36 ^b (4.06)	4.85 (4.56)	22% ^b (22%)	8.63 ^b (2.93)	11.47 ^b (3.65)	2.83 (3.48)	13% (19%)

** At least one group is significantly different based on ANOVA (alpha=0.05)

* At least one group is significantly different based on ANOVA (alpha=0.10)

Grades - An analysis of variance did not reveal significant differences between groups in average grade in the class. However, the difference in grade differential was very significant (even at alpha=0.01). The grade differential was calculated for each student by subtracting their previous semester GPR from their final grade in the class. For example, the Help Seekers had an average grade differential of 0.05. This positive value indicates that they performed just slightly better in Integrated Statics and Dynamics than they did in their previous classes. The other groups had differentials of -0.78 and -0.76, indicating that they performed $\frac{3}{4}$ of a grade point below their own average. Negative values are not out of the ordinary since Statics and Dynamics is generally considered one of the most difficult courses in the Mechanical Engineering curriculum.

Concept Inventories - The SI Dependent group had significantly lower raw and normalized gains on the SCI and lower post-scores on both inventories. Although the

Minimalists had slightly (but not significantly) higher SCI pre-scores, the Help Seekers caught up with them on the SCI post-test while the SI Dependent group lagged behind. The minimalists started and ended highest on the DCI, followed by the Help Seekers. There were no significant differences between groups on DCI raw or normalized gains.

2.4 Discussion and Implications

The three groups identified in the present study appear to parallel the behavior and performance of the groups identified in more controlled study of example elaboration by Stark, et al⁸. The authors gave students worked examples to study and counted the types of elaborations they made. The students were then tested for near and far transfer, and were clustered based on the frequency of each type of elaboration. The three profiles in that study were:

Passive-superficial elaboration: These learners showed low overall elaboration activity. They showed the weakest performance on the transfer tasks.

Deep cognitive elaboration: This group showed above average cognitive elaboration, such as considering principles and concepts, explaining goals and operators, and noticing coherence between examples. They were significantly more successful on far transfer tasks than the passive-superficial group, but not significantly so on near transfer tasks.

Active-meta-cognitive elaboration: The key feature of this group is their distinctly above average use of both positive and negative self-monitoring elaboration. These included any statement of understanding or lack of understanding. The group also

demonstrated a lot of cognitive and superficial elaboration as well. This group outperformed the passive superficial group on both near ($p=0.1$) and far transfer ($p=0.05$).

In our study, homework problems are similar to worked examples. The exams, which make up 80% of the final grade, tend to look like homework problems; therefore final grades may be used as a rough indicator of near transfer. The concept inventories represent far transfer tests since they require a more conceptual understanding.

The Help Seekers reflect the active meta-cognitive group. They are aware of their misunderstandings and seek to resolve them. Mastery appears to be their goal.

The SI Dependent group is much like the passive superficial group. They are going through the motions. They come to class, they turn in the homework, and they go to SI sessions. The SI program can have a very positive influence on students who want to learn the material, but it seems that in this instance many students were attending SI sessions with the goal of getting the right answers. This group very rarely worked by themselves, so they probably were not even aware that they could not do the work on their own. They have seen enough problems worked to develop a formulaic knowledge, but they lack conceptual understanding.

The Minimalists represent the deep cognitive elaboration group. They are not as self-aware as the active-meta-cognitive group, but they are using more effective methods than the passive-superficial group. Since they work alone they are forced to consider questions like “What is the next step?” and “What equations or principles apply here?” because no one is there to show them. It is not clear whether these students work alone because they choose to or because they are shy. When they did seek help, it was mostly

from students who sit at their table, which might indicate that they just did not know many other people in their class.

In terms of how these students worked through problems, there are distinct differences between these three groups. All three groups are working through the same examples, but the SI Dependent group might think that writing it down is the same as learning it. They are able to perform as well as the Minimalists on the tests because they have developed formulaic knowledge, but the concept inventory shows that they do not really understand the principles. The Minimalist group, on the other hand, is forced to think about the problems more because they are working alone. There is no one to just tell them the next step; they must seek answers in the course materials. They spent less time out of class than the SI Dependent group, but had higher gains on the SCI.

Another interesting note is that although it did not appear to have an effect in the active meta-cognitive learners, Stark et al. found that elaboration training was useful in bringing learners up to the deep cognitive elaboration level from the passive-superficial. This may support adopting a cognitive apprenticeship approach to help these students master the material, where steps in problem-solving are illustrated, and students are encouraged to understand not only what steps to take, but why. Thinking Aloud Pair Problem Solving (TAPPS)⁹ may also be an effective approach for teaching students how to elaborate effectively.

Clearly we must find ways to emphasize to students the importance of really working through a problem and checking their understanding of each step and of the big picture. One way to do this is through decreasing the percentage of grade points allotted

to homework. In the classes surveyed, the homework was worth 6-8%, an amount intended to be large enough that students would take it seriously, but small enough that they would not be severely penalized for “learning experiences.” However, many of them still seem to be obsessed with getting the right answer and uninterested in learning from it.

Another option is to limit which problems are discussed at SI sessions. Many of the students will probably continue to work in groups, but maybe there will be more discussion and a less formulaic approach, since no one will spell out the solution for them.

One limitation of this study is that study habit profiles only describe behaviors and not the motivation behind the behaviors. There is likely to be more than one motivation that leads to the same behaviors. For example, the study habits exhibited by the Minimalist group might describe two types of students. One would be those who work alone because they want to avoid appearing to their peers like they are not succeeding or even perhaps because they think they are above their peers in their thinking. The other would be those who are so unaware and unmotivated that they do not do real work of any kind except come to class and take the tests and hope for the best. Their outcomes will be quite different, and this is reflected by the high standard deviations within the dependent variables for this group. Future studies will include a motivational component to examine the relationship between motivation and behavior.

2.5 Conclusions and Future Work

Study habits of students in an integrated Statics and Dynamics course were assessed through a voluntary survey in order to determine which practices are the most helpful to the students. These data indicated that there are three distinct behavior patterns for these students, which lead to different levels of conceptual understanding of the material. The largest group has the most troubling study habits and the worst conceptual outcomes. These students reported doing the homework very regularly and attending Supplemental Instruction sessions almost religiously, but seem to get little out of it. Less than half reported doing the homework on their own. The smallest group took advantage of every resource available to them, including the instructor. On average, this group was able to maintain their GPR. The third group scored an average of $\frac{3}{4}$ of a letter grade worse than their incoming GPR, but did quite well on the concept inventories. More information is needed to really understand the decisions of this group. It could be that they do not need to spend a lot of time outside of class to grasp the material, or it could be they just choose not to and are unaware of or unconcerned about their progress in the course. Because both these types of students would exhibit similar behaviors, this analysis is not sufficient to separate them. Future studies will be expanded to discern students' motivations behind these study habits.

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Appendix: Study Habits Survey

This survey is completely voluntary. The information you provide will be used to identify factors that contribute to success in this course. Your instructor will not see the results of this survey until after final grades have been submitted.

1) I did the homework for this class (circle all that apply)

- a) by myself (0/1)
 - b) with help from my team or table (0/1)
 - c) with help from classmates not at my table (0/1)
 - d) at SI (0/1)
 - e) with help from the instructor (0/1)
 - f) during class (0/1)
 - g) other:
-

2) I did the homework

- a) always or almost always (4)
 - b) usually (3)
 - c) occasionally (2)
 - d) never or almost never (1)
 - e) other:
-

3) I did the reading for this class

- a) always or almost always (5)
 - b) usually (4)
 - c) occasionally (3)
 - d) only when I thought there might be a quiz (2)
 - e) never or almost never (1)
 - f) other:
-

4) I typically read

- a) critically, making sure I understood each section (5)
 - b) carefully, but didn't stop to think about what I was reading (4)
 - c) quickly, skimming for important terms/equations (3)
 - d) during class (2)
 - e) not at all (1)
 - f) other:
-

- 5) I did the journal questions (not used for cluster analysis)
- a) the night before they were due (2)
 - b) as I read the chapter (6)
 - c) after I read the chapter (5)
 - d) after class (4)
 - e) during class (3)
 - f) I didn't read the chapter, I just guessed at the journal questions (1)
 - g) Never or almost never (0)
 - h) other:
-

- 6) I attended SI
- a) as often as possible (_____ times a week) (5)
 - b) when there was homework due (4)
 - c) when I needed help on the homework (3)
 - d) right before the test (2)
 - e) never (1)
 - f) other:
-

- 7) I typically spent _____ hours a week on this class (not including class time)
- a) 0-2 (1)
 - b) 2-4 (2)
 - c) 4-6 (3)
 - d) 6-8 (4)
 - e) 8-10 (5)
 - f) 10-12 (6)
 - g) more than 12 (7)

- 8) I paid attention in class
- a) always or almost always (4)
 - b) usually (3)
 - c) occasionally (2)
 - d) never or almost never (1)
 - e) other:
-

Thank you for your participation.

3. STUDENT-CENTERED ACTIVE, COOPERATIVE LEARNING IN ENGINEERING

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Abstract

The Student-Centered Active Learning in 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 multivariable 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. Survey data indicate positive effects on students’ use of learning resources, and 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.

3.1 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 Active Learning Environments for 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.

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.

3.2 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 3.1.

Table 3.1 Details on SCALE-UP courses included in this study, and comparable courses taught in traditional lecture format.

Course/ Semester		Number of Students Per Section		Student Majors	SCALE-UP Environmen t	Class Schedule
		Traditiona l	SCALE- UP			
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			

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.

3.2.1 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 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.

3.2.2 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 gauge effectiveness of a lecture or in-class activity and better ascertain what concepts were difficult for students [3].

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.

3.3 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 3.2.

Table 3.2 Summary of data gathered for each of the courses involved in this study.

Course/ Semester	Student Performance	Concept Inventories	Course Evaluations	Follow-On Course Grades
Multivariate Calculus (for engineering majors)	Traditional vs. SCALE-UP: <ul style="list-style-type: none"> • Course grades • Adjusted mean grades • DFW rates 			
Statics (for non-ME majors)	Traditional vs. SCALE-UP: <ul style="list-style-type: none"> • Course grades • Adjusted mean grades • DFW rates 	Traditional vs. SCALE- UP: Statics Concept Inventory (pre-post)	Traditional vs. SCALE-UP	Strength of Materials; Dynamics: <ul style="list-style-type: none"> • Adjusted mean grades (non-ME majors)
Integrated Statics and Dynamics (for ME Majors)	SCALE-UP integrated Statics/ Dynamics: <ul style="list-style-type: none"> • Course grades • DFW rates • Time to completion Traditional sequential Statics and Dynamics: <ul style="list-style-type: none"> • Concatenated DFW rates • Time to completion 	Statics Concept Inventory Dynamics Concept Inventory (pre-post)		Strength of Materials: <ul style="list-style-type: none"> • Adjusted mean grades (ME majors)

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 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

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

and the average normalized gain:

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

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.

3.4 Results

3.4.1 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.

