ALIGNMENT OF FACULTY EXPECTATIONS AND COURSE PREPARATION BETWEEN FIRST-YEAR MATHEMATICS AND PHYSICS COURSES AND A STATICS AND DYNAMICS COURSE

A Dissertation

by

KRISTI JO SHRYOCK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2011

Major Subject: Interdisciplinary Engineering

Alignment of Faculty Expectations and Course Preparation between First-Year

Mathematics and Physics Courses and a Statics and Dynamics Course

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May 2011

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ABSTRACT

Alignment of Faculty Expectations and Course Preparation between First-Year Mathematics and Physics Courses and a Statics and Dynamics Course. (May 2011)

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Alignment of the expectations of engineering faculty and the preparation engineering students receive in first-year mathematics and physics mechanics courses provided the motivation for the work contained in this study. While a number of different aspects of student preparation including intangibles, such as motivation, time management skills, and study skills, affect their performance in the classroom, the goal of this study was to assess the alignment of the mathematics and physics mechanics knowledge and skills addressed in first-year courses with those needed for a sophomore-level statics and dynamics course.

Objectives of this study included: (1) Development of a set of metrics for measuring alignment appropriate for an engineering program by adapting and refining common notions of alignment used in K-12 studies; (2) Study of the degree of alignment between the first-year mathematics and physics mechanics courses and the follow-on sophomore-level statics and dynamics course; (3) Identification of first-year mathematics and physics mechanics skills needed for a sophomore-level statics and

dynamics course through the development of mathematics and physics instruments based on the inputs from faculty teaching the statics and dynamics courses; (4) Analysis of tasks given to the students (in the form of homework and exam problems) and the identification of the mathematics and physics skills required; (5) Comparison of the required skills to the skills reported by faculty members to be necessary for a statics and dynamics course; and (6) Comparison of student preparation in the form of grades and credits received in prerequisite courses to performance in statics and dynamics.

Differences were identified between the content/skills developed in first-year mathematics and physics mechanics courses and content/skills expected by engineering faculty members in the sophomore year. Furthermore, skills stated by engineering faculty members as being required were not necessarily utilized in homework and exam problems in a sophomore engineering mechanics course. Finally, success in first-year physics mechanics courses provided a better indicator of success in a sophomore-level statics and dynamics course than that of first-year mathematics. Processes used in the study could be applied to any course where proper alignment of material is desired.

DEDICATION

To my husband, Jason, and our new little girl who will be arriving very soon

ACKNOWLEDGEMENTS

I would like to thank my committee co-chairs, Drs. Arun Srinivasa and Janie Schielack, and my committee members, Drs. Don Maxwell, Helen Reed, and Jeff Froyd for their guidance and support throughout the course of this research. Arun, I especially appreciate all of the hours you spent with me, your encouragement to accomplish this (even before I knew I was ready), and your assistance in getting this completed.

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Last, but certainly not least, thank you to my husband, Jason, and our new little girl who will be arriving very soon. Jason, you have been a source of great joy and inspiration to me. Thank you for your sense of humor, strength, and understanding. More than you may have ever realized, you have been an integral part of helping to make this educational endeavor complete. I also want to thank our new little one who will make your arrival very soon for staying up with me countless nights with promises from me that I would get some sleep next week. Thank you for your unending show of support (and kicks!) each night.

NOMENCLATURE

ANOVA	Analysis of Variance
CBK	Common Body of Knowledge
CCEBM	Committee on Curricular Emphasis in Basic Mechanics
DCI	Dynamics Concept Inventory
FCI	Force Concept Inventory
FYGE	First-year Grade Exclusion
FMCE	Force and Motion Conceptual Evaluation
K-12	Kindergarten to 12^{th} Grade
MAA	Mathematics Association of America
MBT	Mechanics Baseline Test
MEA	Model-eliciting Activity
MSB	Math-Statics Baseline
NSF	National Science Foundation
RQ	Research Question
STEM	Science, Technology, Engineering, and Mathematics
SCI	Statics Concept Inventory
SCT	Statics Competency Test
SSI	Statics Skills Inventory
TAMU	Texas A&M University

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INTRODUCTION

Purpose of Study

One of the reasons engineering students complete first-year mathematics and physics mechanics courses is to prepare them for their engineering courses in the sophomore year and beyond. Therefore, the degree to which these courses actually do prepare engineering students for their sophomore engineering courses would be of interest to faculty members seeking to improve learning and retention of engineering students. For this reason, alignment among expectations of engineering faculty with respect to content and skills students should have, content and skills actually required by the homework and exam problems that engineering faculty members assign, and preparation engineering students receive in first-year mathematics and physics mechanics courses provided the motivation for the work contained in this study.

While a number of different aspects of student preparation including intangibles, such as motivation, time management skills, and study skills, affect their performance in the classroom, the author elected to focus on alignment of the mathematics and physics mechanics knowledge and skills addressed in first-year courses with those needed for a sophomore-level statics and dynamics course. It is motivated by faculty members in sophomore-level engineering courses being dissatisfied with the level of preparation

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This dissertation follows the style of *Journal of Engineering Education*.

students had entering their courses. A critical factor in the alignment process that may have an impact on the skills of students is the question of how well skills that faculty expect are aligned with actual requirements at the sophomore-level.

Studying all of the sophomore engineering courses would exceed the time and resources available for this study. Therefore, selection of a course or courses to study was required. As will be shown, a statics and dynamics course is a key entering sophomore-level course directly combining first-year mathematics and physics mechanics knowledge in the curriculum of many engineering programs at Texas A&M University (TAMU). Each year approximately 1,400 students in the Dwight Look College of Engineering at TAMU enroll in some form of a statics and dynamics course whether it is a course in the departments of Mechanical Engineering, Aerospace Engineering, or Civil Engineering, and statics and dynamics is a common aspect in the curriculum at many engineering programs across the nation. Therefore, the knowledge gained and methodologies used will translate well to other engineering programs with the potential for a large impact.

Rationale

One reason for this study stems from a concern, as will be shown, that students are not persisting with engineering once they are in the program. Evaluation of factors possibly associated with this lack of persistence will hopefully assist administrators and even faculty with trying to determine better procedures to put into place to ensure students are adequately prepared for the program and stay engaged in the program.

A brief look at global statistics related to engineering show that the United States currently lags behind other nations in the number of engineering graduates produced each year. Prepared for the Presidents of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, the committee report of *Rising Above the Gathering Storm* provided some staggering statistics about engineering and science in the United States (Committee on Science Engineering and Public Policy, 2006). Among them, the percentage of science and engineering degrees around the world are provided. In Germany, 36% of undergraduates receive their degrees in science and engineering. In China, the corresponding figure is 59%, and in Japan it is 66%. In the United States, the share is 32%. In the case of engineering, the United States' share is 5%, as compared with 50% in China. The authors of the 2005 report recently revisited the points made in the initial report and found that unfortunately, many things have not changed in this regard (Committee on Science Engineering and Public Policy, 2010). Currently, the United States ranks 27th among developed nations in the proportion of college students receiving undergraduate degrees in science or engineering. Thus, a central question that has plagued college administrators, instructors, and educators is how to educate a greater number of students in engineering while maintaining high quality standards for which the United States' college educational establishment is known.

The Dwight Look College of Engineering at TAMU also follows this national trend notwithstanding numerous efforts that have been undertaken at the freshman level (Office of Institutional Studies and Planning, 2009). The first-year College of

Engineering retention rates for the Fall 2003 cohort of first time in college students enrolled after one year in the same college into which they entered was 70%. It is important to note that any student who is enrolled in an engineering department in the College of Engineering as a first time in college student is considered in these statistics regardless of the classes in which they are enrolled. The six-year College of Engineering graduation rates for the 2003-2009 cohort of first time in college students graduating within six years from the same college into which they entered was 55%. Therefore, a sizable retention problem exists even past the freshman year (Frair, Froyd, Rogers, & Watson, 1996; Richards & Rogers, 1996). Freshman engineering programs have made concentrated efforts to improve first-year retention. Activities, such as restructuring the freshman year curriculum to integrate mathematics, physics, and engineering (Froyd & Ohland, 2005) and introducing freshman design projects (Weinstein et al., 2006; Froyd et al., 2006), have been referred to as potential factors in helping to increase first year retention in engineering, but the alignment of these activities to increase retention in sophomore, junior, and senior levels is not evident.

The College has been a leader in transforming the undergraduate engineering program through such programs as Foundation Coalition and STEPS. Through these programs, both curriculum integration and design projects have been incorporated. In the Foundation Coalition, which was founded in 1993, the engineering curriculum was transformed based on four thrusts: "integration of conceptual concepts across courses, active and cooperative learning, use of technology in the classroom, and on-going assessment and evaluation" (Merton, Clark, Richardson, & Froyd, 2001). The STEPS program in the College, which began in 2003, utilized a project-based format in the first-year engineering courses based on three principles:

> Students must be able to plan before they build,…students must be able to use the concepts they are learning in science and mathematics to analyze the performance of their proposed design,…and students must be able to transfer learning from concept-based courses, such as mathematics and science, to project-based activities. (Howze, Froyd, Shryock, Srinivasa, & Caso, 2005b, p. 3)

During the time these extensive efforts have been incorporated, an increase in the rate of students still enrolled in engineering after their first year has increased from 1998-2009 as shown in Figure 1 (Office of Institutional Studies and Planning, 2009). While there has been an increase in the six-year graduation rate during this time period as well, there is still a large difference in the rate of students still enrolled in engineering after their first year and those students graduating in engineering within six years.

