AC 2010-590: THE EFFECT OF AN INTEGRATED DYNAMICS AND STATICS COURSE ON THE PROGRESS AND PATHWAYS OF MECHANICAL ENGINEERING STUDENTS

Marisa Orr, Clemson University

Marisa K. Orr is a doctoral candidate in the Mechanical Engineering program at Clemson University. She is a research assistant in the Department of Engineering and Science Education and is a member of the inaugural class of the Engineering and Science Education Certificate at Clemson University. As an Endowed Teaching Fellow, she received the Departmental Outstanding Teaching Assistant Award for teaching Integrated Statics and Dynamics for Mechanical Engineers. Her research involves analysis of the effects of student-centered active learning in sophomore engineering courses, and investigation of the career motivations of women and men as they relate to engineering.

Lisa Benson, Clemson University

Lisa C. Benson is an Assistant Professor in the Department of Engineering and Science Education at Clemson University, with a joint appointment in the Department of Bioengineering. Dr. Benson teaches first year engineering, undergraduate research methods, and graduate engineering education courses. Her research interests include student-centered active learning in undergraduate engineering, assessment of motivation, and how motivation affects student learning. She is also involved in projects that utilize Tablet PCs to enhance student learning. Her education includes a B.S. in Bioengineering from the University of Vermont, and M.S. and Ph.D. degrees in Bioengineering from Clemson University.

Sherrill Biggers, Clemson University

Sherrill B. Biggers is Professor of Mechanical Engineering at Clemson University. He has over 29 years of experience in teaching engineering mechanics, including statics, dynamics, and strength of materials at two universities. His technical research is in the computational mechanics and optimal design of advanced composite structures. He developed advanced structural mechanics design methods in the aerospace industry for over 10 years. Recently he has also contributed to research being conducted in engineering education. He received teaching awards at Clemson and the University of Kentucky. He has been active in curriculum and course development over the past 20 years. He received his BS in Civil Engineering from NC State University and his MS and Ph.D. in Civil Engineering from Duke University.

The Effect of an Integrated Dynamics and Statics Course on the Progress and Pathways of Mechanical Engineering Students

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.

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 work[1-4] has shown that students in the integrated class performed as well as students in a statics class on the Statics Concept Inventory[5] and as well as students in a dynamics class on the Dynamics Concept Inventory[6]. 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.

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.

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 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.

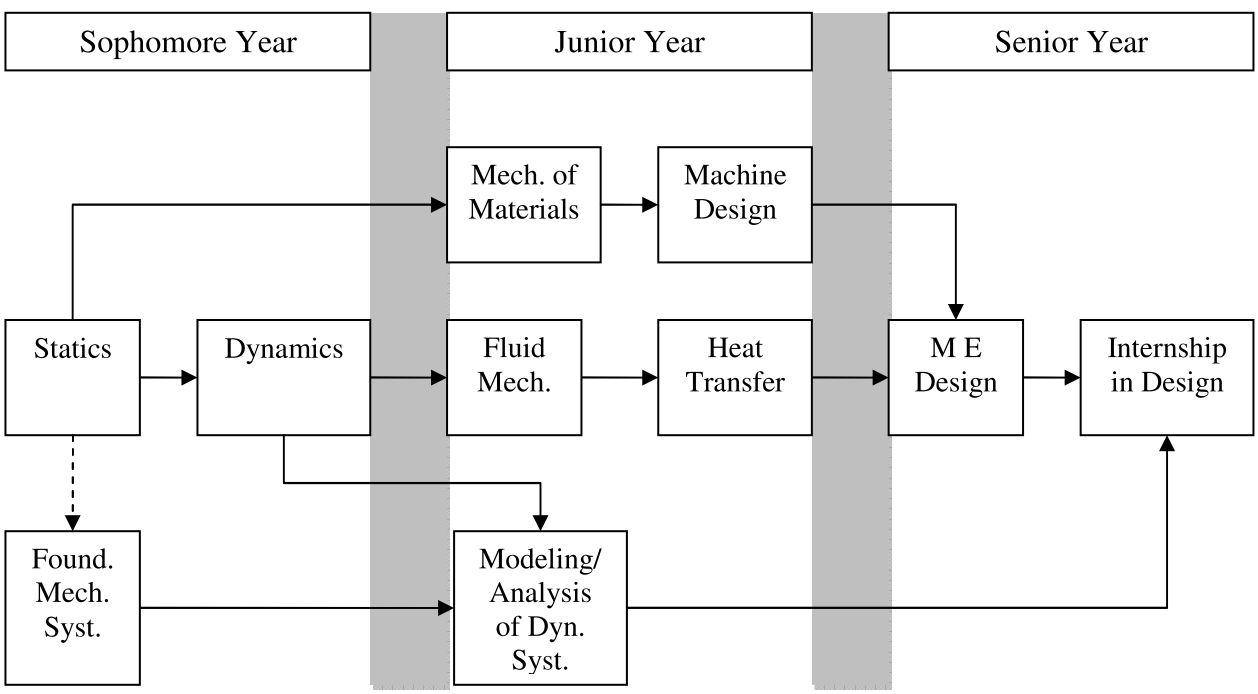

Figure 1. Flow chart of key courses in the old curriculum. Solid arrows indicate pre-requisites; dashed arrows indicate co-requisites.