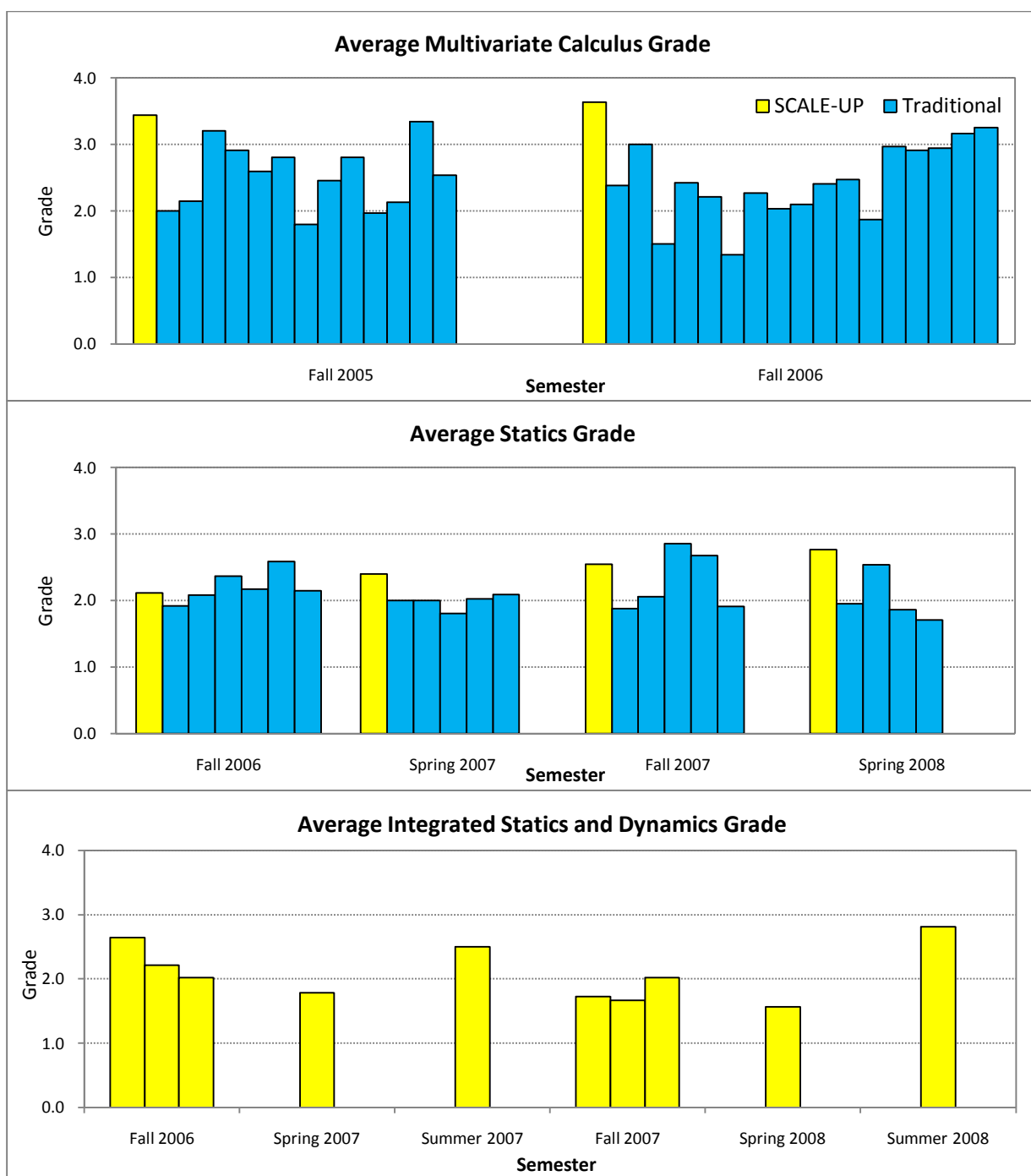


Figure 3.1 Course grades for courses taught in SCALE-UP and traditional formats in multivariate calculus, statics for non-ME majors, and integrated statics and dynamics for ME majors (offered in SCALE-UP only). Course grades are reported on a 4.0 scale (A = 4, B = 3, etc.). The sections are ordered from smallest to largest enrollment.

As shown in Table 3.3, 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%.

Table 3.3 Adjusted mean course grades after controlling for incoming GPA in Multivariate Calculus and Statics and standard errors. 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

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 (Figure 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.

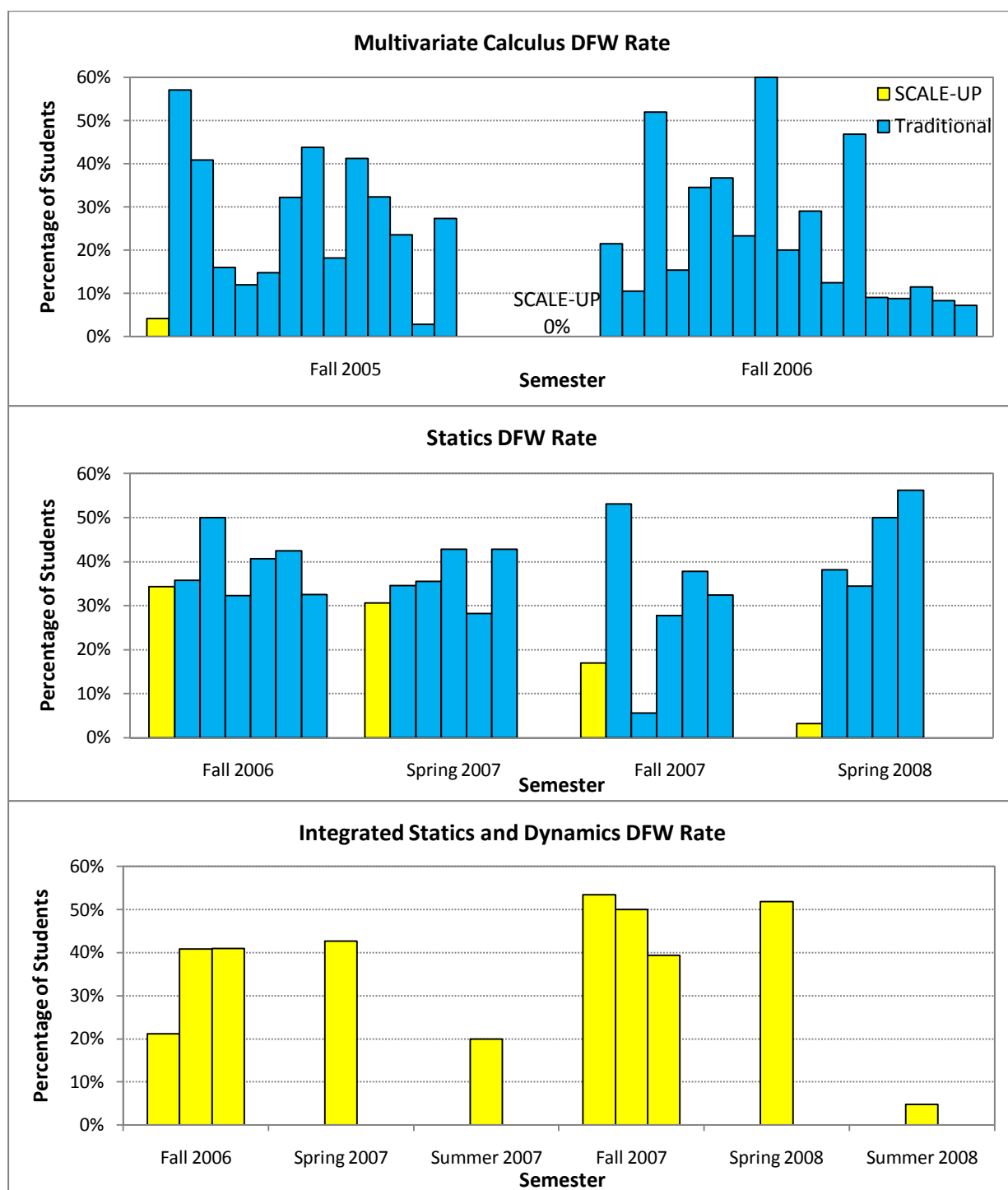


Figure 3.2 Student attrition, reported as a percentage of students earning a D or F, or withdrawing from SCALE-UP statics (DFW rate) over four semesters. Where there are multiple sections of the same course, the sections are ordered from smallest to largest enrollment.

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.

3.4.2 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].

Table 3.4 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%

3.4.3 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 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 3.5.

Table 3.5 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

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 3.6). 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.

Table 3.6 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

3.4.4 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 Figure 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:

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.”
- 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.”

- 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.”

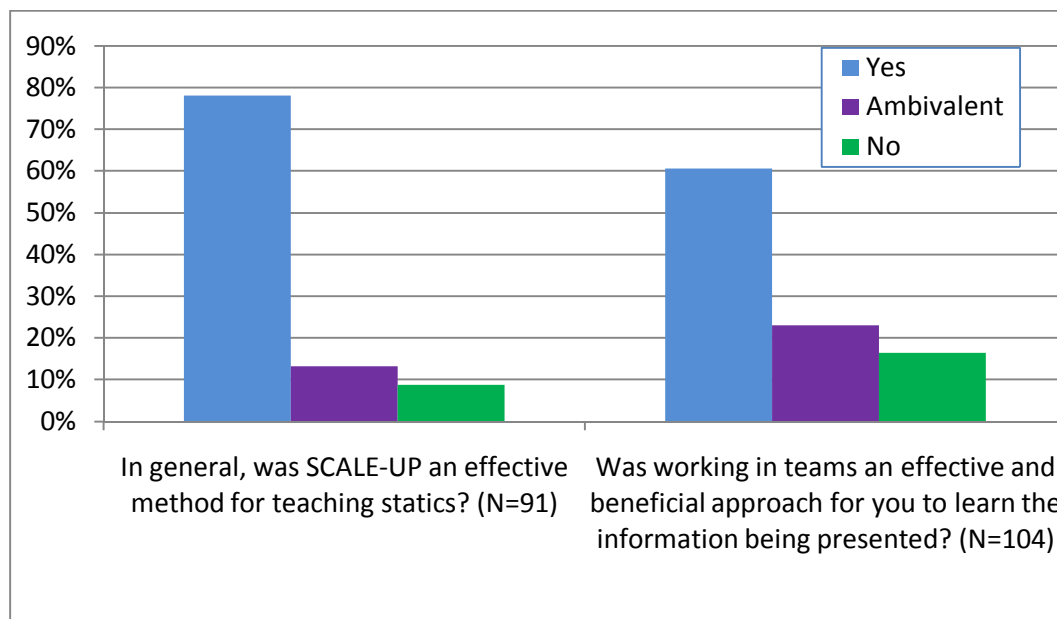


Figure 3.3 Responses to open-ended questions on course evaluations for SCALE-UP statics courses from Fall 2006 – Spring 2008 (n=154 evaluations; not all students responded to all questions), reported as percentages of responses that were coded as “Yes,” “Ambivalent,” and “No.”

Results of comparisons of responses to close-ended questions on course evaluations in statics are summarized in Table 3.7, 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).

Table 3.7 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	.061	0.02
	no	158	4.03	.058	(0.26)
The instructor made the relevance of the course material clear.	yes	154	4.19	.061	0.20
	no	157	4.06	.063	(0.15)
The course was well organized.	yes	155	4.40	.064	0.33
	no	158	4.26	.062	(0.11)
There was a positive interaction between the class and instructor.	yes	155	3.91	.075	0.30
	no	158	3.75	.078	(0.12)
The instructor's teaching methods helped me understand the course material.	yes	154	3.90	.083	<0.01
	no	158	3.55	.076	(0.33)
The instructor's verbal communication skills helped me to understand the course material.	yes	155	3.97	.075	<0.01
	no	157	3.66	.073	(0.34)
The instructor clearly explained what was expected in assignments and tests.	yes	155	4.12	.068	<0.01
	no	157	3.80	.069	(0.38)
The instructor kept me informed about my progress in the course.	yes	152	4.15	.074	<0.01
	no	158	4.44	.060	(-0.36)
The feedback I received on assignments and tests gave me the opportunity to improve my performance.	yes	155	3.94	.079	<0.01
	no	156	3.62	.069	(0.35)
Overall, the instructor is an effective teacher.	yes	155	4.21	.069	0.07
	no	157	4.00	.066	(0.21)
The instructor's grading procedures gave a fair evaluation of my understanding of the material.	yes	153	4.05	.076	0.63
	no	158	4.01	.065	(0.06)
How much work did you put into this course relative to your other courses?	yes	153	4.62	.050	<0.01
	no	158	4.33	.061	(0.41)
How difficult was this course for you relative to you other courses?	yes	155	4.34	.061	0.19
	no	158	4.22	.063	(0.15)

3.4.5 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.

Table 3.8 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		M E
	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

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.

3.5 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.

3.6 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.

3.7 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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4. THE EFFECT OF AN INTEGRATED DYNAMICS AND STATICS COURSE ON THE PROGRESS AND PATHWAYS OF MECHANICAL ENGINEERING STUDENTS

M. K. Orr, L. C. Benson, and S. B. Biggers, “The Effect of an Integrated Dynamics and Statics Course on the Progress and Pathways of Mechanical Engineering Students,” *Proceedings of the American Society for Engineering Education Annual Conference and Exposition (2010)*.