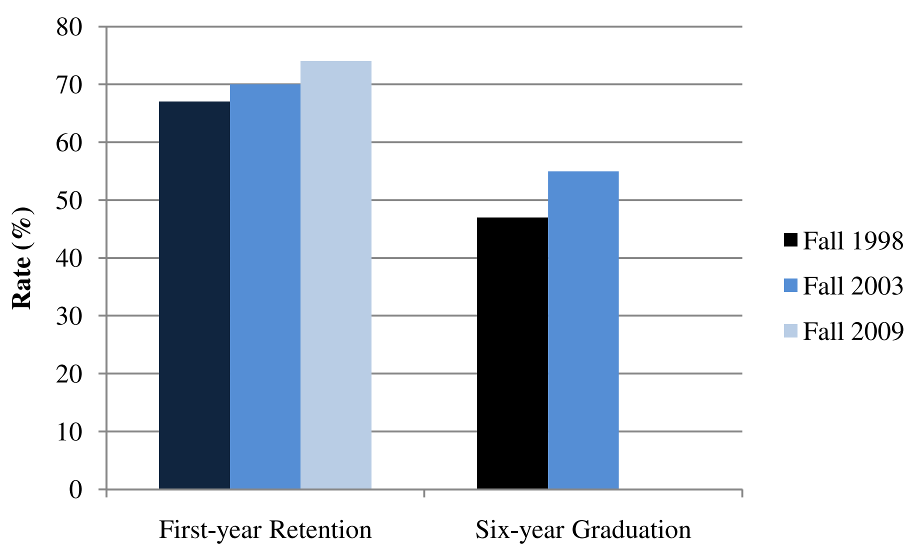


Figure 1. First-year retention and six-year graduation rates for the College of Engineering at TAMU (Office of Institutional Studies and Planning, 2009).

Needs of engineering community addressed

Rising Above the Gathering Storm (2006) and the revisit (Committee on Science Engineering and Public Policy, 2010) emphasize the need for reform in science, technology, engineering, and mathematics (STEM) education. Mathematics and science are vital parts of an engineering curriculum as evident by the requirements of ABET. ABET Engineering Criteria require that at least 25% of the credits for an engineering program be taken in mathematics and science courses (ABET, 2010). At least one study has even shown that success in the first mathematics course is useful in predicting persistence in an engineering program (Budny, Bjedov, & LeBold, 1997). While importance of mathematics and physics for success in studying engineering is unquestioned, deeper understanding of both how engineering faculty members expect their students to apply mathematics and physics and the extent to which engineering students are prepared to satisfy the expectations of faculty members is required. The outcomes of these expectations affect not only faculty and students but also administration in making policy decisions and program enhancements.

Impact of expectations on administration

Administration in the College of Engineering seeks opportunities for the College and departments to be leaders in transforming undergraduate engineering programs to prepare students for productive careers. This emphasis is highlighted in The Dwight Look College of Engineering's Strategic Plan for 2011-2015 (2010). Focus Area #1 in the plan contains details on the strategy for the undergraduate academic experience. The plan includes transforming engineering education on the basis of utilizing experiential learning and developing creative and practical approaches to enhance the education engineering students receive. As part of this process, keeping qualified students in the program and efficiently using of classroom resources become high priorities to help materialize these plans. Having a plan and developing a method for formalizing it is one part of the process. Having the right students in place to take advantage of these methods becomes essential. Determining factors that attempt to predict the success of a student in the sophomore-year would be of interest to administrators.

Administrators continually seek better ways to select students for their department or college who have the best chance for success. Some examples include implementing a mandatory minimum SAT mathematics score of 550 or ACT mathematics score of 24 for all incoming freshmen in the College of Engineering in 2007, focusing recruitment efforts on high schools with a large majority of high-achieving students in 2008, forming a task force committee that studied increasing the minimum mathematics test scores in 2009, and evaluating alternative ways to select students for promotion into departmental specific courses in 2010.

Therefore, implications of alignment related to administrators in a department or college in this study mainly focus on selection of students. For example, how does considering alignment of material or success of students in freshman-level courses affect departmental operations? Selecting students with the highest chance of success in the program is crucial. For retention purposes and to graduate the best engineers, administrators in departments should have an idea of how to better select students for their program. To obtain a better appreciation for how students could be selected, it is important to understand how students are even admitted into an engineering program at TAMU.

Enrollment management practices have been in place at TAMU since the early 1990s. Students are admitted into the University and into a particular department in the College of Engineering on a first-come, first-served basis as an incoming freshman. Once the student completes certain courses and obtains the necessary grades, the student is then admitted into a department's upper-level program.

There are three ways for an incoming freshman student to gain admission into a particular engineering department at TAMU. With any of the three ways, students must have earned at least a minimum score of 550 on the SAT Math section of the test or a corresponding minimum score of 24 on the ACT Math section to gain admittance into a department in the College of Engineering.

The first method is Top 10% admission. Students qualify for Top 10% admission if, "they attend, a recognized public or private high school within the state of Texas and rank in the top 10% of their graduating class" (TAMU Admissions, 2011b). The second method is Automatic Academic admission. Applicants qualify for Automatic Academic admission if, "they are ranked in the top quarter of their graduating class and achieve a combined SAT Math and SAT Critical Reading score of at least 1300 with a test score of at least 600 in each of these components; or achieve a composite ACT score of at least 30 with a test score of at least 27 in ACT Math and ACT English" (TAMU Admissions, 2011a). Students who do not qualify for Top 10%

or Automatic Academic admission can be considered through the University's review admission process.

The student is then a part of the lower-level program in the particular engineering department and can take preparatory first-year mathematics, physics, and engineering courses, along with core electives. To then gain admission into the upper-level departmental course sequence, students must have completed nine common body of knowledge (CBK) courses as well as have certain grade point averages in these nine courses and in TAMU courses in general. All departments in the College of Engineering consider the same nine courses with the exception of Computer Science and Engineering Technology. Table 1 depicts the nine CBK courses needed by students entering the upper-level sequence in the majority of engineering departments at TAMU. The grade point averages required by each of the departments in the College of Engineering are listed in Table 2.

Table 1

Courses Comprising CBK Grade Point Average

Course Title	*Credit Hours*
Foundations of Engineering I	2
Foundations of Engineering II	2
Engineering Mathematics I	4
Engineering Mathematics II	4
Physics Electricity and Optics	4
Physics Mechanics	4
General Chemistry for Engineers	3
General Chemistry for Engineers Lab	1
English Composition	3
Total Credit Hours	27

Table 2

Upper-Level Departmental Requirements for Grade Point Averages

Department	*Required Grade Point Average*
Aerospace Engineering	2.85
Biomedical Engineering	3.25
Chemical Engineering	2.75
Civil Engineering	2.75
Computer Science and Engineering	2.75
Electrical and Computer Engineering	2.75
Engineering Technology	2.00
Industrial Engineering	2.50
Mechanical Engineering	2.85
Ocean Engineering	2.75
Nuclear Engineering (and Radiological Health Engineering)	2.75
Petroleum Engineering	2.75

When a department calculates the CBK grade point average of a student, only the highest grade received in the particular course is considered. Therefore, if a student fails a course the first time and then retakes it and makes a B, the grade of a B is used in the calculation of the CBK grade point average. Grades received at institutions other than TAMU are included as earned for the CBK calculation. For example, an A received at TAMU in a course and an A received at a community college by a student are factored in exactly the same way in the CBK grade point average calculations. CBK courses must, however, be completed with at least a C grade. It is up to academic advisors in the individual departments to qualify their students for upper-level admittance and at the discretion of an advisor in a department to allow a student to begin upper-level courses without completing all three requirements for upper-level admittance.

All grades received at TAMU are included in the overall grade point average calculation with the exception of those excluded with Freshman Year Grade Exclusion (FYGE). Students entering college as freshmen may exclude up to three courses from their overall grade point averages in their first calendar year of coursework completed at TAMU. Grades and any credits received from these courses are not included in their overall grade point averages.

When a department selects students to gain admittance into their upper-level program, there can be significant differences in students with similar grade point ratios. For example, a student with an overall grade point average of 3.0 that has completed all courses with a B grade and a student that has used FYGE to exclude three science-related courses where they received an F but completed their humanities courses with higher grades to achieve a 3.0 overall grade point average would have different backgrounds and possible skill sets entering the upper-level courses.

As departments consider moving to upper-level admittance requirements based on specific number of students rather than simply grade point averages, the dilemma of how to select students with the highest chance of success is crucial. Factors that provide the best chance of success for students in their program must be determined. There are many factors that comprise the make-up of a student. Table 3 lists factors that the researcher felt should be considered when determining how well the success of a student in sophomore-level engineering courses would be. Most all of the factors included are either part of the initial admission requirement into the University or part of the course requirement into the upper-level program. It should be noted that gender, the year a student entered TAMU, and scores on the researcher's instruments are not currently included when evaluating students. They were included in this study to see if differences in these factors were significant. Having a better idea of the skills necessary for and even factors that predict a better chance of success in sophomore-level engineering courses is a first step in hopefully selecting and then keeping students engaged in the engineering curriculum.