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 Orr[7]. 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 Orr[7]. 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 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.

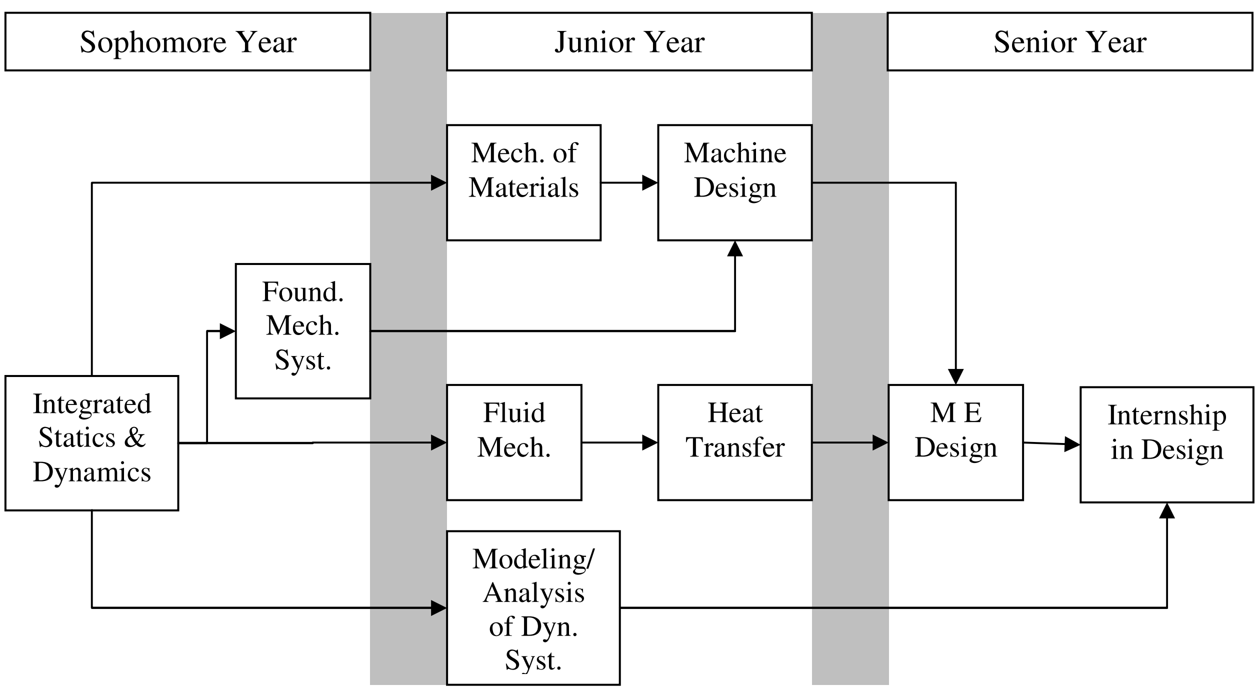

Figure 2. Flow chart of key courses in the new curriculum. Solid arrows indicate pre-requisites; dashed arrows indicate co-requisites.

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 courses[1-4]; 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.

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.

Results and Discussion

Enrollment

From Table 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 proportions[11]. 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 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

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 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 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

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 3.

Table 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 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.