Abstract

At Clemson University, the three-credit statics and dynamics courses required for mechanical engineers have been combined into one integrated, five-credit active-learning course where statics is taught as a special case of dynamics. Beichner’s SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) instructional format has been adapted to help make optimal use of limited calendar time and promote conceptual understanding. The goal of these changes was to provide more effective instruction, to improve passing rates, and to provide better and more timely preparation for subsequent courses in the mechanical systems stem of the program. Prior studies have shown that the course has resulted in increased average normalized gains on Statics and Dynamics Concept Inventories. For this study, we turn our attention to the curricular effects of the new course, including enrollment, retention, progression, and completion rates of the statics and dynamics course sequence.

Students in both the old and new curricula ($n=316$ and 366 , respectively) were tracked to glean information about the paths students take as they progress through their

degree program and the effects that the new integrated course has had on these paths. For each student, the number of attempts and grades for the courses of interest were recorded.

Results indicate that the same proportion of students pass the integrated dynamics and statics course on their first attempt as pass both the separate courses on their first attempt at Clemson University ($p < 0.05$). Students in the new curriculum are also less likely to quit before completing the course sequence ($p < 0.05$). As expected, it takes students fewer attempts to pass the new course than to pass both the old courses. Combining this with our previous findings that students in the new integrated curriculum show improved conceptual gains and earn better grades in a follow-on course (even when controlling for incoming grade point ratios) indicates that this curricular change has made a positive impact on student success.

4.1 Introduction

In 2006, a new curriculum was implemented for students enrolling in mechanical engineering (ME) at Clemson University. The most significant change was the integration of statics and dynamics into one five-credit active-learning course where statics is taught as a special case of dynamics. The primary goal of the integration was to improve conceptual understanding of mechanics principles by placing statics in the context of dynamics. Students must first determine whether a problem is static or dynamic, a skill that is often overlooked in separate courses. An additional benefit is that teaching dynamics concepts in the first semester of the sophomore year allows the second semester courses to put these concepts into practice.

Previous work¹⁻⁴ has shown that students in the integrated class performed as well as students in a statics class on the Statics Concept Inventory⁵ and as well as students in a dynamics class on the Dynamics Concept Inventory⁶. Still, such a challenging course has a large percentage of students earning a D, F, or W (withdrawal from the course). The purpose of this study is to examine the effects of the curriculum change on progress and retention of mechanical engineering students to ensure that the new course is not having a negative effect on enrollment or student success.

4.2 Engineering at Clemson

Our institution has a common first year “general engineering” program in which all engineering students fulfill general education requirements, learn basic engineering principles, and are introduced to various engineering disciplines. Near the end of their first year, students who have completed all the general engineering requirements declare their major discipline. Discipline-specific courses begin in the Fall of the sophomore year.

4.2.1 Statics as a Pre-requisite to Dynamics

Under the old curriculum, students were expected to take Statics in their first semester as a mechanical engineering student, and then proceed to Dynamics in their second semester, as shown in the Figure 4.1. The curricular content in the first and second semesters was therefore quite limited because students would not yet have mastered the fundamentals of engineering mechanics. Students were not fully immersed in mechanical engineering content until their junior year. Foundations of Mechanical

Systems was taught co-requisite with Statics, therefore instructors had their hands tied, and were forced to limit the content to rules of thumb and formulaic approaches for analyzing motion because students had not been formally introduced to the dynamics of rigid bodies.

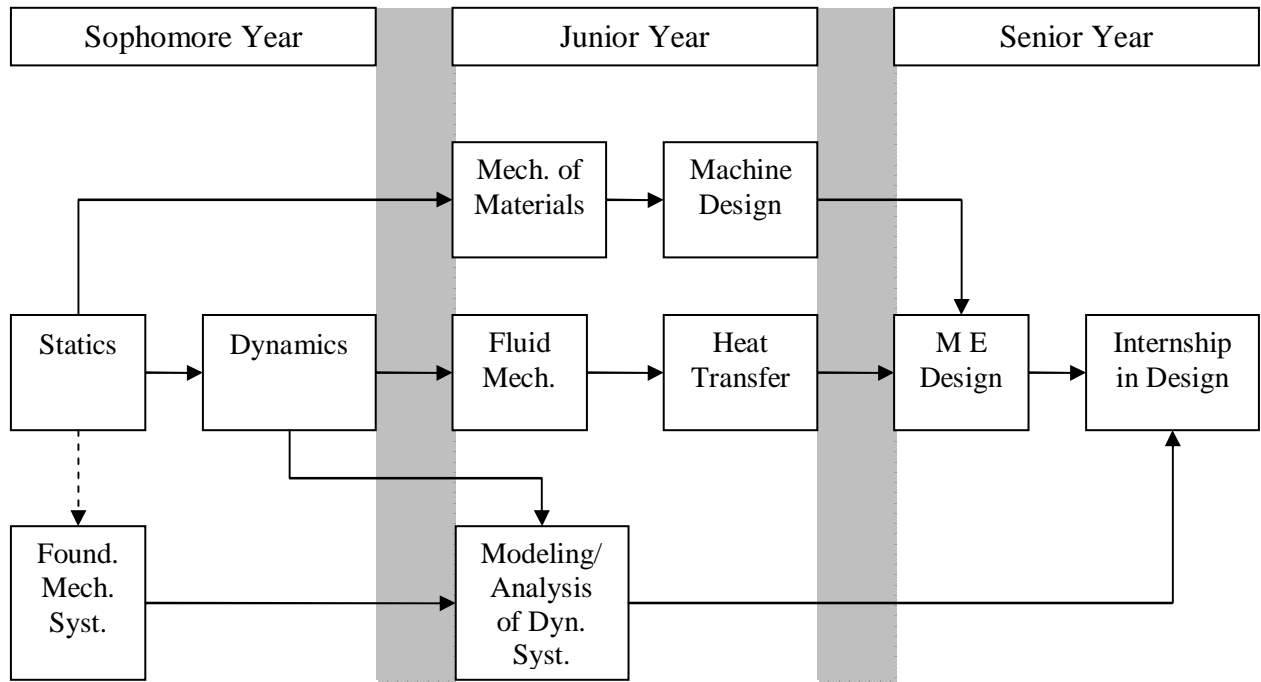


Figure 4.1 Flow chart of key courses in the old curriculum. Solid arrows indicate pre-requisites; dashed arrows indicate co-requisites.

4.2.2 Integrated Statics and Dynamics

Several years ago, a university-wide curriculum reform took place and programs were encouraged to reduce the required number of credit hours. One of the authors saw this as an opportunity for innovation and introduced a new, fully integrated statics and dynamics course. In his 29 years experience teaching statics and dynamics, he had found that students had trouble relating the two subjects and often struggled in dynamics

courses to let go of techniques that are suitable only for statics problems and the intuition they developed in statics. He hypothesized that teaching statics as a special case of dynamics would result in a stronger understanding and enhanced problem solving abilities in both subjects. Implementation of the course raised many challenges, which are discussed in detail in a companion paper by Biggers and Orr⁷. A large amount of content to cover in a single course required many contact hours each week, which made active participation essential to maintaining students' attention. The instructional format is loosely based on Beichner's Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP)⁸⁻¹⁰. Details of this adaption are also addressed by Biggers and Orr⁷. The key elements are that statics is taught as a special case of dynamics and students must be actively engaged in their learning. SCALE-UP facilitates active learning, even in large sections.

Introducing dynamics at an earlier stage also enables follow-on courses to be modified to improve technical content. Foundations of Mechanical Systems is now taught with Integrated Statics and Dynamics as a pre-requisite (see Figure 4.2), allowing instructors freedom to account for students' knowledge of kinematics, kinetics, and statics in the analysis and design of mechanical systems whereas previously students had neither completed statics nor started dynamics.

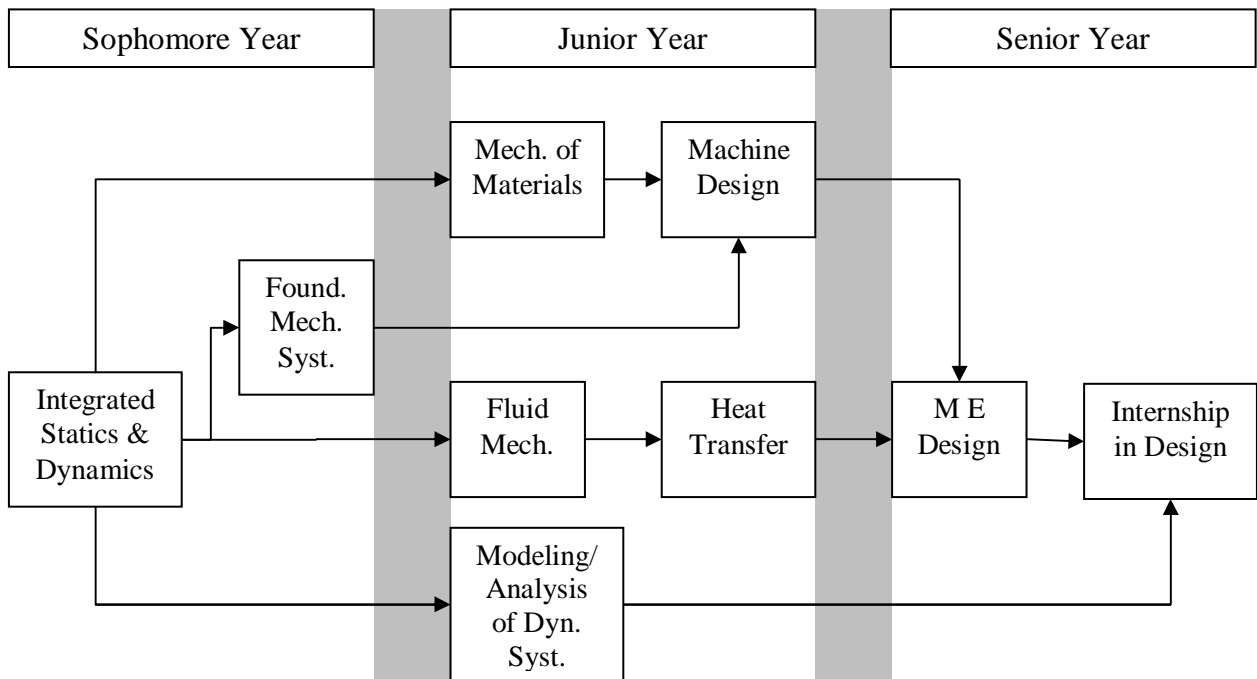


Figure 4.2 Flow chart of key courses in the new curriculum. Solid arrows indicate pre-requisites; dashed arrows indicate co-requisites.

Course assessment was only slightly modified. In both the old and new courses, three to four traditional exams and a final exam typically make up about 85% of the course grade. Quizzes, homework, and participation make up the remaining 15%.

Previous work has shown that this new approach is pedagogically effective based on concept inventory scores and performance in follow-on courses¹⁻⁴; however, practical concerns still remained about the effect of the new course sequence on students' progress towards their degree. Anecdotal evidence tells us that many students believe that Statics and Dynamics are two very difficult courses and therefore their combination would be even more difficult. The research team was concerned that some students might shy away from mechanical engineering due to this fear factor, which could change the

population being studied. The goal of this study is to examine the impact of the curricular change on the enrollment, timely progress, course completion, and retention of mechanical engineering students.

4.3 Data Collection

As is the case in most education research, an experimental set-up to test each component independently was not feasible, so the data was collected to compare the old curriculum as a whole to the new one. While exact comparisons between cohorts are not possible because of multiple factors changing, the data has been selected to compare metrics which are as equivalent as possible.

The data collected represent six cohorts of students, three that matriculated into the old curriculum (2003, 2004, 2005) and three that matriculated into the new curriculum (2006, 2007, 2008). Each cohort contains only the students who began their ME curriculum in the Fall semester of their cohort year and had declared mechanical engineering as their major by the end of that semester; students entering in off-peak semesters are not included in this study. The totals presented are a summation of the Fall cohorts. Withdrawal from the course is considered a failed attempt.