Table 3

Factors Considered in Selection of Students

Factors
ACT math score
ACT verbal score
CBK grade point average
Chemistry for Engineers grade
Chemistry for Engineers Lab grade
English Composition grade
Foundations of Engineering I grade
Foundations of Engineering II grade
Gender
High school percentile
Engineering Mathematics I grade
Engineering Mathematics II grade
Mathematics instrument score
Mathematics linear algebra questions correct
Overall TAMU grade point average
Physics Electricity grade
Physics Mechanics grade
Physics free-body diagram questions correct
Physics instrument score
SAT verbal score
Year students entered TAMU

Impact of expectations on first-year engineering program at TAMU

To address the issue of students leaving engineering and not being prepared for the follow-on courses in engineering, first-year engineering programs have relentlessly incorporated ways to combine mathematics and science from the first-year with engineering to better prepare students. Some of the methods undertaken include promoting understanding of engineering processes of design and modeling and in combining the roles of science and mathematics in engineering (Hoit & Ohland, 1998; Pomalaza-Ráez & Froff, 2003; Srinivasa, Conkey, Froyd, Maxwell, & Kohutek, 2005). In addition, the use of projects to motivate and guide the course content rather than simply supplement the subject matter has been incorporated. The freshman-year engineering program at TAMU directs the curriculum and teaching of the curriculum in Foundations in Engineering I and Foundations in Engineering II. The focus in these two courses is to address two important challenges encountered in first-year engineering courses. Specifically, these challenges include students' difficulty in associating engineering methods with some of the more conceptual topics learned in mathematics and physics and address the lack of solid understanding that students have of the engineering design process (Howze, Froyd, Shryock, Srinivasa, & Caso, 2005b). Thus the curriculum is structured such that applied engineering methods can be directly related to aspects of mathematics and science that freshman students generally consider to be disconnected or abstract.

Starting in 2004, a freshman-level engineering course at the TAMU was converted into a project-based learning environment in which projects acquaint students with the engineering design process and allow them to apply the design process in a meaningful way (Howze, Froyd, Shryock, Srinivasa, & Caso, 2005a; Prince, 2004; Pomalaza-Ráez, 2003; Sheppard & Jenison, 1997; Woods, Felder, Rugarcia, & Stice, 2000). Project guidelines have been refined over the years as to what works well in the freshman engineering classroom. Project specifications for the courses include having the project: (1) be relevant to the student's major, (2) emphasize the typical engineering design process and not have students use only trial and error, (3) be within the scope of concurrent mathematics and physics courses, (4) have a graphics component to address communication issues, (5) not rely on fabrication ability of students, and (6) be conducted within a suitable time period for the class (Howze, Froyd, Shryock, Srinivasa, & Caso, 2005a; Howze, Froyd, Shryock, Srinivasa, & Caso, 2005b; Srinivasa, Conkey, Froyd, Maxwell, & Kohutek, 2005).

The first-semester freshman-level engineering class, Foundations of Engineering I, at TAMU typically includes two projects, both of which exemplify an experiential learning environment and are designed to resolve the same curriculum challenges. Each project normally relates to topics in statics and dynamics, respectively. The beginning of the semester primarily covers basic physics concepts as they apply to fundamental engineering methods: free-body diagrams and static equilibrium, calculating moments and forces on a rigid body, and the determination of internal forces in truss members (Plesha, Gray, & Costanzo, 2006). The last portion of the class covers dynamics-related material. The next course in the curriculum is Foundations of Engineering II where the focus is on teaching Solidworks and programming through Robolab. Therefore, the researcher selected to focus on details in the Foundations of Engineering I course as it more directly relates to the mathematics and physics concepts covered in a sophomore-level statics and dynamics course. Faculty and coordinators of the freshman program continually seek to improve the course and provide intervention for students to help them succeed in engineering. Over the years, projects have been refined and material has been altered to address deficiencies of students and attempt to help them succeed in follow-on engineering courses, as well as current courses they are completing.

Impact of faculty identifying skills needed from first-year courses

Faculty can be divided into two parts in this study: follow-on (engineering) and source (mathematics and physics). Instructors teaching follow-on courses, like many instructors, want to make the best use of classroom resources, the most important typically being time, and want to teach material to improve the performance of students in their classes and beyond. The alignment issue is critical in this case. As an instructor, it is important to understand the skill levels of students in the classroom as it affects how instruction is delivered. If students already have the particular skills, there is no need to devote an extensive amount of classroom time to the topic. On the other hand if students do not have the foundational skills, there is no need to try to introduce new skills without properly covering the background needed to understand them. With the researcher also serving as an academic advisor, she has seen the different backgrounds with which students enter the classroom. Some students have failed mathematics and science courses at TAMU or decided not to even attempt such courses at TAMU and completed them, or re-took them, at their local community college. Other students have admitted only being able to pass a class because they paid a local tutoring service for copies of old exams. If there was a way to better understand the skill levels of the students entering the course, classroom instruction could be tailored to meet areas that need attention or even outside resources could be developed to assist the students with learning the material needed in preparation for the class.

Source instructors have an interest in the utilization of the information presented in the class. With the researcher also serving as an instructor in courses that directly help students prepare for their intended majors, she understands that utilization of the course material is very crucial. Knowing that the skills being taught will be useful for a student in future courses is important. Spending extensive time on topics not directly tied to the best interest of a student does not seem as wise as spending time on topics and skills helpful for students to be successful in future classes. This issue of alignment becomes prevalent as the progression of skills and needs for these skills become clear. Knowing how future courses might incorporate the prerequisite skills taught or what additional topics might be introduced to make the course more beneficial to students is vital.

Impact of proper alignment of skills from first-year on students

Students generally attend college to learn new skills. In day-to-day conversations with students, they overwhelmingly want to succeed. Students inquire about resources to help them in the classroom and about course options and implications of not grasping the information presented in class. They inquire about how prior preparation or courses they have completed should be utilized in their curriculum. For students, properly aligned course content provides that additional chance for success as material learned in prior classes can truly be built upon in the follow-on courses. In addition, if students have an understanding of what skills are required in a course to be successful, they can ensure they have the necessary knowledge or know it needs to be acquired for a better chance of success.

Proper course at sophomore-level to evaluate

With the foundation in place on the importance of the tie between expectations of first-year mathematics and physics courses have on the follow-on engineering courses and the fact that engineering cannot manage the problem alone, an appropriate engineering course to evaluate in this study needed to be selected. To determine expectations of engineering faculty for the knowledge of mathematics and physics mechanics and skill in applying this knowledge that students in their course should have to be successful, the researcher identified a core, required, first semester, three credit hour, sophomore-level engineering science course in the Mechanical Engineering curriculum at TAMU, Statics and Dynamics. One reason this course was selected is because it is also common to many engineering majors at TAMU. In addition, while students complete several engineering courses in their sophomore-year including statics and dynamics, materials, thermodynamics, and numerical methods, the course selected is a statics and dynamics course that resembles many courses in Mechanical Engineering curricula across the world because it uses material taught in the first-year mathematics and physics mechanics courses and is most directly related and closer in time being at the sophomore-level to the first-year engineering classes.

In this course, Mechanical Engineering students are expected to apply what they learned in their first-year mathematics and calculus-based physics mechanics courses, as well as the mathematics and physics they learned in high school. The importance of this course in an engineering curriculum was conveyed by Danielson and Danielson (1992) who determined, "Success in later (sic) courses is directly correlated to success in statics." While other courses in the engineering curriculum utilize mathematics and physics, this course is more directly tied to material covered in the freshman year and is almost considered a gateway course into other engineering courses in the curriculum. As evidence of this, the Statics and Dynamics course has the most direct follow-on courses for which it is a prerequisite than any other Mechanical Engineering course in the curriculum, which is shown in Figure 2 (TAMU Mechanical Engineering, 2011). There is a likelihood that students who fail to successfully complete this course will be delayed due to the statics and dynamics course since it is the direct prerequisite for three follow-on courses in the second semester of the sophomore-level curriculum. The entire Mechanical Engineering degree plan and course flowchart are provided as a reference in Appendix A.

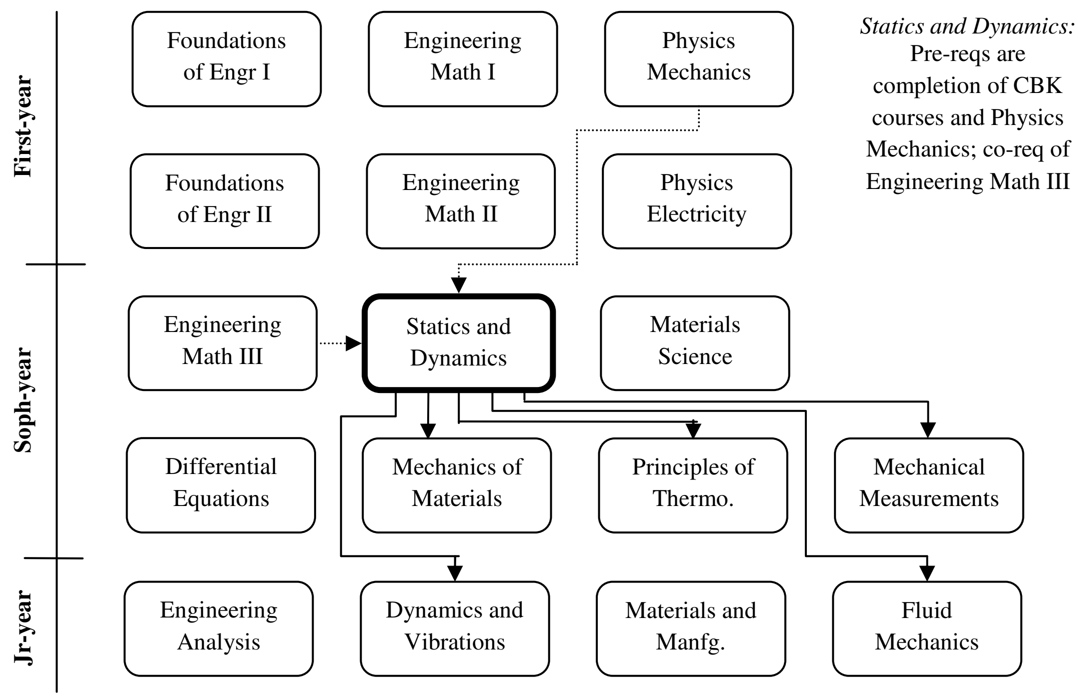


Figure 2. Portion of mechanical engineering degree plan depicting critical path of statics and dynamics (TAMU Mechanical Engineering, 2011).