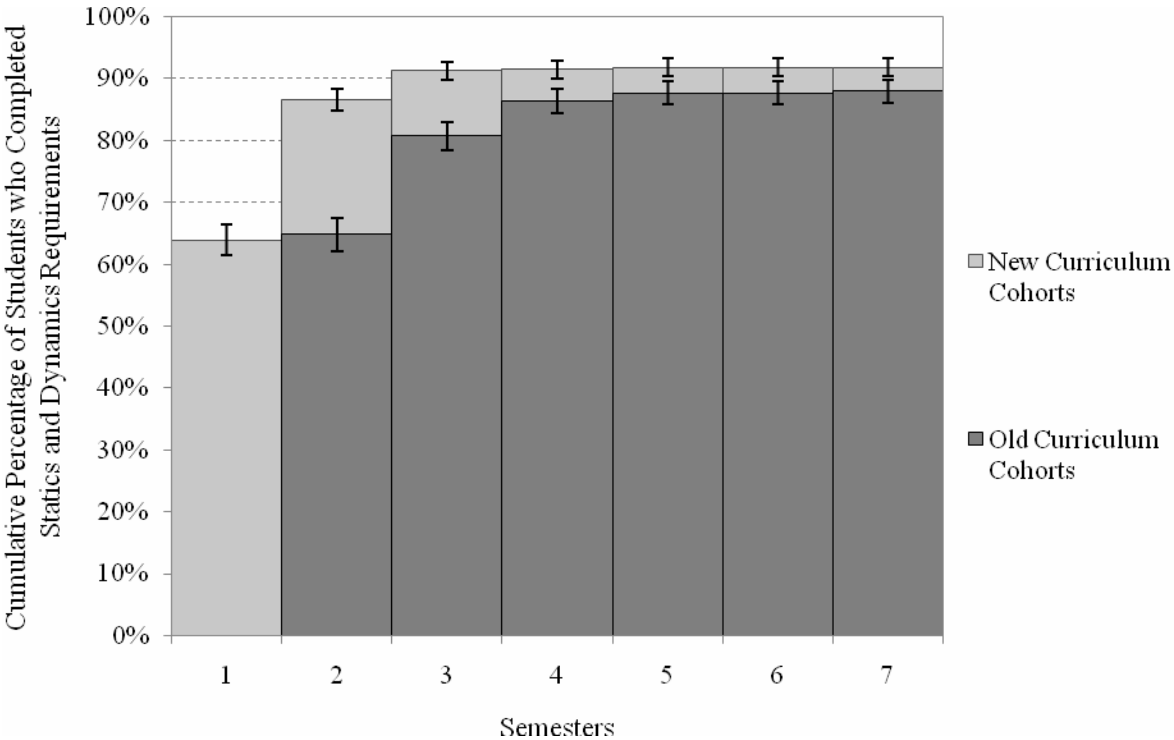

Figure 2. Cumulative percentage (and standard error of the proportion) of students completing statics and dynamics requirements as a function of semesters in the Mechanical Engineering program.

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 Table 3.

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 3. 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	

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.

References

1. L. Benson, S. Biggers, W. Moss, M. Ohland, M. Orr and S. Schiff, Adapting and Implementing the SCALE-UP Approach in Statics, Dynamics, and Multivariable Calculus. Proceedings of the Annual Meeting of the American Society for Engineering Education (2007).
2. L. Benson, S. Biggers, W. Moss, M. Ohland, M. Orr and S. Schiff, Student Performance and Faculty Development in SCALE-UP Engineering and Math Courses. Proceedings of the Annual Meeting of the American Society for Engineering Education (2008).
3. L. Benson, S. Biggers, W. Moss, M. Ohland, M. Orr and S. Schiff, Adapting and Implementing the SCALE-UP Approach in Statics, Dynamics, and Multivariable Calculus. Proceedings of the Annual Meeting of the American Society for Engineering Education (2009).
4. L. C. Benson, M. K. Orr, S. B. Biggers, W. F. Moss, M. W. Ohland and S. D. Schiff, Student-Centered Active, Cooperative Learning in Engineering, International Journal of Engineering Education, 26, (accepted, Sept 2009).
5. P. S. Steif and J. A. Dantzler, A Statics Concept Inventory: Development and Psychometric Analysis, J. of Engineering Education, 94(4), 363-371G (2005).
6. G. Gray, F. Costanzo, D. Evans, P.Cornwell, B. Self, and J.L. Lane, The Dynamics Concept Inventory Assessment Test: A Progress Report and Some Results. Proceedings of the Annual Meeting of the American Society for Engineering Education National Conference (2005).
7. S. B. Biggers, M.K. Orr, Integrated Dynamics and Statics for First Semester Sophomores in Mechanical Engineering, Annual Meeting of the American Society for Engineering Education (2010).
8. R.J. Beichner and J. M. Saul, "Introduction to the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) Project. Proceedings of the International School of Physics (2003).
9. R. Beichner, J. Saul, D. Abbott, J. Morse, D. Deardorff, R. Allain, S. Bonham, M. Dancy, and J. Risley, "Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) project," in *PER-Based Reform in University Physics*, *Vol. 1,* edited by E. F. Redish and P. J. Cooney, American Association of Physics Teachers, College Park, MD (2007).
10. J. D. H. Gaffney, E. Richards, M. B. Kustusch, L. Ding, and R. Beichner, "Scaling Up Educational Reform," Journal of College Science Teaching, 37(5):48-53 (2008).
11. Hinkle, Dennis E., William Wiersma, and Stephen G. Jurs. *Applied Statistics for the Behavioral Sciences*. 5th ed. Boston: Houghton Mifflin, 2003.