4.4 Results and Discussion

4.4.1 Enrollment

From Table 4.1, we see that both the number and proportion of freshman engineering students who select ME as their major and enroll in the integrated course (new curriculum) are not significantly different ($p < 0.05$) than the number and proportion

of students selecting ME and enrolling in Statics (old curriculum). This indicates that students are not changing majors to dodge a potentially difficult course. If the proportion of students selecting ME had dropped significantly, there would be a concern that the populations being compared might be different. The test statistic used for this measure is the difference between the proportions divided by the standard error of the difference between independent proportions¹¹. To further confirm that the incoming population was not changed, a t-test was performed on the GPR of the students at the end of the freshman year, right before they begin their ME coursework. The average GPR of the groups was not significantly different ($p>0.05$).

Table 4.1 Proportion of freshman engineering students enrolling in ME and their incoming GPR

Old Curriculum Statics as a pre-requisite to Dynamics					New Curriculum Integrated Statics and Dynamics					Sig. p=
Cohort:	Fall 2003	Fall 2004	Fall 2005	TOTAL	Cohort:	Fall 2006	Fall 2007	Fall 2008	TOTAL	
New Freshmen in General Engineering in the previous Fall	662	700	736	2098	New Freshmen in General Engineering in the previous Fall	762	714	722	2198	
Number of ME students enrolled in Statics	104	112	100	316	Number of ME students enrolled in Integrated Statics and Dynamics	125	138	103	366	
% of General Engineering students	16%	16%	14%	15%	% of General Engineering students	16%	19%	14%	17%	0.08
Avg. incoming GPR	3.15	3.16	3.01	3.11	Avg. incoming GPR	3.00	3.16	3.09	3.09	0.56

4.4.2 Student Progress

The proportion of students passing (earning an A,B, or C) in the integrated course on schedule is right in line with the proportion of students passing both statics and dynamics on schedule (Table 4.2). “On schedule” implies that the student passed the course or pair of courses with a grade of A, B, or C on their first attempt. This implies that students who would pass Statics and Dynamics on their first attempt are equally likely to pass the integrated course on their first attempt. Also, the proportion of students who are “off-schedule” due to retaking a course has not changed with the implementation of the new curriculum.

Table 4.2 Number and percentage of students passing (earning an A, B, or C) on schedule.

Old Curriculum Statics as a pre-requisite to Dynamics					New Curriculum Integrated Statics and Dynamics					Sig. p=
cohort:	Fall 2003	Fall 2004	Fall 2005	TOTAL	cohort:	Fall 2006	Fall 2007	Fall 2008	TOTAL	
ME Students enrolled in Statics	104	112	100	316	ME Students enrolled in Integrated Statics and Dynamics	125	138	103	366	
Students passing Statics on first attempt and passing Dynamics on first attempt	62	79	64	205	Students passing Integrated Statics and Dynamics on first attempt	85	82	67	234	
% of Initial Enrollment	60%	71%	64%	65%	% of Initial Enrollment	68%	59%	65%	64%	0.40

4.4.3 Course Completion

Of course, not all students are successful on their first attempt. The students in the old curriculum sample took up to 5 attempts to pass Statics and up to 3 attempts to

pass dynamics. In the new curriculum, one student took 5 attempts to complete the integrated course. This data is summarized in Table 4.3.

Table 4.3. Summary of Attempts. “Percent passing” indicates the percentage of students that pass the course on the stated attempt, i.e., 70% of the 27 students from the 2003 cohort who enrolled in Statics a second time successfully completed it with an A, B, or C.

Old Curriculum Statics as a Pre-requisite to Dynamics					New Curriculum Integrated Statics and Dynamics				
Cohort:	Fall 2003	Fall 2004	Fall 2005	TOTAL	Cohort:	Fall 2006	Fall 2007	Fall 2008	TOTAL
Students enrolled in Statics for the 1st time	104	112	100	316	Students enrolled in Integrated Statics and Dynamics for the 1st time	125	138	103	366
Percent passing	70%	85%	76%	77%	Percent passing	68%	59%	65%	64%
Enrolled in Statics a 2nd time	27	16	22	65	Enrolled in Integrated Statics and Dynamics a 2nd time	31	49	35	115
Percent passing	70%	81%	55%	68%	Percent passing	65%	73%	77%	72%
Enrolled in Statics a 3rd time	5	2	9	16	Students enrolled in Integrated Statics and Dynamics a 3rd time	8	10	4	22
Percent passing	40%	100%	67%	63%	Percent passing	63%	80%	100%	77%
Enrolled in Statics a 4th time	3		1	4	Students enrolled in Integrated Statics and Dynamics a 4th time	2	1		3
Percent passing	67%			75%	Percent passing	50%	0%		33%
Enrolled in Statics a 5th time	1			1	Students enrolled in Integrated Statics and Dynamics a 5th time	1			1
Percent passing	100%			100%	Percent passing	100%			100%
Students enrolled in Dynamics	91	105	91	287					
Percent passing	76%	83%	85%	81%					
Enrolled in Dynamics a 2nd time	20	16	12	48					
Percent passing	70%	100%	100%	88%					
Enrolled in Dynamics a 3rd time	4			4					
Percent passing	75%			75%					

Figure 4.3 shows the cumulative percentage of students who have completed the statics and dynamics requirements as a function of the number of semesters in the program. Clearly it is not possible to complete the sequence in one semester under the old curriculum. At the end of the second semester, 87% of students on the new curriculum have completed Integrated Statics and Dynamics while only 65% of the students on the old curriculum have done so. This provides evidence that despite the perceived difficulty of the course, more students progress faster than in the old two-course sequence. Three semesters into the program, 91% of new curriculum students are prepared for the subsequent M E courses, compared to 81% of the old curriculum students. Differences are significant at every semester ($p < 0.05$). Also note that more students in the new curriculum are prepared to move on by the end of the second semester than old curriculum students at the end of the third semester. A slight, but statistically significant ($p < 0.05$), improvement (88% to 92%) is noted in the proportion of students who eventually complete the course sequence.

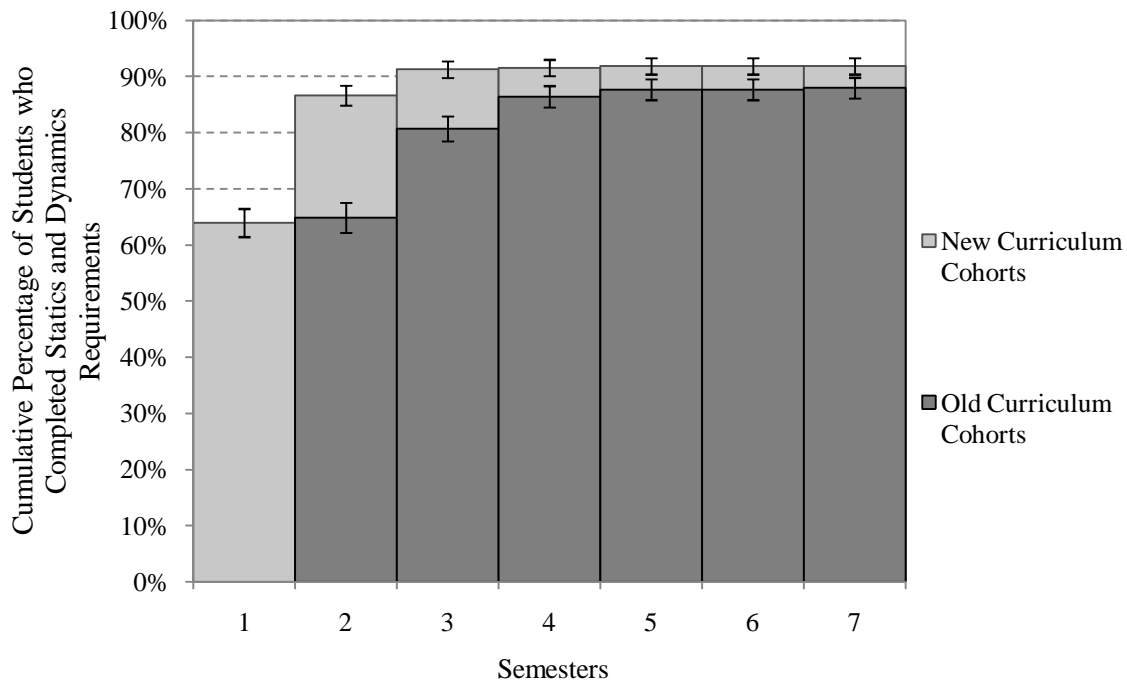


Figure 4.3 Cumulative percentage (and standard error of the proportion) of students completing statics and dynamics requirements as a function of semesters in the Mechanical Engineering program

4.4.4 Retention

Nearly all the students who complete the integrated course are retained in mechanical engineering as of the following Fall semester. The one-year retention in mechanical engineering is virtually unchanged by the new curriculum, as shown in .

Ideally, the number of students completing the course sequence would be the same as the number of students retained. A greater number of students retained could indicate students who are “stuck” in mechanical engineering. They have not been able to complete statics and/or dynamics successfully, but their GPR may have dropped too low to be admitted to another major. This scenario occurred in 2003, 2004, 2005, and 2008. A greater number of students passing than being retained (as in 2006 and 2007) indicates that some students had successfully completed the course but decided that mechanical

engineering was not for them. In this case, at least they could leave with an understanding of the fundamental principles of mechanics and could potentially use that knowledge (and the course credit) in the discipline of their choice. A student completing the course and then leaving the major could cancel out a student who is stuck, however, so these net values are only rough indicators of the trends.

Table 4.4 Number and percentage of students who eventually passed the one or two course sequence, one year retention rate, and two year retention rate. One year retention in ME is based on the student's declared major one year after their enrollment in the program. Two year retention in ME is based on the declared major two years after their enrollment.

Old Curriculum Statics as a Pre-requisite to Dynamics					New Curriculum Integrated Statics and Dynamics					Sig. p=
Cohort:	Fall 2003	Fall 2004	Fall 2005	TOTAL	Cohort:	Fall 2006	Fall 2007	Fall 2008	TOTAL	
Students enrolled in Statics	104	112	100	316	Students enrolled in Integrated Statics and Dynamics	125	138	103	366	
Students who eventually passed Statics and Dynamics (separately)	86	103	89	278	Students who eventually passed Integrated Statics and Dynamics	112	126	98	336	
% of Initial Enrollment	83%	92%	89%	88%	% of Initial Enrollment	90%	91%	95%	92%	0.04
1 year retention in M E	91	104	93	288	1 year retention in M E	109	125	101	335	
% of Initial Enrollment	88%	93%	93%	91%	% of Initial Enrollment	87%	91%	98%	92%	0.32
2 year retention in M E	86	101	93	280	2 year retention in M E	108	121	-	229	
% of Initial Enrollment	83%	90%	93%	89%	% of Initial Enrollment	86%	88%	-	87%	0.27
Students who are potentially "stuck"	5	1	4	10	Students who are potentially "stuck"	0	0	3	3	
Completed and changed majors	0	0	0	0	Completed and changed majors	3	1	0	4	

4.5 Conclusions and Future Work

The curricular change described herein has been found to have neutral effects in student enrollment and retention, while boosting the timely progression and completion of the statics and dynamics course sequence. These results are quite satisfactory as the change has been shown to improve conceptual understanding and performance in follow-on courses in other reports. This also highlights the value of using a student-centered approach for course innovations and the integration of related but traditionally separate courses. Although the data presented is limited to one institution, it provides evidence that a carefully executed and monitored educational innovation has improved student conceptual understanding and future performance without sacrificing enrollment, retention, or timely completion of courses. This assessment suggests that using a student-centered approach to integrate statics and dynamics can be beneficial not only to students' learning, but to their degree progress as well. Future work includes dissemination of the materials required for such a change as well as recommendations for implementation.

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5. INTEGRATED DYNAMICS AND STATICS FOR FIRST SEMESTER SOPHOMORES IN MECHANICAL ENGINEERING

S. B. Biggers and M. K. Orr, "Integrated Dynamics and Statics for First Semester Sophomores in Mechanical Engineering," *Proceedings of the American Society for Engineering Education Annual Conference and Exposition* (2010).

Abstract

A modified SCALE-UP approach that emphasizes active learning, guided inquiry, and student responsibility has been described as applied to an innovative and challenging sophomore course that integrates Dynamics and Statics. Details regarding implementation of this course are the focus of this paper. Challenges to achieving success in this new course have been many and demanding. These include (1) development of a dedicated textbook, (2) development of learning exercises to foster student comprehension, (3) reorganization of topical content including topic deletion and added emphasis on certain topics, (4) preparing faculty for change, (5) accommodating limited student maturity, and (6) dealing with widespread misgivings about the project. Some previously presented data are shown to indicate that the new approach and new course have been effective in terms of improved student performance on a required follow-on course, reduced time to completion and increased rate of completion, and slight improvements in concept comprehension.