To further illustrate the importance of the course, prerequisites for Statics and Dynamics and the courses it serves as a prerequisite for will be discussed. As shown in the figure, Engineering Mathematics III is a co-requisite for the statics and dynamics course, but it builds upon mathematics skills learned in the first year. Engineering Mathematics II is completed in the second semester of the first year and serves as a prerequisite for Engineering Mathematics III. Likewise, Engineering Mathematics I is completed in the first semester of the first year curriculum and is a prerequisite for Engineering Mathematics II. Students also complete Physics Mechanics in their first year, which is a prerequisite for Statics and Dynamics. The figure depicts the direct prerequisite function that the statics and dynamics course serves for five follow-on courses by the solid arrows leaving from the Statics and Dynamics box. It is a direct prerequisite for Mechanical Measurements, Mechanics of Materials, Principles of Thermodynamics, which are all completed as part of the second semester sophomore-year courses, and Dynamics and Vibrations and Fluid Mechanics taken in the junior-year.

Taught as a service course in the fall, spring, and summer semesters in the Mechanical Engineering department, almost 1,000 engineering students per year at TAMU enroll in this particular Mechanical Engineering three credit hour statics and dynamics course from almost all engineering majors. Students completing this course have engineering majors that include Biological and Agriculture, Chemical, Electrical, Engineering Technology, Industrial and Systems, Mechanical, Nuclear, and Petroleum. There are typically six sections of the Mechanical Engineering statics and dynamics course taught in the fall semesters with approximately 90 students in each section, an additional four sections with approximately 90 students in each section in the spring semesters, and one section with approximately 40 students in the summer semester. In addition, since it is taught as a service course for many other departments, the curriculum is common among the different sections of the course, and standardized sets of exams are utilized. For these reasons, it is relatively easy to extract necessary data for comparison.

The Aerospace Engineering and Civil Engineering departments have developed their own statics and dynamics courses to include in their specific curriculum. Aerospace Engineering majors complete Aerospace Mechanics I - Statics, which is equivalent to the first half of the Mechanical Engineering Statics and Dynamics course, and Aerospace Mechanics II - Dynamics, which is equivalent to the second half of the Mechanical Engineering Statics and Dynamics course. These two Aerospace Engineering courses are each taught as two credit hour courses and enroll approximately 100 students per year. Similar to Mechanical Engineering, the statics and dynamics courses are direct prerequisites to key follow-on courses in the Aerospace Engineering curriculum, and the prerequisites for the statics and dynamics courses are equivalent as well. The degree plan and course flowchart for Aerospace Engineering are provided in the Appendix A.

Civil Engineering takes a slightly different approach by requiring their students to complete a three credit hour statics course in the first semester of the sophomore year and then a three credit hour dynamics course in the junior year of the curriculum. Approximately 300 Civil Engineering students complete this particular statics course. The degree plan and course flowchart for Civil Engineering are also provided in Appendix A. Since the two course combinations in Civil Engineering are slightly different in nature and timing than Mechanical Engineering and Aerospace Engineering, the focus of this study lies with the statics and dynamics courses in the Mechanical Engineering and Aerospace Engineering departments. Figure 3 depicts the engineering majors at TAMU and the percentage of each major included in the study that complete the statics and dynamics courses through one of these two departments. This percentage is then compared to the total percentage representation of the particular department in the College of Engineering in the figure.

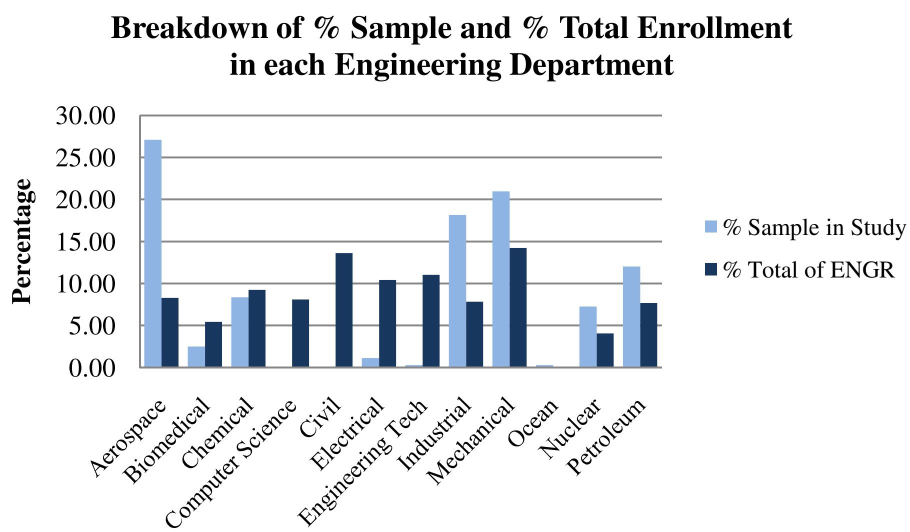


Figure 3. Comparison of the percentage of each engineering major included in the study and the total percentage representation of the department in the College of Engineering.

As shown, a sophomore-level statics and dynamics course contains necessary requirements, importance, and details to make it an ideal course in this study to determine the alignment between faculty expectations and course content between the follow-on engineering course and first-year mathematics and physics mechanics courses. Therefore, hopefully it can provide a mechanism to better understand the implications of courses, material, and expectations not being properly aligned.

Defining alignment

Previously, researchers have defined alignment as the degree or extent of agreement or match between areas to work together to achieve a purpose (Bhola, Impara, & Buckendahl, 2003; La Marca, 2001; Martone & Sireci, 2009; Resnick, Rothman, Slattery, & Vranek, 2003; Roach, Niebling, & Kurz, 2008). Bhola et al. (2003) state, "Alignment can be defined as the degree of agreement between a state's content standards for a specific subject area and the assessment (s) used to measure student achievement of these standards." La Marca (2001) describes alignment as "the degree of match between test content and the subject area content identified through state academic standards." Martone and Sireci (2009) define alignment as the degree to which assessments yield results that provide accurate information about student performance regarding academic content standards at the desired level of detail, to meet the purposes of the assessment system. Broader than coherency between course content and assessment, Resnick et al. (2003) refers to alignment as the extent that factors or elements work together to guide instruction and learning. In 2008, Roach et al. defined alignment as the extent to which curricular expectations and assessments are in agreement and work together to provide guidance for educators' efforts to facilitate students' progress toward desire academic outcomes.

Most of work in the literature on alignment has been applied to decision and policy making implications related to K-12. On the other hand, the focus of this study is at a college-level. In order to extend the notions of alignment to the college level, a broader definition of alignment as compared to the definitions given above is needed.

Hence, motivated by definitions in this study, alignment will be defined in a broader context as the extent to which components or constituents of a system are configured to fit together for the system to function as a whole in the desired manner.

In this study, the system was the first-year mathematics and physics mechanics courses and a sophomore-level statics and dynamics course, and the function studied was success of students in a sophomore-level statics and dynamics course. The relationship between these constituents is shown in Figure 4. The components or constituents are: (1) prerequisite courses for the statics and dynamics course completed by students (alignment area #1 in the figure), (2) advisors who promote students into upper-level departmental courses (alignment area #2), (3) mathematics and physics instruments completed as pre-tests by the students in the statics and dynamics course (alignment area #3), and (4) instructors in the statics and dynamics course (alignment area #4).

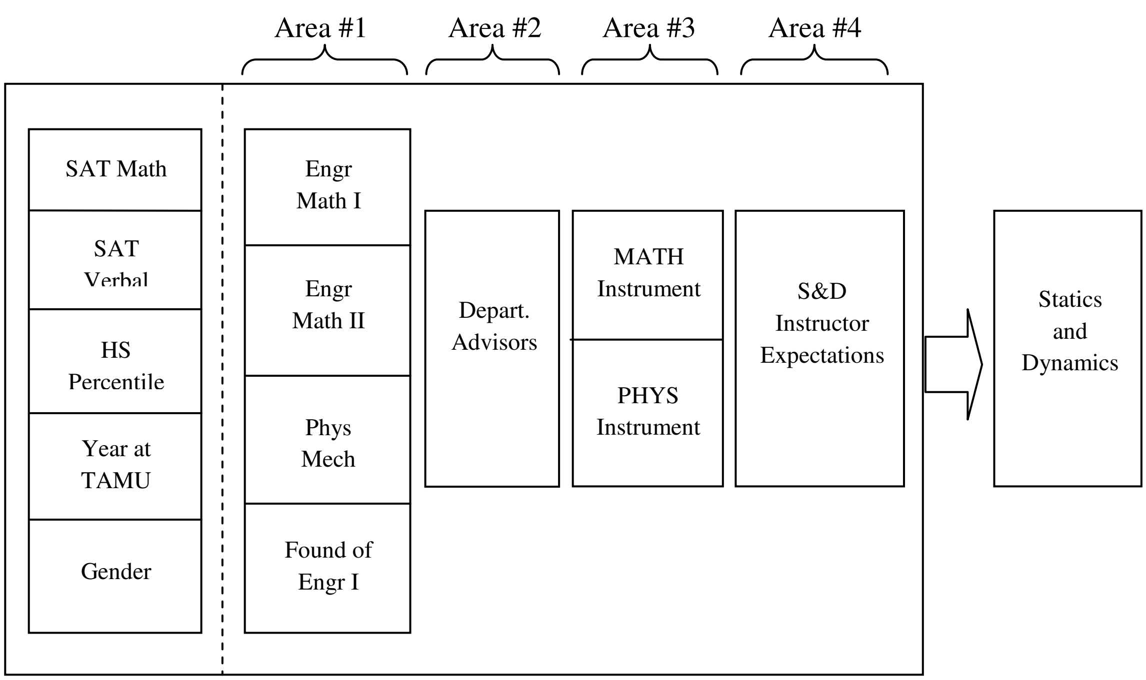


Figure 4. Alignment system used in study.