5.1 Introduction

During a total revision of the Mechanical Engineering curriculum at Clemson University five years ago, the need to bolster our students' abilities in dynamics and to do so at an earlier stage was recognized. This led us to consider integrating Dynamics and Statics into a single 5-credit course that would be offered in the first semester of the sophomore year, replacing the conventional Statics course taught then and the conventional Dynamics course taught the following semester. Despite widespread and vocal reservations, we are now in our fourth year of offering this integrated course and we are convinced that the decision to move in this direction was a good one. There are a few other universities that offer combined statics and dynamics courses, as 4-credit or 5-credit courses. However most of these teach the subject in a serial manner, starting with statics and progressing to dynamics. There are a few that, like ours, integrate statics into dynamics but cover only statics and particle dynamics. Some of these require a course in particle dynamics as a prerequisite and present the course over two semesters. We believe that our course is unique in its integrated nature and its focus on rigid body dynamics as a final objective.

Our previous publications¹⁻⁵ on the adaptation of SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs⁶⁻⁸) methods in engineering and math have presented data showing the integrated course has been effective in terms of improved preparation of students for follow-on courses, reduced time to completion of the material, and concept comprehension, all compared to the pair of courses previously taught in a serial manner. This paper focuses on the implementation of the integrated

course while summarizing some evidence of its effectiveness in terms of learning outcomes and placement in the curriculum. It details how major challenges to implementation were overcome. These challenges include:

- Finding or creating a **textbook** that treats the subjects as truly integrated as opposed to binding serially arranged statics and dynamics volumes in a single book.
- Promoting student **learning effectiveness** in longer classes three days a week, or normal class periods five days a week.
- Deciding what, if any, **topical material** could be eliminated or minimized and what should receive extra attention given the students' mechanical engineering major.
- **Preparing faculty** to deal with the new order of material and a different way of conducting each class period.
- Adapting to students having **limited maturity** in their approach to learning.
- **Overcoming misgivings** among students, faculty, and administration.

The paper is organized around the above challenges.

5.2 Textbook Development

Innovation in topical coverage in undergraduate courses is often limited, delayed, or abandoned because of the lack of appropriate textbooks. Instead, courses continue to fit the existing textbooks. New textbooks have to fit existing course demand to be successful for the publisher. Thus the status quo is perpetuated. This is particularly true in courses such as statics and dynamics that are foundational courses in nearly every engineering curriculum. New presentation methods, including online learning aids, are assisting in instructional effectiveness, and new textbooks are written in a fashion to

better fit current students' learning styles. But, with a very few exceptions, the traditional order of presentation of topics has not changed much over many decades. Because of our desire to integrate statics and dynamics into a single semester, to increase the emphasis on rigid body dynamics, and to do so at an earlier point in the curriculum, we realized that a new textbook would be a necessity. Custom publishing of a specialized text was the natural choice here due to the ability of the publisher to keep production costs to a minimum and allow low numbers of books to be acceptable to them.

5.2.1 General Presentation Approach

A custom textbook was created by the senior author to enable the new integrated course to be brought into the curriculum⁹. The book focuses on vector methods for rigid body mechanics. It addresses most topics found in traditional statics and dynamics courses in a reasonable but integrated order while maintaining depth and rigor appropriate for 3rd semester students. The number of words and pages is intentionally kept as low as possible to encourage critical reading by every student, as they are required to do prior to each class. Currently this text is packaged with access to portions of an online version of a traditional pair of Statics/Dynamics books, the latter providing most of the homework problems and offering some supplemental reading to students who need another source. It is printed in color and includes many photographs of structures and machines that students encounter on campus and around the local region. Real-world examples that students can relate to can strongly assist motivation. To encourage critical reading, rather than surface reading, questions are posed to the student throughout the

book that may require rereading or asking for clarification in class. The instructor can use these questions to initiate in-class discussion if students do not raise them.

The text attempts to present equations and methods in ways that students can relate to easily. It uses overbars and carets to symbolize vectors and unit vectors, respectively, and students are required to do likewise in all their work. Observations over many years indicate that using a bold font to symbolize a vector does not translate well into student thinking or into their work. Hand-drawn and hand-written work is often used in examples to show students what is expected in their work. A sample taken from an example in the book is shown here.



Scissors Lift

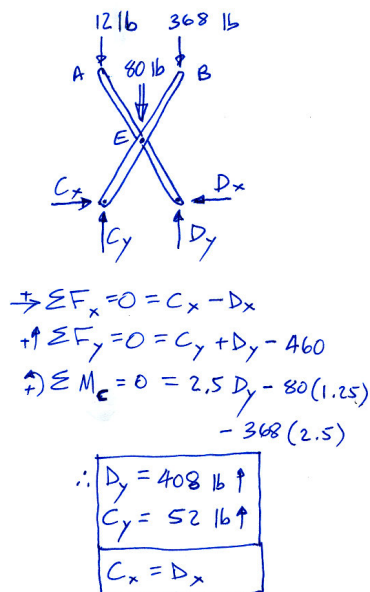


Figure 5.1 Example from textbook.

Lists of good practices and bad practices that the author has observed over many years are presented in the introduction and summary lists of important points at the end of each chapter. In all parts of the book, proper *model development* is given top priority. Beyond given facts, students are asked to differentiate between *assumptions* and

observations as they develop the model. *Evaluation* of the reasonableness of the results after doing the *mathematical solution* is also stressed. Students are encouraged to rely on proper modeling practices built on the fundamental principles and to avoid using intuition to simplify a model or to try to find a quick answer. Many studies have shown that, even at advanced learning levels, immature intuition can be a dangerous thing, especially in dynamics.

5.2.2 Topical Sequence

The course begins by drawing **free-body diagrams** of situations where the nature of supports and their reactions are obvious based on simple observations. Then we analyze **straight line translation** of a rigid body, first with concurrent forces where the problem is equivalent to particle dynamics, then with non-concurrent forces where lack of rotation must be enforced by the reaction forces. Therefore in the second week of classes students solve rigid body translation problems such as the one shown here that are dynamic with respect to forces and static with respect to moments. Letting the acceleration go to zero, the static condition is recovered as one special case of dynamics allowing students to quickly see how forces differ when they create acceleration, deceleration, constant speed, and zero motion.

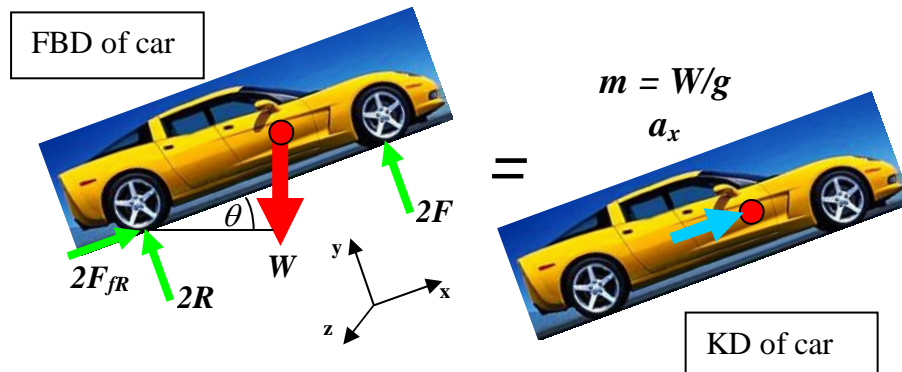


Figure 5.2 Rigid Body Translation

Friction is introduced as an enabler of motion or a resistance to motion depending on the nature of the motion or the lack of motion. Development of **kinematic relationships** between position, speed, acceleration and time naturally follows such examples. **Curvilinear translation** in terms of rectangular, polar, and normal-tangential coordinates is considered next and the kinematic and kinetic effects of change in direction are studied. The traditional topic of computation of **center of mass and moments of inertia** are incorporated. At this point the necessity for knowledge of the CG location is already evident from working the rigid body translation problems and the moment of inertia is computed in anticipation of consideration of rotation. Attention is then focused on static structural and mechanical systems such as **trusses, frames, and machines** including friction. Questions naturally arise as to what would happen if some supports or connections failed in some way. Thus here thinking starts with statics and progresses to dynamics. Statical determinacy, indeterminacy and instability become rather easy to understand as students see bodies as potentially static, quasi-static, or dynamic. **Kinematics of general 2-D motion** of rigid bodies comes next followed

quickly by **kinetics of general 2-D motion** by direct application of Newton's laws. Newton's Second Law is integrated over change in position to create **work-energy methods**, and finally over change in time to create **impulse-momentum methods**. We do not apply the latter two methods to pure translation as is common in texts that treat "particle" dynamics as an initial separate topic, but rather we delay these methods until students can deal with general rigid body motion. We cover **impact** of bodies through eccentric, imperfectly elastic collisions. **Kinematics of general 2-D motion with sliding supports and connections** is generally a confusing topic. We delay this until the end of the course when students have developed some maturity in their thinking and we find that they have surprisingly little difficulty. The course concludes with kinetics of assemblies that include sliding contacts. The table of contents is attached as Appendix A.

5.2.3 General Instructional Philosophy

A common instructional theme is what one could call "layering" of learning. Topics are introduced and reintroduced throughout the course whereas the complexity or generality of the situations increases each time. Some might call the approach just-in-time learning. Students may not become masters of a given topic until some point later in the semester. Mastery of such topics prior to proceeding is not expected or assessed in testing. An analogy might be to view learning as creating an oil painting where additions, corrections, and refinements are continually made all over the canvas rather than working from bottom to top, or rather than constructing a length of chain one link at a time. Some examples follow:

- As mentioned above, free body diagrams (FBD) and kinetic diagrams (KD) are drawn on the first day of class but are restricted to cases where the support forces (no support couples yet) should be obvious to most students based on their common sense. The objective is to break bad habits we continually observe that students bring with them and to immediately establish proper practices. The bad habits include not drawing the FBD, showing internal forces between bodies that are still connected, and not showing forces where they actually occur on a body. FBD/KD exercises are revisited as more complex support or connection conditions, including couple reactions and 3-D problems, are encountered and as internal forces and couples become the objective.
- Friction is addressed first as it accompanies translation, then as it occurs in static conditions. Again, bad habits such as automatically setting the static friction force equal to the static coefficient of friction times the normal reaction, or automatically assuming friction opposes the direction of motion, are dealt with early. Friction is reexamined in rigid body static and dynamic conditions, then again in rolling with and without slip, once more as it occurs in machines including belts and bearings, and finally as it is accounted for in energy and in momentum approaches.
- We avoid discussion of “particle” statics and dynamics, opting for more realistic rigid bodies that at first may be treated as one would treat a “particle” then quickly moving on to those where size and shape are important. Therefore, we focus on translation, then rotation, then general motion. Conditions required to cause the motion to be limited or eliminated to create static conditions are often examined as special cases.

The main objective is to keep the problems as realistic as possible using problems students can relate to so as to avoid students thinking the course is just a “theory” course.

- Another layering technique is to initially solve problems where simplifying assumptions must be made, to return to those same problems where the simplifications are removed, and then to compare the results. For example, wheeled vehicles are first simplified by neglecting rotational inertia of the wheels, then the same vehicles is reexamined without the simplification later in the course. The effects of simplifying assumptions are easily made clear with this approach.
- Equivalent force systems, then equivalent force-couple systems are treated as they naturally occur in various problems throughout the course, rather than attempting to master the rather abstract conceptual idea prior to applications. For example, without difficulty, students recognize that the distributed weight of a body can be replaced by the equivalent concentrated force at the CG of the body. They have been doing this in physics in high school and in the university. Our main objective here is to show that the sum of forces and the sum of moments appearing in Newton’s Second Law is in fact the simplest and most easily understood equivalent force-couple system. The idea of equivalency also naturally reappears when elements in assemblies are disassembled and their equivalent effects are transferred to the other elements. We spend very little time on equivalent force-couple systems as a separate topic.
- After kinematics of rigid bodies with points of interest attached to the body is understood, and kinetics of such cases have been addressed using all three major

formulation methods, we return to the more conceptually difficult case of kinematics of rigid bodies having points moving (sliding) along the same body. Local coordinate systems that rotate with a body are used for this purpose. We use a silly gimmick to emphasize the conceptual differences between the earlier approach and the new one. Students easily buy in to this approach and in fact they plead for a problem in this area on the final exam! The fact that these more complex kinematic equations can be viewed as containing the prior simpler ones as a special case is pointed out. We have observed that students understand the differences between the two approaches more easily if their study is separated in time.

5.3 Promoting Learning Effectiveness

5.3.1 Class Schedule:

Because our course is listed by the registrar as a 3-hr “lecture” plus 4-hr “lab” course, we have the equivalent of seven 50-minute periods available for instruction. As discussed below, the course is neither lecture nor lab in the traditional sense. However, students register expecting to spend about 350 minutes per week in class. Often faculty and students consider longer classes to be inferior to shorter classes given students’ short attention spans. In the first offering of this 5-credit course, we addressed this concern by having normal 50-minute classes three days a week and 100-minute classes two days a week. The argument was made that relatively short classes and having students address the subject every day of the week should offer advantages. Though the 5-day approach worked reasonably well, we decided to try back-to-back, classes held on Monday-

Wednesday-Friday for a total of 115 minutes each during the following semester. We have stayed with this schedule for several reasons, including student comments that they like having a day between classes. Having longer classes allows instructors the flexibility to expand on certain topics according to student interest as it develops. Classes are comprised of multiple short periods of instructor led discussions and student working on learning exercises. Several optional evening homework sessions are led by former students who also assist with learning exercises during classes. We have also taught this course in a standard summer session several times. Here students meet for 4 hours Monday through Thursday and 90 minutes on Friday. These even longer classes create an informal workshop atmosphere that the students report enjoying. Success rates tend to be higher in the summer than in the normal semesters, probably partially due to the extended classes and more focused attention on the subject. Therefore, using our combination of lecture and learning exercises, the preference shifts from shorter to longer classes.

5.3.2 Student Responsibility

On the first day, students are told their learning has four main components: **critical reading** from the textbook prior to class, **listening and asking questions** during and after class, working on the **learning exercises** in class including assisting others in their team, and doing **homework** which might involve asking questions out of class. Neglecting any part is almost certain to produce failure. Successful students accept the fact that the responsibility for learning is theirs and that the instructor is primarily a facilitator. For many of our students, this is the first truly rigorous course they have

taken. Some of them do not really know what it really means to accept the responsibility for learning in an active way, as opposed to continuing to act as an observer and as a storage place for facts collected from the instructor. These students largely comprise the unsuccessful group. End of semester course evaluations from this group inevitably include complaints such as “he doesn’t teach us anything, he just makes us learn everything by ourselves.” Comments from the successful group of students generally praise the progression of learning: starting at reading a straight-forward book, moving to in-class discussion and guided learning exercises, through solving more complex homework problems on their own or in groups.

5.3.3 Active Learning and Peer Instruction

Each class period is conducted using a modified SCALE-UP² approach. That is, classroom instruction is focused on in-class learning exercises supplemented by critical reading by each student prior to class, mini-lectures at one or more times during class, physical demonstrations, and short reading/attention quizzes using “i>clickers”¹⁰. With this approach, attention span become less problematic and students quickly learn that to perform in class, they must both be alert during class and prepare by reading the text before class. We are fortunate to have a classroom designed for 72 students sitting at eight large round tables. Dual computer projection screens and multiple white boards are available. The architecture enables and encourages peer instruction and collaboration. Students are assigned to certain tables and reassignments occur after each major test. We try to have more than one student within any social minority assigned to any given table. We make assignments so as to include a range of GPRs and class performance levels at

each table. We have at least one or two undergraduate learning assistants who move through the room along with the instructor providing assistance and guidance during the in-class learning activities. The room can become wonderfully noisy during their in-class work and it is infrequent that the noise is due to anything other than actual class work. Those few observed having social conversions sometimes have to be called out and reminded that they are here to work and learn. Despite this, we observe excellent social connections being developed in a great majority of students. Students always complain about table reassignments which occur once or twice during the semester, but quickly develop new connections. It is not uncommon to see students from different tables mingling as they teach and learn. Some instructor skill is required to bring an activity to a close and reestablish quiet in order to reenter the mini-lecture mode. However, one sign of a good class is one that is noisy but focused during in-class learning.

Over time, we have come to relax the original idea of using formal 3-member team groupings found in most SCALE-UP classes in favor of informal teams of the table size. This seems to promote much more interaction among students. Often instructors have to encourage a few shy students to become more interactive in their learning though some such students remain fairly solitary in their working. Rarely personality conflicts have to be dealt with, either in or out of class. General reassignment of seating usually solves such problems. In over six semesters involving over 800 students, only two students have requested to be separated from a specific student.

With observations being made of student progress throughout each class, it is easy to identify students who are advanced and those who are falling behind. Sometimes I

privately ask a particularly strong student to move to sit beside a weak student and to give them special help. This past semester a student who was failing at midterm was paired with an A-student with excellent communication skills and, much to his surprise, the weak student completed the course with a B. In turn, the A-student learned about the satisfaction of teaching.

5.3.4 Real-time Assessment

In addition to observations of students during in-class learning exercises, we use some technology to assist in assessment and motivation. Because students are required to critically read the text prior to each class, we often begin class with a few “clicker questions” as they have become known due to the use of the i>clicker. These consume only five minutes or so and they can cover the day’s reading or lessons learned from the last class. This is an effective way to encourage students to be on time to class and to do the reading prior to class. Sometimes additional clicker questions are asked during class based on the given learning exercise or mini-lecture. Such questions that occur at the end of a class encourage continued attention throughout the class. Questions are graded either right or wrong, but sometimes multiple answers are acceptable. Many classes, a few questions that are very easy or intentionally humorous provide a chance to earn “participation” points. Results are automatically entered into the computer system immediately for use in grading and results can be shown to the class in the form of bar charts after each question. Loud groans of incredulity are often heard when 60 students are correct and one is not. Sometimes that one even identifies himself or herself with humor. However, students who consistently find themselves in the minority recognize

that they must change something in their approach to learning, hopefully before a major test occurs. If a majority of the class misses a question, the instructor can correct the misconception before it compounds itself. Students seem to enjoy this activity and, aside from assessment, it encourages many positive actions including attendance, attention, preparation, participation, emphasizing critical concepts, and it generally enhances learning. Often students remind the instructor that it is time for some clicker questions. As further incentive, results of these in-class questions typically account for at least 10 to 15 percent of the course grade.

Clicker questions tend to focus on concepts. It is not uncommon for some students to grasp the concepts but to find it difficult to transfer these into problem solving. Early identification of this problem allows special assistance to be given to such students who have potential to improve. Clicker scores tend to be considerably higher than test scores; however we have noticed that in general, clicker scores clearly mimic course grades. See the typical class performance illustrated at right. Examining the differences between individual clicker scores and the class average value, we find that students earning A, B, or C have positive differences with the relative magnitudes as expected. D students are typically close to average while F students have a large negative difference. There are always a few students who do well on the clicker questions but are not successful in the class because of poor problem solving ability, but the opposite situation essentially never occurs. It is notable that on average the successful (ABC) students are clearly superior on the conceptual questions than the unsuccessful (DF) group.

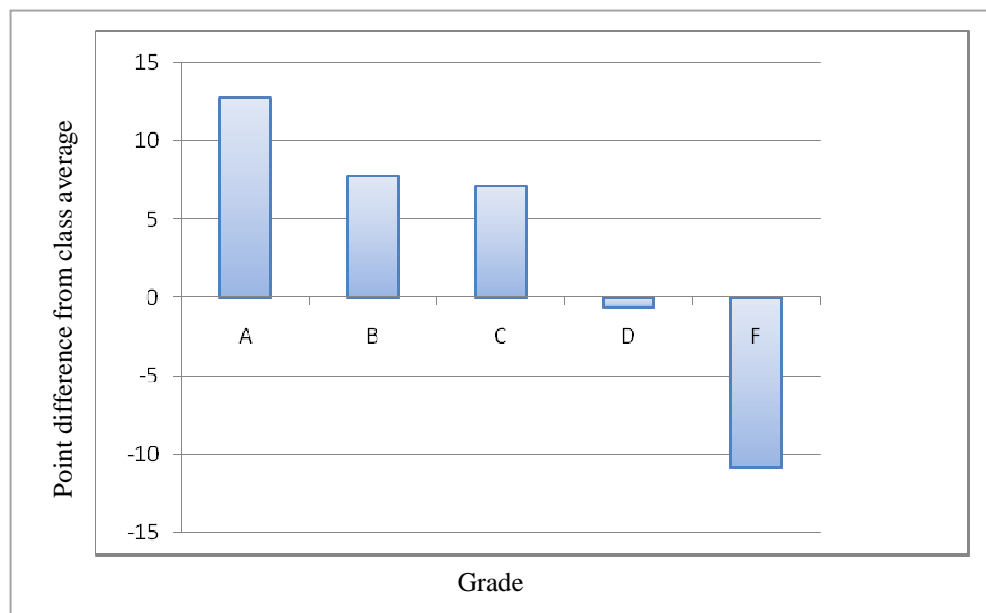


Figure 5.3 Clicker score difference from class average, by course grade.

5.3.5 Learning Exercises

The daily learning exercises have been constructed as a required adjunct to the text. Students are required to purchase the complete package from a local copy shop at the same time they purchase the main textbook. The exercises are designed to provide a link between the reading, the mini-lectures, and the homework. They are primarily paper activities that allow good work habits to be established and offer the instructor and assistants to observe and correct student work in real-time. This way, misconceptions or bad practices are not given a chance to develop into larger problems. In fact, many times exercises are designed to bring out commonly observed errors so that they can be eliminated quickly. Another tool used here is to develop activities that allow students to PROVE certain concepts to themselves rather than just being told that these concepts exist. For example, when learning to take moments of forces, students prove by example

that forces are transmissible vectors, that Varignon's theorem is valid, that the reference point for moments of couples is arbitrary, that a given couple can be located anywhere with no change in motion or equilibrium. The exercise set associated with couples is included in Appendix B. Similarly, some exercises are designed to prove that certain commonly assumed facts are actually not true. Friction and its direction relative to the direction of motion is a good example of this. A primary focus of the learning exercises is to allow students to make mistakes, but to have them corrected so as to quickly establish firm understanding of fundamental principles and practices. Instructors new to teaching with this approach often find it difficult to accept this idea of allowing and correcting mistakes, rather than preventing students from making mistakes. Most of us can relate to learning from our mistakes but often those were painful. Here they are expected, and even encouraged in controlled ways.

5.3.6 Homework

Homework is assigned every class to be completed by the next class. These may be standard problems which are sometimes modified to address both statics and dynamics. Homework may also be to complete unfinished Learning Exercises. The importance of doing the homework problems is stressed at multiple times during the semester, especially after each test. Numerous students who have had to repeat the class remark that their subsequent successful attempt was primarily the result of accepting the fact that homework was really a requirement. Recently we have not been collecting homework daily, but only at test time and then only checking for completeness. Solutions are posted on BlackBoard two days after each assignment. We typically allot

two percent of the final grade to homework. This way, successful students come to accept the responsibility for doing their homework in order to learn, not just to earn points toward their grade. When a major percentage of the grade is allotted to homework, the publisher's solution manuals somehow find their way into the hands of an astonishingly large number of students. Our learning assistants hold several evening sessions each week that students can attend if they need special help with homework problems. Students who decide not to do the homework and only study from the posted solutions, despite stern warnings against this practice, almost always find themselves repeating the course. It is not uncommon for such students to earn a high grade after failing on one or more attempts, and they inevitably admit that the warning regarding the necessity for doing the homework was accurate.

5.4 Topic Elimination and Topic Emphasis

Devoting a full semester to statics alone allows time to delve into many topics that are mathematically and physically interesting, often mainly to the instructor, but that have very limited application in later courses or engineering work after graduation.

Discussions with mechanics instructors from other universities has indicated that they too have found material that has been carried in statics courses through the years partly to make the course a full semester course and partly because well respected textbooks include the material. Sometimes we have referred to this as "legacy material." When the decision was made to move from 6 total credit hours in the serial course pair to five credit hours in our integrated course, the incentive to eliminate some legacy material in statics was recognized and acted on.