The extent to which the constituents are aligned will be determined by the following measures. The measures are detailed based upon the alignment area depicted in the figure, which includes the entire system defined in the alignment process in this study.

The factors on the left hand side of the dashed line are factors that are part of the composition of the student entering TAMU. After evaluating correlation of these factors to success in a sophomore-level statics and dynamics course, the factors were determined to have no significance. Therefore, the system used in this study is all of the information to the right of the dashed line.

Alignment area #1 includes the four prerequisite courses for a sophomore-level statics and dynamics course at TAMU. The courses are Engineering Mathematics I, Engineering Mathematics II, Physics Mechanics, and Foundations of Engineering I. The alignment measures used in this study for these courses will be Spearman's rank correlation between defined factors, grades received in the courses, comparison of topic coverage and skills used in a statics and dynamics course, and variance the defined factors have on the final grade in statics and dynamics explained through Analysis of Variance (ANOVA).

In alignment area #2, the information engineering departmental advisors use to make decisions promoting engineering students into a department's upper-level program, course grades and grade point averages, are included. Currently only CBK grade point averages and overall TAMU grade point averages are considered when evaluating whether or not to promote an engineering student into a department's upper-level program, in addition to whether or not the student earned a grade of at least C in each of the CBK courses. As the College of Engineering at TAMU considers changing this process to accept the best qualified students, more details might be helpful to departmental advisors. Therefore, alignment factors considered in this study include success in statics and dynamics in relation to final grades in prerequisite courses, grade point averages, and consideration of the use of transfer credit and advanced placement credit.

For the mathematics and physics mechanics instruments developed as part of this study shown in alignment area #3, breakdowns of the scores received by students on the instruments and the success of the students in a statics and dynamics course will be measured to determine alignment. In addition, a content validity study using item-objective congruence will be conducted to determine alignment between the instrument questions and the intended skills represented by the questions. Finally, further evaluation of the alignment of specific instrument scores on a subset of the population will be considered.

Alignment area #4 includes the instructors teaching the statics and dynamics course and their expectations of the first-year mathematics and physics mechanics skills necessary to be successful in a sophomore-level statics and dynamics course. The alignment measures for this area consist of identifying these skills and comparing them to the actual homework, exam, and quiz problems assigned in statics and dynamics.

Benefits of alignment include having students adequately prepared for a course and allowing a course instructor to focus on course material instead of having to teach material again that students should have mastered previously in courses. A number of variables or dimensions must be considered to determine the degree that expectations and measures to gauge the expectations correspond.

Research Questions

Alignment of the expectations of faculty in a sophomore-level statics and dynamics course and the preparation engineering students receive in first-year mathematics and physics mechanics courses provided the motivation for the work contained in this study. The objectives of this study included: (1) the development of a set of metrics for measuring alignment appropriate for an engineering program by adapting and refining common notions of alignment used in K-12 studies; (2) the study of the degree of alignment between the first-year mathematics and physics mechanics courses and the follow-on sophomore-level statics and dynamics course; (3) the identification of first-year mathematics and physics mechanics skills needed for a sophomore-level statics and dynamics course through the development of mathematics and physics instruments based on the inputs from faculty teaching the statics and dynamics courses; (4) the analysis of tasks given to the students (in the form of homework and exam problems) and the identification of the mathematics and physics skills required; (5) the comparison of the required skills to the skills reported by faculty members to be necessary for a statics and dynamics course; and (6) the comparison of student preparation in the form of grades and credits received in prerequisite courses to performance in statics and dynamics.

To achieve these objectives, this study intends to address the following research questions:

1) Can engineering faculty members teaching a sophomore-level statics and dynamics course identify skills they think students need from first-year mathematics and physics mechanics courses? (Address alignment area #1 in Figure 4.)
2) Do the expectations of these engineering faculty members align with the classroom implementation in a sophomore-level statics and dynamics course? (Address alignment area #4 in Figure 4.)
3) Is what students learned in their first-year mathematics and physics mechanics courses aligned with a sophomore-level statics and dynamics course? (Address alignment areas #1, 2, and 3 in Figure 4.)

Figure 5 shows the connections between the three research questions. The research questions in this study evaluate if there is a break or weak link between any of the three arrows depicted in the figure.

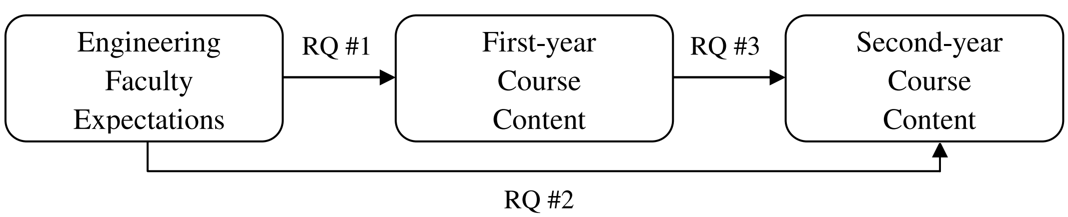


Figure 5. Connections between the three research questions (RQs) in the study.

LITERATURE REVIEW

The focus of this study is on the alignment of faculty expectations and course content between first-year mathematics and physics courses and a statics and dynamics course. As has been introduced, mathematics and physics skills are crucial in the engineering curriculum. Further works introduced in this section will provide an even more in-depth look at what has been done and how the works differ from the work in this study. How other researchers have evaluated the mathematics and physics skills of students and even the work that engineering programs have done at the first-year will be detailed. In addition, the concept of alignment and its role with course content will be discussed to provide a foundation with which to build upon throughout the study.

Prior Work on First-Year and Second-Year Course Content

Work related to mathematics

Evaluating how mathematics from the first year is used downstream in the engineering curriculum is not new. In 1974, the Committee on Curricular Emphasis in Basic Mechanics (CCEBM) was formed out of concern within the Mechanics Division of ASEE for the quality of instruction in basic mechanics. This led to the development of an extensive national survey and preparation of a readiness skills test for students entering their first engineering mechanics course (Snyder & Meriam, 1978a). The test focused on providing "hard" data for proper discussions on the emphasis and coverage of basic mathematical skills that are prerequisites to mechanics. It consisted of questions related to both pre-college and college-level mathematics that serve as prerequisites to the mechanics course. The breakdown of the main areas covered on the test is depicted in Table 4.

Table 4

Topics Covered on Mechanics Readiness Test (Snyder & Meriam, 1978b)

Topic	*% of Test Questions*
Trigonometry	14
Trigonometry Equations	
Trigonometry Identities	
Law of Cosines	
Geometry	50
Equation of Circle	
Equation of Parabola	
Area of Triangle	
Perpendicular and Parallel Lines	
Vectors	14
Sum of Vectors	
Dot Product	
Cross Product	
Calculus	22
Small Angle Theorem	
Logarithms	
Area Under a Curve	

Given on a trial basis to a few institutions in 1976 and then nationally to 9,500 students from 37 four-year engineering schools and 11 junior colleges and engineering technology programs in 1977, it provided convincing evidence of the lack of mathematics preparation students bring into the mechanics curriculum (Snyder & Meriam, 1978b). Students scored an average of 12.8 correct responses out of a total of

25 questions (Snyder & Meriam, 1978a). The test was revisited in 1987 and given to 3,850 students from 21 participating schools to see if any significant changes had occurred (Snyder, 1988). The same version of the test was administered, so direct comparisons could be made. While the average number of correct responses did increase to 13.7 in 1987, closer inspection of the data showed a wider spread between schools participating. Snyder (1988) noted that "The pressures to maintain enrollments may have softened the entrance requirements in some institutions" (p. 1346). In either administration, an average score of 55% was considered much lower than the expected average score of 75%. Snyder also stated in his 1988 review:

> The dismal results on this test substantiate the allegations that our students as a group are seriously deficient in their understanding and ability to use even elementary tools of mathematics…It is no wonder that students have difficulty learning mechanics in our basic courses; they have to spend much of their time relearning elementary mathematics. (Snyder, 1988, p. 1346)

Studies such as the ones cited in the preceding paragraph may have contributed to the motivation for the Neal Report, which emphasized the need for postsecondary institutions to reform undergraduate STEM education (National Science Board, 1986). In a recent study by the Mathematics Association of America (MAA), mathematicians, who led the study, brought together groups of engineering and computer faculty members as well as other downstream consumers, students who took mathematics courses, to explore the evolution or in some cases lack thereof of new instructional practices (Ganter & Barker, 2004). Summarizing conversations of the different disciplinary faculty, Ganter and Barker (2004) reported concerns about the mathematics preparation of undergraduate students for their disciplinary courses.