5.4.1 Vector Mathematics

Students in our course must concurrently take, or must have already taken, Calculus III which starts with vector operations including addition, dot products and cross products. We coordinate the timing of this topic with the Mathematics Department so that we can simply apply the methods and refer students to their math course for details. This allows us to save time and there is an educational advantage to expecting students to connect knowledge from math and engineering courses and this expectation has not led to any problems in our course. We also provide engineering examples to math instructors to solidify the connection.

5.4.2 Equivalent Systems

As discussed earlier, we use this idea not in an abstract sense but only in the context of applications of Newton's Laws for a body or a component of an assembly. We do not take this topic to the point of replacing a complex set of forces and couples with a single force as a location to be determined, or to the definition of a "wrench". Furthermore traditional treatment of this topic prior to rigid body equilibrium or discussion of centers of gravity can be more confusing than helpful to most students. An illustration of our approach, taken from one of our learning exercises, is included in Appendix A.

5.4.3 Geometric and Mass Properties

We minimize time spent on using integration to find volumes, masses, and CGs since students have done this in freshman calculus courses. We concentrate on

assemblies of simple shapes and use of the parallel axis theorem. We leave principal axes and principal moments of inertia to later courses. Theorems of Pappus-Guldinus are omitted. Forces on submerged surfaces, a topic sometimes included in this general area, is left to fluid mechanics courses.

5.4.4 Structures and Machines

We do not consider cables having self-weight or distributed loading. However, we devote more than average time to internal forces and couples in beams, trusses, columns, shafts, and frames in both 2-D and 3-D. Students proceed to their Strength of Materials course well prepared and are highly successful. Having taught Strength of Materials many times and having observed student conceptual difficulties in this area who entered from our standard statics course, the senior author of this paper was convinced this added emphasis was necessary at an early stage. Instructors of this course have commented on the superior preparation they are finding in their students.

5.4.5 Virtual Work

This topic is not introduced, although work-energy methods are well covered in dynamic cases.

5.4.6 Kinematics

Relationships between a point's position, speed, acceleration and time are treated very thoroughly including cases where position or speed is the independent variable. However, this is done in a rapid manner with the focus on preparation for subsequent use of these tools in kinetics problems. Relationships between the motions of bodies in

cable-pulley systems are given more emphasis than in many current dynamics books. Relationships between the motions of two points on a body, including cases where one point is sliding on the body, are treated thoroughly in 2-D using vector methods. We do not move far into 3-D kinematics.

5.4.7 Kinetics

Here too, we limit coverage to 2-D rigid body problems. Emphasis is on direct application of Newton's Laws using vector methods and the kinematics noted above. Rigid body translation is followed by pure rotation and then general motion. Newton's Laws are modified by integrating over position and over time to develop work-energy methods and impulse-momentum methods, respectively. Impact problems, including eccentric rigid body collisions, are thoroughly covered. Emphasis is placed on the student's ability to select the most suitable method in various scenarios.

By making the above changes from our previous standard statics course, by not focusing separately on particle statics or dynamics, and by achieving efficiencies by discussing static and dynamic conditions as companions, we have found it easy to reduce the credit hour total from six to five for the integrated course. In fact, some important topics have been given more emphasis than in standard statics and dynamics courses. At the same time, we have found the learning efficiencies of the integrated approach provide time for more extensive coverage of dynamics topics than we were able to achieve in our previous stand-alone course.

5.5 Preparing Faculty for Course Innovation

Innovation in specialty elective courses and graduate courses can often be achieved by individual instructors. In fundamental required undergraduate courses with large enrollments, innovation requires sustainability over time that can only be achieved with a team of competent instructors who are supportive of the innovation. The latter is the case in our Dynamics and Statics course. In the fall semester, we typically require three large sections and in the spring and summer we manage with a single section. This requires that three instructors are available to instruct in the fall semester. We have been fortunate to have instructors who believe in the project and who are willing to adapt their teaching techniques to make the innovation work. However, the process of adaptation is neither one without trials nor one in which instant success is a given. It is interesting to note that at the same time our new integrated course was introduced in the fall of 2006, another department independently initiated a different approach to integrating Statics and Dynamics in a 5-credit hour course in which the emphasis was more on Statics and Dynamics was deemphasized. Different sections used different presentation methods and common exams were not used. This and lack of total commitment among the instructors were probably the leading causes that the course was abandoned before the semester ended. Our course succeeded and is becoming easier to sustain as time goes on. Some of the keys to success are noted below.

Having a team of faculty members who are willing to adapt to new approaches and course content was certainly a key factor. Faculty accepting and fully embracing the major changes in mode of presentation has, for us, been a development over time. We

began by having workshops on the SCALE-UP method presented by faculty from outside the university to describe challenges to expect and methods that have worked. We followed these with workshops within the university presented by engineering and mathematics faculty to spread the word internally. Probably the major adjustment on the part of instructors is moving away from the lecture mode in which every detail is masterfully described by the instructor and students listen and absorb. Learning when to stop explaining and to allow students to experiment is difficult. Our team members come to the conclusion that “less” instruction is actually “more” as they observe their students’ progress over a period of time. Often it takes a year or more for instructors to sufficiently cut back on lecturing and to come to a productive mix of lecture and guided inquiry. The difference in level of student involvement in their learning during lecture and during activities become evident over time and helps convince faculty that the changes are positive. The same applies to the new order of material. Upon first teaching the new order, progressing to rigid body translation in the first two weeks seems to be much too rapid in pace and instructors underestimate the ability of students to learn kinetics in this way. In subsequent classes, this resistance disappears. Just as students must experience learning for themselves, we have found faculty members are no different.

Complete commonality among all sections is also a key to success. Students are not allowed to play one instructor’s expectations off another’s. Commonality allows for a lead instructor to guide the others and to prepare the common schedule, text, learning exercises, homework solutions, and exams. The level of work in doing these things is quite high prior to the first offering of the course. With some team members relieved of

these duties, they are free to develop their own presentation methods that they find effective to their own style. As they develop their facility with the methods, we have found that the lead instructor often needs to encourage the other members to continue to adjust to lecturing less and individualized guiding more. Staying on schedule with the new topical order also often requires continual encouragement from the course leader.

Having courses in other departments conduct their courses using similar inquiry-based methods such as SCALE-UP is also important because students come to see the approach as more mainstream and are more willing to be flexible themselves. At Clemson University, we are fortunate that the General Engineering Program has been using SCALE-UP in freshman engineering courses and the Math Sciences Department adopted SCALE-UP in the freshman engineering calculus courses starting in Fall 2006. As we received these students as sophomores the following year, we observed a much more willing acceptance of the method by the students than we had found in our first two semesters of offering our new course.

Finally, without the physical architecture and instructional equipment required to allow extensive interaction between students and the instructor and teaching assistants, success would be difficult regardless of the amount of faculty enthusiasm and flexibility. Fortunately our administration has been strong in this regard in support of our effort.

5.6 Adapting to Student Maturity

Those who have taught students as seniors and as sophomores know that each group offers different challenges. Our students are first semester sophomores who have barely been challenged in prior courses. As a result, most students come to us with high

GPRs and levels of confidence. Unfortunately their study habits, discipline in thought processes, and willingness to accept good practices from their instructor are generally at a very much lower level. In addition, in earlier years students came to our course with a high degree of skepticism that we were following a reasonable path by integrating dynamics and statics. The failure of such integration in the other department at Clemson reinforced their belief that we too would abandon the approach. As the permanence of our course has become solidified, we are finding much more positive attitudes among our students. While positive attitude is helpful, this does not overcome the above problems we find in early sophomores.

The general approach of mini-lectures interspersed with multiple in-class learning exercises is well suited to young students with limited attention spans. We use numerous physical demonstrations, often involving students to illustrate dynamic behavior. Computer simulations are also helpful using such software as WorkingModel¹¹. YouTube has an unlimited variety of videos of interesting occurrences, ranging from the realistic to the absurd, which demonstrate important dynamic principles or modes of failure under static or dynamic loadings. Student comments on the end of semester course evaluations always single out these attention grabbers as high points in their learning.

Holding students accountable by using clicker questions gives them motivation to prepare prior to each class and to maintain their attention level and effort level during each class. As described earlier, those students who prepare and work well in class naturally score higher on the clicker questions and also comprise the successful portion of

the class. Most students are motivated just knowing that, on average, their clicker score is a good indicator of their level of success as shown in an earlier figure. We continually reinforce that the final step involving homework is perhaps the most important requirement. We show them actual data and testimonials from past classes to make these points real to them.

While some might call part of what we do edutainment, we nevertheless hold the students to the highest standards. They realize that a larger percentage of their classmates will be unsuccessful in passing this course than most any other course they have attended. These realizations, and the fact that grades are based on performance and not on level of effort, seem to motivate most students to serious study. Those who do not make these realizations are never successful on their first try. We relate data to students about students who are at first unsuccessful but who are successful on subsequent attempts after they come to accept the realities of the way to be successful in the course. We have been criticized by some administrators who see our high rates of nonsuccess and for whom retention is a primary objective. However, at least half of the students in this group typically are also unsuccessful in another course in the same semester. Since many students are highly successful, including some who are surprised at their own level of success, we know our standards are appropriate. Data described later supports our thinking. Basically, we require students to mature to a reasonable degree while taking this course rather than passing along large numbers of students with poor preparation and study habits to later courses.

5.7 Overcoming Misgivings

Gathering support within the department to attempt this innovation was not difficult. Our faculty members have the greatest respect for each other and are encouraging of new ideas as long as they do not negatively impact follow-on courses or ABET accreditation. Obtaining our course approval at the College level posed much more skepticism and resistance. This came especially from those who were not directly involved with teaching fundamental mechanics courses, yet nevertheless had a vote on approval of the changes. Eventually we obtained approval with concerns noted for the record.

Students discussed their reservations about this change with parents and older siblings who are practicing engineers and with alumni that they encountered during their co-op work. Because these engineers were educated in a more traditional manner, and because in many cases they recalled having difficulty in the old serial courses, they often reinforced the students' skepticism that we were moving in a rational direction by integrating two difficult courses into one, which their logic told them would be twice as difficult! Students were happy to report this external support for their concerns. Our job was to reassure the students that our change was well planned and deliberate and that those outside our thought process had neither the complete picture about the need for the change nor the details about how we were using new instructional methods to ensure the topical changes were successful. As time has moved on since the first offerings of the course, negative feedback from students has become less common but remains at a low level especially from students who find the course exceeds their abilities.

The primary tools for overcoming such resistance are maintaining a positive attitude in the face of criticism, communication of the benefits of the change, and perseverance toward the main goals while being flexible enough to change implementation details as experience dictates.

5.8 Effectiveness of Changes

In several papers, we have reported data-driven conclusions regarding the effectiveness of the integrated course and the modified SCALE-UP method of presentation. Some of these data are repeated here for completeness.

5.8.1 Follow-on Course:

For mechanical engineering students, integrated Dynamics and Statics is a prerequisite for a three credit-hour Strength of Materials course normally taken in the junior year. We tracked first 182 ME students who completed the integrated course and then attempted the follow-on course. We compared their grades in Strength of Materials to the grades of 818 ME students who previously took the serial pair of statics and dynamics courses taught in a traditional lecture format. In order to account for differences in student overall achievement, the adjusted means of grades in the follow-on course have been adjusted using the students' GPA prior to taking statics or integrated statics/dynamics as a covariate. These adjusted means are estimates of the average follow-on course grade under the condition that all students in both groups have the same incoming GPA. To avoid duplication, only each student's first attempt at each course is included in the analysis. Using a 4.0 scale, the students who took the integrated course

had an adjusted mean grade of 2.817 in Strength of Materials compared to the control group value of 2.503. More details are available in Orr et al, 2010. It should be noted that without the adjustment for average GPA, the difference is larger for the group having the integrated course. Therefore the data show that topical integration combined with the SCALE-UP approach used in the mechanical engineering 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.

5.8.2 Time to Completion and Rate of Completion

Although the integrated course has a relatively high percentage of students who are not successful (receive a D, F, or W) on their first attempt, history shows that the same can be said for both the serial statics and dynamics courses. We have tracked the time required to complete either the integrated course or the pair of serial courses by ME students. We found that 86% of ME students (n=280) complete the integrated with a C or better taking an average of 1.30 semesters. These data can be compared to the 72% completion rate for ME students (n=773) who took the traditionally taught separate statics and dynamics courses at Clemson in an average of 2.49 semesters. Additionally, 63% of these students passed the integrated course with a C or better on their first try, compared to 55% who completed both of the separate statics and dynamics courses with a C or better on their first attempt. More details are available in Orr et al, 2010. It should be noted that our DFW rates in early courses are undoubtedly inflated by a very liberal withdrawal policy and by an academic redemption policy that allows students to expunge

a certain number of credit hours of D or F grades after successful retaking of the course. Sophomores see little harm in either withdrawal from a course or from receiving a D or F final grade.

5.8.3 Concept Comprehension

We have administered the Statics Concept Inventory (SCI)¹² and the Dynamics Concept Inventory (DCI)¹³ to students at the start and the completion of the separate courses and the integrated course. Students in the integrated course had normalized gains on the SCI and the DCI of 23% and 14%, respectively. Students in the traditionally taught separate courses had normalized gains on the SCI and the DCI of 20% and 13%, respectively. More details are available in Orr et al, 2010. Therefore, slight conceptual comprehension improvements in both statics and dynamics are shown due to the combination of topic integration and SCALE-UP. The chart shown here shows that the average normalized gains are reasonably good indicators of final grades in the integrated course.

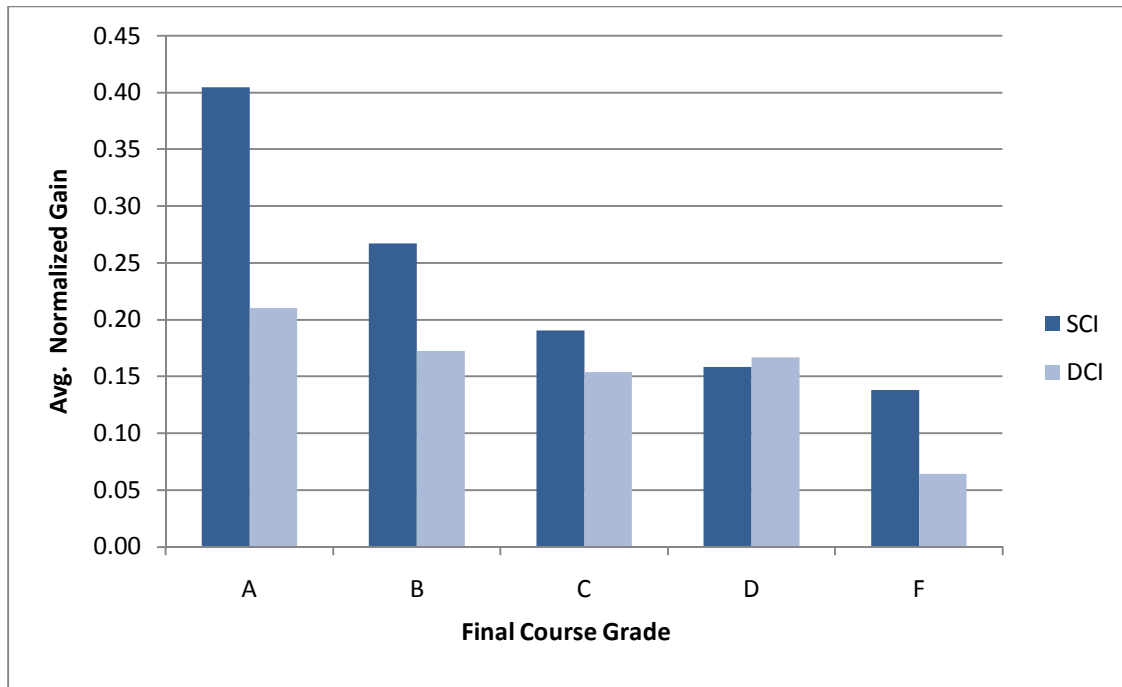


Figure 5.4 Average normalized gains on the Statics Concept Inventory (SCI) and Dynamics Concept Inventory (DCI).

5.10 Conclusions

A modified SCALE-UP approach that emphasizes active learning, guided inquiry, and student responsibility has been described as applied to an innovative and challenging sophomore course that integrates Dynamics and Statics. Challenges to achieving success in this new course have included (1) development of a dedicated textbook, (2) development of learning exercises to foster student comprehension, (3) reorganization of topical content including topic deletion and added emphasis on certain topics, (4) preparing faculty for change, (5) accommodating limited student maturity, and (6) dealing with widespread misgivings about the project. Although these challenges were not trivial to overcome, the authors agree that the effort has been worthwhile, as

evidenced by improved student performance on a required follow-on course, reduced time to completion and increased rate of completion, and slight improvements in concept comprehension.

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Appendix B: Learning Exercise 1b: Moments, Couples, Equivalent Systems

Objectives: Understand moments and couples, applied and reactions
 See applications for Newton's Third Law relative to FBDs
 Understand equivalent force-couple systems

1. The 10 inch long body shown is subjected forces as shown. Find the tendency the forces have to rotate the body about the left and right ends and about the center of the body. That is, find the moments (magnitude, units, and direction) that the forces create about these points. After doing these, write in your own words what you discovered about the moment of a couple compared to the moment of a force.

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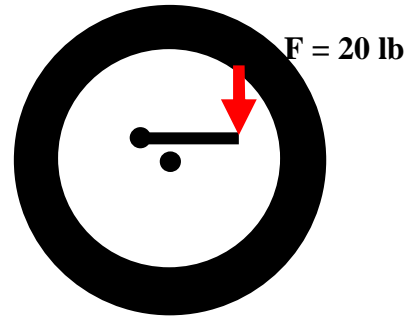
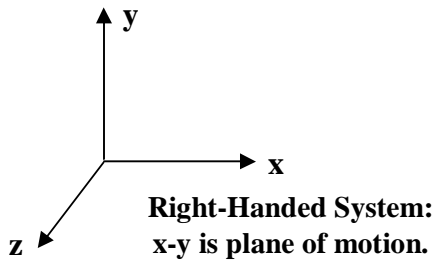
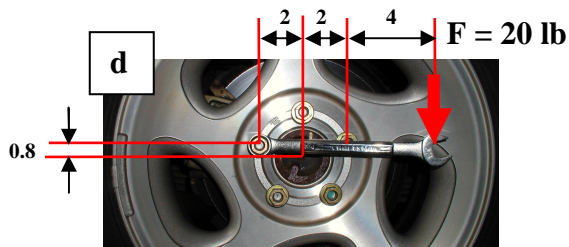
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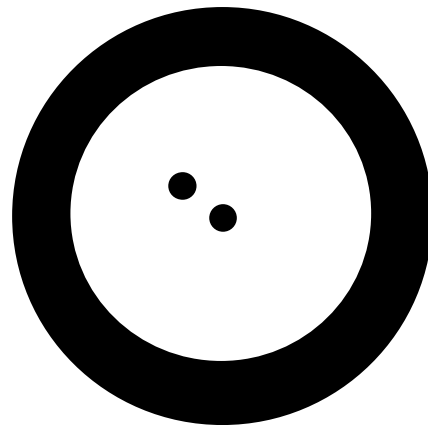
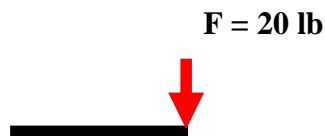
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If the wheel in Figure 1.8 is in firm contact with the ground (center is 14 inches above ground) with the transmission in neutral, no brakes applied, and sufficient contact friction to keep the wheel from rotating, find the friction force for case (d). In doing this, first draw the FBD of the wheel with wrench in place to solve for the friction force. Then write the sum of forces and sum of moments equations and solve.

(lengths in inches)

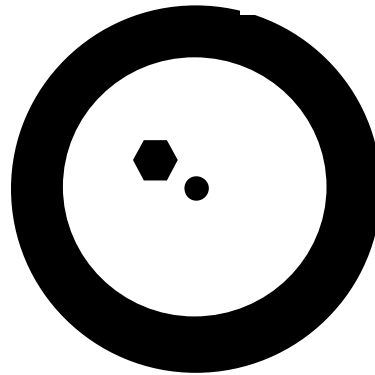
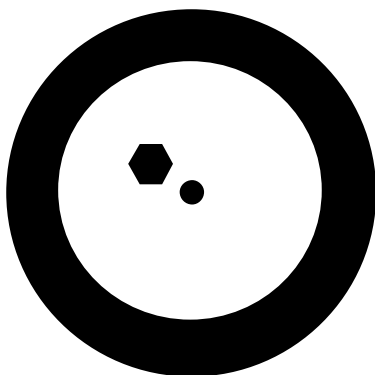
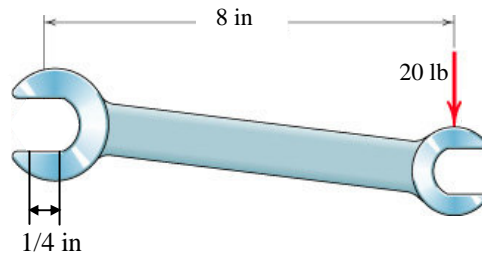
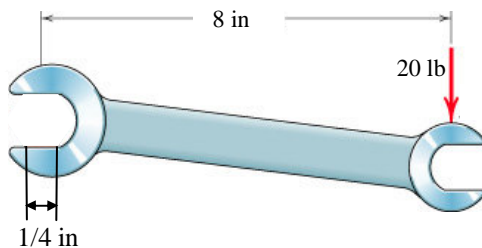
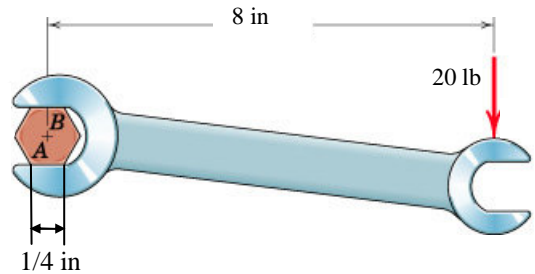


Now draw separate FBDs of the wrench by itself and then for the wheel by itself (with nut still in place). Represent the couple reaction on the wrench and on the nut by a curved arrow on each FBD. Then repeat the sum of forces and sum of moments equations for the wrench and then for the wheel and show that you get the same results as for the combined wheel and wrench on the first page. This exercise demonstrates both Newton's



Second and Third Laws.

2. If the closed box wrench in the photo is replaced with an open end wrench similar to the one shown in the figure, think of exactly where the wrench and nut contact. Neglect friction between the wrench and nut. Draw FBDs of an open end wrench separated from the nut and then the FBD of the wheel and nut showing the opposing reactions on the nut. In the second FBD for each, show that the net effect of the contact forces that are equivalent (single force and single couple) to the actual contact forces between the wrench and nut. Observe that these are the same as the FBDs in #1. What effect would the presence or absence of friction between the wrench and nut have on the moment applied to the nut? What would be the effect of friction on the contact force magnitudes and directions applied to the nut at the contact points?



In both #1 and #2, the FBDs of the wheel alone illustrate another useful idea known as the “equivalent force-couple system”. The wheel with the “equivalent” force and couple moment from the wrench, applied on the nut, is still in static equilibrium. In simple terms, describe the relationship between the reactions of the nut on the wrench and the wrench on the nut. Describe in your own words how the actual contact forces relate to the “equivalent force-couple system”. Also, remember Newton’s Third Law about bodies in contact with each other.

6. CONCLUSIONS AND FUTURE WORK

Based on results herein, SCALE-UP has been successfully adapted in second-year engineering and mathematics courses. Adapting the SCALE-UP approach has allowed the successful integration of course materials from what are traditionally separate courses, which otherwise would have been overwhelming for students in a traditional lecture environment. The results have also 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. There has been a decrease in the DFW rate for SCALE-UP statics and integrated statics/dynamics compared to traditionally taught courses and 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 have been noted. Students passing integrated statics/dynamics are more successful in follow-on courses, while students 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 work includes further dissemination through workshops, hosting visitors, and the Clemson SCALE-UP website. Additionally, student interview transcripts collected during the first two years will be analyzed to explore how students self-regulate in a student-centered course.