Stimulated by the Neal Report and the willingness of the Federal Government to support efforts by the National Science Foundation (NSF) for innovation in undergraduate STEM education, NSF initiated several major initiatives to promote new STEM curricula. One initiative was the Calculus Reform Movement (National Science Foundation, 1996). According to studies funded during the movement, students felt more positive about calculus and perceived they were better prepared (Armstrong, Garner, & Wynn, 1994; Bookman, 2000; Jackson, 1996; Keith, 1995). However, little data has been generated to support assertions that reform efforts have had a significant impact on downstream engineering courses (Ganter, 2000; Ganter, 2001). Manseur, Ieta, and Manseur (2010) reported that little progress has been made in mathematics education in engineering. They admitted that teaching needs to be different, but they were not sure how to accomplish this. Ganter and Barker stated in their 2004 work, “There is often a disconnect between the knowledge that students gain in mathematics courses and their ability to apply such knowledge in engineering situations.”

More recently, there have been several studies that assess the mathematics needed for engineering, but it has been from a taxonomy level as opposed to skills based (Cardella, 2007; Fadali, Velasquez-Bryant, & Robinson, 2004; Goldfinch, Carew, & McCarthy, 2009). For example, in 2007 Cardella’s work investigated the mathematical Knowledge Base, Problem Solving Strategies, Use of Resources, Beliefs and Affects, and Practices of students. She looked at the ability of a student to frame problems, apply mathematics to engineering problems, and use software to aid in the learning process

(Cardella, 2007). A study by Fadali, Velasquez-Bryant, and Robinson (2004) evaluated the link between attitude and competence in mathematics. They found that:

> Most topics in engineering use the language and processes of mathematics as a medium of knowledge representation. It is therefore necessary for students to learn this language to be able to learn engineering problem solving. To state it mathematically, basic skills in mathematics are a necessary, though not sufficient, condition for learning engineering problem solving" (Fadali et al., 2004, p. F1F-20).

Reviews of ASEE conference papers published within the last four years suggest that work has still been focusing on first year integration of mathematics with physics and engineering through the use of projects or curriculum incorporation or moving this integration in the sophomore year of curriculum with project-based learning (Gomes, Bolite, & Powell, 2010; Manseur et al., 2010; Raubenheimer, Ozturk, & Duca, 2010). Some of the literature is beginning to outline skills from mathematics, but the focus has been on identifying topics from the course and not on the impact on engineering if a student does not possess these skills. For example, Gomes, et al. (2010) looked at assessing the mathematics skills necessary for a final course project. The skills outlined were still framed using the taxonomy level outlined in Cardella's work in 2007. In 2010, Manseur et al.'s work addressed the relationship between mathematics and engineering but from a curriculum standpoint. Their work on mathematics preparation looked at mathematics skills from a curriculum change standpoint. In their results, the authors proposed modifications to the mathematics course sequence and advocated the use of computer tools to modernize an engineering curriculum. Raubenheimer et al. (2010) addressed a mechanism to assist students who did not enter an engineering course with the required mathematics skills. Their work focused on a junior-level biomedical engineering course that utilized on-line review materials and a chance for students to test and retest to ensure learning of concepts deemed necessary by the course instructors. While the work briefly discussed that a pre-test covering mathematics skills was given, the main focus on the work was the on-line review modules developed and their impact on a student's learning. No details about specific skills were mentioned.

Work related to physics

At least as far back as the 1960s, researchers began to discover that learners offered explanations for physical phenomena that were at odds with common scientific understanding (Gentner & Stevens, 1983). For example, researchers found that many learners thought that forces needed to be exerted on bodies so that they would continue to move at constant, non-zero velocities. Perhaps the most intriguing result of this research was that learners retained their belief in the alternative explanations, even after instruction. Today, a multi-disciplinary research field studies conceptual understanding of learners, including what conceptual understanding is, how conceptual understanding can be assessed, what common alternative explanations learners offer for physical phenomena, and how learners can be influenced so that their explanations reflect common scientific understanding. Duit (2009) maintains an active bibliography for this field that contains over 8000 references.

Determining the physics skills of students

A pivotal event in the field of conceptual understanding occurred when Halloun and Hestenes synthesized research on understanding (and misunderstanding) of concepts of force and motion to create the Force Concept Inventory (FCI) (Hestenes, Wells, &

Swackhamer, 1992). Consisting of 29 multiple-choice questions, the FCI assessed a student's understanding of Newtonian concept of force and requires a student to select between Newtonian concepts and common sense alternatives. It focused on six conceptual dimensions: Kinematics, Newton's First Law, Newton's Second Law, Newton's Third Law, Superposition Principle, and Kinds of Force. Results from the FCI showed that students may struggle with qualitative problems but end up doing well on conventional tests (Hestenes, Wells, & Swackhamer, 1992). The main focus of FCI in the literature has been on improving teaching of a physics course and not specifically on the preparation of students for follow-on courses.

A more recent alternative to the FCI is the Force and Motion Conceptual Evaluation (FMCE). Covering a wider variety of topics than the FCI, such as more questions on kinematics, the 47 multiple-choice question inventory also determined that using new techniques provides significant gains over teaching with a traditional lecture approach (Thornton & Sokoloff, 1990; Thornton, 1996; Thornton & Sokoloff, 1998; Ramlo, 2002).

In addition to being interested in how learners understand concepts in physics mechanics, physics and engineering faculty members are also interested in learner abilities to solve physics problems. To assess these abilities Hestenes and Wells (1992) developed the Mechanics Baseline Test (MBT). As a complement to the FCI, questions on the MBT focus on learner abilities to solve physics problems in three areas of physics mechanics: kinematics, general principles, and specific forces. It has 26 multiple-choice questions that, unlike the FCI, require that students perform computations to find answers to the questions. It is intended to assess student learning after instruction in mechanics. Using both the FCI and MBT, the authors determined "a good score on the Inventory [FCI] is a necessary but not sufficient condition for a good score on the Baseline" (Hestenes & Wells, 1992, p. 5).

Determining mathematics, statics, and dynamics skills of students

In statics, objects do not move. Therefore, many of the questions in the FCI, while relevant to statics, do not directly assess student knowledge of statics. Researchers have worked to explore how learners understand statics. Developed in the late 1990s, the Math-Statics Baseline (MSB) Test explored basic mathematics skills taught in high school or first-year calculus (Danielson & Mehta, 2000). Composed of 10 questions related to mathematics and 10 questions related to statics, the results for the mathematics portion were very high, but few statistically significant differences between test groups were found. Further work on the MSB included expanding the statics portion of the test (Mehta & Danielson, 2002). In 2003, work began to refine the statics portion of the MSB into a Statics Skills Inventory (SSI) (Danielson, 2004). The process involved determining the actual skills critical to the mastery of statics, not simply the conceptual knowledge of the subject (Danielson, et al., 2005). The authors focused on determining the actual skills required in a statics course and began work on developing questions to highlight only one skill as opposed to typical engineering problems, which require multiple skills to solve. As of 2008, the original list of 53 skills had been narrowed down to the top 11 ranked skills, based on feedback the authors had received from the faculty members involved, and an alpha version of the SSI had been developed complete with 12 questions (Danielson & Hinks, 2008). The focus of the SSI is on four groups of skills: vector manipulation, modeling and free body diagrams, equilibrium equations, and manipulation of forces and force systems.

Around the same time as the work on the SSI was being undertaken, the Statics Concept Inventory (SCI) was developed in 2002 to detect errors associated with incorrect concepts in statics (Steif, 2004). The authors of this inventory took a different approach than the SSI as they evaluated the conceptual knowledge and not skill-level knowledge. Authors of the inventory stated that mathematical skills were needed for statics, but they were not part of conceptual content covered in the SCI. Through the current version containing 27 multiple-choice questions, the SCI focused on five groups of conceptual errors: free body diagrams, static equivalence between different combinations of forces and torques, type and direction of loads at connections, limit on friction forces, and equilibrium conditions. The largest errors by students were reported on questions pertaining to constraints and constraint forces (Steif & Dantzler, 2005).

Both the SSI and the SCI were designed to be post-assessments to quantify the amount of material students learned in statics. In a similar way, the Statics Competency Test (SCT) evaluated the material learned in statics but was used as a pre-assessment to the follow-on course (Morris & Kraige, 1985). First used in the fall of 1984, the SCT was given as a precursor to students entering the Strength of Materials course to see how much students retained knowledge learned in their statics course. Students scored an average of 39.4% on the test, which was an unexpected result. The expectation by a number of statics instructors was that a minimum average score of 50% would not be unlikely. The authors concluded that grading standards were too lenient on average.

The work on dynamics-related problems has been more limited, mainly focusing on the work of Gray et al. (2005), which formed a team from both large public universities and small private universities, to create a Dynamics Concept Inventory (DCI) to address the student learning of dynamics concepts. The first version of the instrument was given in 2004 and tested 11 different concepts from rigid body dynamics (Gray, Evans, Costanzo, Cornwell, & Self, 2004; Self et al., 2004). After students selected many of the same distracters on the pre- and post-test administrations of the DCI, faculty members instituted the introduction of the concepts during 10-15 minute sessions each week in class with substantial gains recorded in the increase of knowledge of the students on the topics (Gray et al., 2005).

Work on conceptual understanding, including the FCI, FMCE, SSI, and SCI, has provided considerable information about how students understand (or misunderstand) concepts in many different subjects (Hestenes, Wells, & Swackhamer, 1992; Thornton & Sokoloff, 1990; Thornton, 1996; Thornton & Sokoloff, 1998; Ramlo, 2002; Steif, 2004; Steif & Dantzler, 2005; Morris & Kraige, 1985).

First-year engineering curriculum strategies

Many institutions have tackled the predicament of helping students with difficulty in applying first-year mathematics and physics courses by restructuring the freshman year curriculum to integrate mathematics, physics, and engineering together. Froyd and Ohland (2005) detailed how students have seen “few connections between their mathematics and science courses." Forming these connections has been tried in many forms by various institutions. Some institutions have tried combining pedagogy strategies, such as teaming and cooperative learning with curriculum reform. In this combined model, students work in groups on multi-disciplinary tasks that illustrate the connections between mathematics, science, and engineering. The intent is for students to continue integrating their mathematics, science, and engineering past the freshman year to better understand the fundamentals needed for engineering.

Villanova University introduced a freshman design project incorporating four engineering disciplines utilizing the Lego Mindstorms Robotics Invention System (Weinstein et al., 2006). Students built a vehicle to navigate a given route that contained a gap the vehicle had to cross over to complete the task. This project required the integration of knowledge across many departments. For example, student success depended on their ability to use what they learned about gears from Mechanical Engineering, span design from Civil and Environmental engineering, power due to electromechanical reactions from Chemical Engineering, and programming from Electrical and Computer Engineering. Projects have allowed students to learn engineering by applying the mathematics and physics they have been taught in their classes. Understanding why they have been learning the material and applying the knowledge was believed to help the students learn more of the key skills needed from their mathematics and physics courses in engineering.

TAMU has developed projects to accomplish providing the connections between mathematics, physics, and engineering by also using the Lego Mindstorms kits (Froyd et al., 2006). However, the projects completed by students have been developed to teach a specific task, such as analysis by truss joints, kinematics, or thermal analysis. Results have shown success in the ability to apply the knowledge gained in subsequent courses, but the success has been at the specific skill level and not necessarily on the larger mathematics and physics levels.

Alignment and the Importance of Proper Alignment between Course Content

Alignment

Expectations from administrators and faculty would be that students who perform well in prerequisite courses will perform well in follow-on courses. Alignment is the extent to which components or constituents of a system are configured to fit together for the system to function as a whole in the desired manner. (Bhola, Impara, & Buckendahl, 2003; La Marca, 2001; Martone & Sireci, 2009; Resnick, Rothman, Slattery, & Vranek, 2003; Roach, Niebling, & Kurz, 2008). Most of the work regarding alignment shows the utilization of alignment in relation to standards-based reform for "improving classroom instruction and increasing equity across the educational system" (Roach, Niebling, & Kurz, 2008, p. 158) in the K-12 grade levels. Rothman, Slattery, Vranek, and Resnick (2002) stated in their work that the term alignment "is a widely used term (it occurs more than 100 times in the recently passed legislation reauthorizing the Elementary and Secondary Education Act) whose meaning appears simple, but whose technical definition has remained elusive" (p. 5). Webb (1997) addresses alignment by evaluating the extent policy elements work together guiding instruction and thereby guiding student learning. While the system selected for the alignment process can vary, Martone and Sireci (2009) evaluated alignment from the viewpoint of curriculum, assessment, and instruction. In their work, they defined instructional alignment and curricular alignment. Instruction alignment is the "agreement between a teacher's objectives, activities, and assessments, so they are mutually supportive" (Martone & Sireci, 2009, p. 1334). This type of alignment would address alignment area #4 in Figure 4 by evaluating the alignment of the expectations of first-year mathematics and physics mechanics skills necessary for success in a sophomore-level statics and dynamics course denoted by faculty teaching the statics and dynamics course and the actual skills needed in the course. Curricular alignment is the "degree to which the curriculum across the grades builds and supports what is learned in earlier grades" (Martone & Sireci, 2009, p. 1334). This would address alignment area #1 in Figure 4 by considering the four prerequisite courses for statics and dynamics.

The Council of Chief State School Officers addresses three preferred models useful for evaluating alignment. They include Webb's alignment model (Webb, 1997), Achieve model (Rothman et al., 2002) (Roach, Niebling, & Kurz, 2008), and Surveys of Enacted Curriculum model (Porter & Smithson, 2001). These models are also referenced in other works on alignment (Bhola, Impara, & Buckendahl, 2003; Martone & Sireci, 2009).

The alignment model developed by Webb (1997) investigates degree of alignment between assessments and standards. His method evaluated in alignment studies relates to the area of content focus, which comprise four subcategories. The subcategories analyzed in alignment studies include categorical concurrence, depth of knowledge, range of knowledge, and balance of representation (Webb, 1997). Trained participants in the alignment process review content and assign certain values related to the different categories when there is an objective match. The results are then tabulated and an alignment value determined. In 1999, Webb used his methodology to study mathematics and science assessment and standards in four states. His results showed varied levels of alignment across grade levels and states (Webb, 1999).

In the Achieve model, Rothman et al. (2002) developed an alignment model to compare a state's assessment to its related standards related to specific subject areas. In the two step process, trained participants verify a mapping of test items to the objectives item by item. Only once a consensus is reached by the participants is a holistic evaluation performed on the overall level of challenge, balance, and range (Rothman et al., 2002). In 2002, Rothman et al. applied the method in an assessment of five states. They found that while most states were well matched when content and performance standards were compared but were not as successful in assessing the full range of standards and objectives.

The Surveys of Enacted Curriculum methodology assesses the alignment between what is taught in the classroom and what is then assessed (Porter & Smithson, 2001). This methodology has been used in K-12 classrooms with teachers providing the content to be assessed. While this method seems to refer to the second research question in this study on the alignment of instructor expectations with actual course content, the extent of a teacher's participation in this process is limited to providing the course materials unless specific feedback is requested. This process is largely utilized by administrators determining program level changes, especially at the state level. As with the two previous methods, trained participants are used to determine the alignment of content, expectations for student performance, and instructional content. Including measure of instructional content makes this method much different than the other two methods previously discussed. The process by which teachers provide input on instructional content is through the use of surveys on what is being taught. The assessments evaluated in the method are statewide assessments, although the use of content validity methods as one portion of the process is addressed by the authors (Porter & Smithson, 2001). In 2001, Blank, Porter, and Smithson used the Surveys of Enacted Curriculum method to evaluate the degree of alignment between instruction and assessments across six states. Results from the study showed the alignment of instruction and assessment within a state was not different than the alignment across states. The results were not as expected since Porter defined in his 2006 work that "the alignment index between a state test and that state's content standards should be higher than the alignment of that state's test to other standards."

While all three methods have been discussed in the literature, all three methods have not been applied to a single study to provide an accurate comparison between them. In their 2002 work, Martone and Sireci summarized the three methods as follows:

> The Webb approach provides the most detailed quantative results…The Achieve methodology builds on the Webb methodology, with the addition of the source and level of challenge dimensions…The Surveys of Enacted Curriculum (sic) methodology is the only method that considers the instructional piece of the educational process…However, this approach does not probe as deeply as the other two into the quality of the alignment. (Martone & Sireci, 2002, p. 1351)

The literature provides reference to many large-scale assessments being conducted on alignment at the state and even national levels. The literature does address some work at the local levels, but the main work has been limited to using portfolios with in-service teacher education (Biggs, 1996), improving standardized test scores (Tallarico, 1984), and overcoming initial aptitude differences in community college students (Fahey, 1986). Studies related to using actual course content in the form of homework, exam, and quiz problems, a q-matrix tool for addressing alignment, or even course grades of prerequisite courses has not been found in the literature. In addition, the work on alignment in the literature refers mainly to policy implications and decision-making at the K-12 level. The development of a comprehensive measurement strategy to evaluate alignment in college curricula is not prevalent in the literature but is a part of this study.

Alignment between content in courses

Importance of proper alignment between courses and the magnitude of difference that can be made when attention is directed to it can be shown by evaluating the work completed by faculty in the College of Engineering at TAMU related to MATH 150, which is a pre-calculus course. All degree programs in the College of Engineering at TAMU have a required first mathematics course of Engineering Mathematics I. Even as a prerequisite, this course serves as an important point when discussing first-year mathematics skills for engineering students. In 2002, 14% of first-year engineering students reported a need for remediation in mathematics (Science & Engineering

Indicators, 2004). The percentage of engineering students varies widely depending on the mission of the particular institution (Moore & Orengo-Aviles, 1999).

However, enrollment in a pre-calculus mathematics class is not working as well as anticipated. Students nationwide who start in pre-calculus persist in engineering at lower rates than students who start in calculus (Herzog, 2005). Statistics collected by personnel in the mathematics department at TAMU as well as in the engineering department state that 76% of engineering students who start in Engineering Mathematics I at TAMU are still in engineering one year later, as compared with 60% of students who start in Pre-calculus. In addition, the statistics gathered show that only 46% of all new under-prepared students who took developmental courses gained college-readiness (readiness to take the first required course in college) in their first year at TAMU.

Informal interviews with students suggested that part of the problem was that students were not taking the pre-calculus math course seriously—they felt that it was a form of “punishment” since they were enrolled in engineering but were not allowed to take any engineering courses. Furthermore, students felt that the pre-calculus class offered did not meet their needs in preparing students for Calculus I. In other words, rather than treating it as a preparatory course for Calculus I, (i.e., forward looking), the course, as currently structured, had a feeling of remedial math, (backward looking). In addition, informal interviews with engineering faculty highlighted the importance of pre-calculus mathematics in most engineering courses.

These observations led to a strategy of developing an “engineering pre-calculus course” that is specifically tuned to the needs of engineering students that simultaneously helps in the preparation for calculus in a "forward" looking manner and highlights vital roles played by pre-calculus mathematics in real-world engineering tasks. The new engineering pre-calculus course developed was founded on three premises: (1) most problems asked in calculus are actually algebra problems; (2) most calculus problems can be reformulated as algebra problems; and (3) apart from their utility in calculus, problems in algebra have tremendous impact in engineering.

Results from other initiatives suggest that an engineering emphasis in mathematical preparation can improve performance and retention of engineering students. At Wright State University, engineering faculty members have developed an engineering course that provides the required elements of mathematics for many core engineering courses (Klingbeil, Mercer, Rattan, Raymer, & Reynolds, 2006). In the Wright State Model, engineering students take this new engineering course, which is intended for calculus-ready students, during their first semester. Then, they can take several engineering courses while they concurrently complete a traditional four-course mathematics sequence in calculus and differential equations. In its first iteration, over 80% of the students successfully completed the new engineering course (earning a grade of 'A', 'B', or 'C'), compared with around 42% of the students who, based on performance in prior years, successfully completed the first-year calculus sequence at Wright State (Klingbeil et al., 2006). At Boise State University, engineering faculty members created a preparatory engineering course that students can take concurrently with their pre-calculus course. Their preliminary results indicate that students who take the engineering course concurrently with the pre-calculus course achieve higher success rates in pre-calculus than those who do not (Hampikian, Gardner, Moll, Pyke, & Schrader, 2006). At Wayne State University, faculty members included a course on introduction to the engineering profession, together with courses in pre-calculus, chemistry, physics, and English, in a one-year bridge program (Grimm, 2005). These examples demonstrate that engineering students' success can be enhanced by helping them to build stronger connections between engineering and the study of mathematics, including pre-calculus.

In all these cases, the engineering content was either developed for calculus ready students or was a separate course that is taken concurrently with the pre-calculus course. On the other hand, given the credit restrictions at TAMU, the model proposed by TAMU was a new "pre-calculus engineering class" that combines pre-calculus mathematics with engineering content. Integration of engineering content into the pre-calculus class was achieved through the use of model-eliciting activities (MEAs), which are activities in which students develop a process that could apply to individual problems instead of solving a specific problem. In an MEA, students are offered a description of a phenomenon and asked to propose a mathematical model to capture some aspect of the phenomenon; MEAs have been developed and used with first-year engineering students at Purdue University with good results (Diefes-Dux, Moore, Zawojewski, Imbrie, & Follman, 2004; Moore & Diefes-Dux, 2004).

In addition to introducing MEAs in the class to reinforce engineering concepts, changes were made to the actual skills taught between a typical pre-calculus course and the engineering pre-calculus course in an effort to closer align with topics needed for engineering. For example, there are several topics that are not covered in the engineering pre-calculus course but are covered in the typical pre-calculus course, such as real numbers, complex numbers, and rectangular coordinate systems. Evaluating the scores of most students entering the engineering pre-calculus course, students typically had low scores on the mathematics placement exam used to determine their entering mathematics course in which to enroll, but no student typically received a score of zero. Therefore, many students lack the knowledge of higher level skills and practice of these skills, and they are just not used to applying them. These topics were intentionally left out of the curriculum of the engineering pre-calculus course to avoid the misconception of the course being classified as a remedial class.

The number of weeks listed on each course syllabus or weekly schedule was compared for each topic to determine the amount of time spent covering each item as shown in Figure 6. As detailed in the figure, approximately two and a half weeks extra is devoted to trigonometry and functions in the engineering pre-calculus course over the typical pre-calculus course. In addition, the MEAs are another means to reinforce the engineering applications of the skills taught.

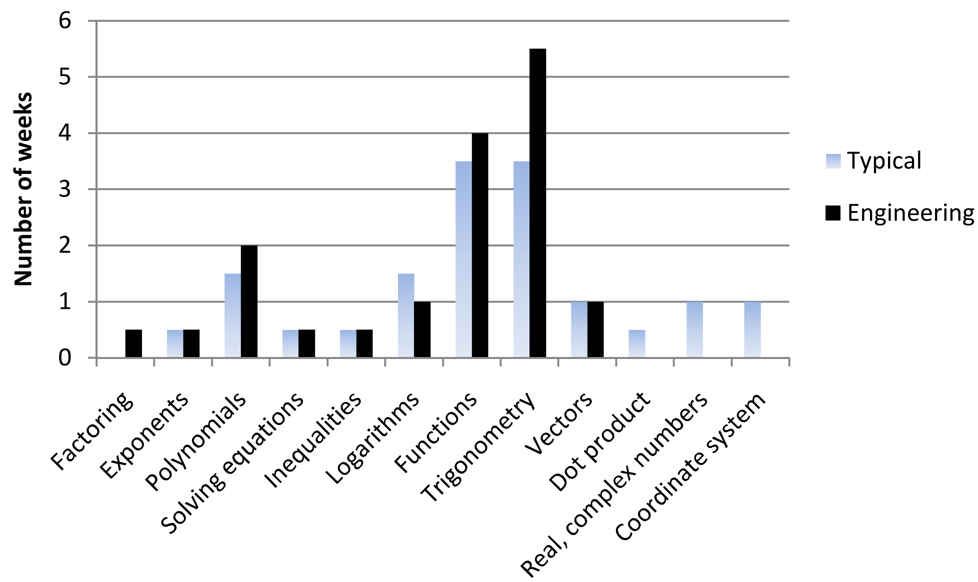


Figure 6. Comparison of topics taught in typical pre-calculus course versus new engineering pre-calculus course.

Results from new alignment of course content and introduction of MEAs

Overall, the central question to be addressed is to what extent participation in the new engineering pre-calculus course as preparation for the first-year engineering curriculum aided the performance and retention of students when compared to the performance and retention of other students who took a regular pre-calculus course in prior years. This new course has been offered each fall and spring semester since fall of 2008 with approximately 110 TAMU engineering students completing the course through fall of 2010. Overall, the students have shown a dramatic improvement in their initial mathematics placement exam when taken again at the end of the semester with scores rising from an average of 13% at the beginning of the course to 87% at the completion of the course. Results from 52 students completing the course in fall of 2010 have not been compiled yet. However, 50 students were followed through two years of pre-calculus and into the calculus sequence, and their performance was compared with that of a regular pre-calculus course taught at TAMU, for which 10 year's worth of data on 2,705 students was available. The results are quite remarkable. The percentage of students who took this course and then continued on to pass calculus jumped from 47% for regular pre-calculus students to 61% for engineering pre-calculus students. The grade distribution of those who passed the engineering pre-calculus was remarkably consistent with the usual pre-calculus courses except for those who got a grade of B. There was, among those who took the engineering pre-calculus course and earned a grade of C, a larger percentage (33%) who received a grade of B in the subsequent math class as compared to the regular pre-calculus classes (17%). This is a very encouraging sign since this is an indicator that the pre-calculus as taught by this new method might be helping students who earned a grade of C in the engineering pre-calculus course by possibly motivating them and enabling them to do better in calculus. Studies at TAMU for the last 10 years show that getting a grade of B or higher in the first calculus course is vital to subsequent performance in mathematics courses. Findings show that an approach based on a positive looking engineering pre-calculus course tuned to prepare students for calculus is making an impact. By properly aligning the curriculum, in addition to incorporating related activities, such as MEAs, significant gains in follow-on courses was achieved.

Summary

As shown by the preceding literature review, there have been extensive efforts to evaluate the preparation with respect to mathematics and physics of engineering students for their post-first-year engineering curricula and reform first-year mathematics courses. However, the research does not provide explicit articulation of what engineering faculty members who teach core engineering courses that require first-year mathematics or physics mechanics as prerequisite knowledge think their students should know and be able to do at the beginning of one of these courses. Nor does the research shed light on how well students satisfy expectations of their faculty members. In addition, the researcher could find no studies that addressed either expectations for mathematical and physics mechanics knowledge and skills for specific core engineering courses or the degree to which engineering students beginning a core engineering course satisfied these expectations. While the efforts detailed in this section provided students with an excellent mathematical and physics foundation and solid engineering applications, they did not result in any systematic research efforts that documented deficiencies/strengths in mathematics or physics preparation for sophomore and/or junior-level engineering courses. In summary, while the researcher found many studies related to mathematics and physics skills, engineering preparation, and importance of alignment, none of the work directly answered the questions posed in this study.

SKILLS FROM FIRST-YEAR COURSES – RESEARCH QUESTION #1

The first research question in this study looks at the skills that engineering faculty members think students need from their first-year mathematics and physics mechanics courses. Anecdotally, engineering faculty members complain that students taking sophomore engineering science courses are not prepared with respect to mathematics and physics. In response, faculty members from mathematics and/or physics contend their courses have adequately prepared students in terms of needed knowledge and skills in their respective subjects. Many times engineering faculty members will only describe in very general terms the lack of preparation they feel students have, such as needing better mathematics or physics skills. Sometimes specifics are provided by the faculty members, but they are lost in the translation between disciplines. A part of the reason is that while both groups use the same terminology, they mean different things. As an example when physics instructors discuss vectors, they are referring to the "directed line segments" following trigonometric rules, whereas the mathematics instructors mean orders sequence of number that satisfy certain algebraic rules. Lost in the discussion is the ability of the student to seamlessly go back and forth between the two representations depending upon the problem at hand. The purpose of this research question was to identify the specific mathematics and physics mechanics skills engineering faculty members felt were useful for a sophomore-level statics and dynamics course. As part of this process, these skills would then be incorporated into new instruments designed to test students' knowledge of these skills. That way a baseline could be established on the amount of knowledge students have about these skills.

Methodology

To determine expectations of engineering faculty for the knowledge of mathematics and physics mechanics and skill in applying this knowledge that students in their course should have to be successful, the core, required, sophomore-level statics and dynamics course was used. Engineering faculty members from senior-level down to junior-level who teach this course were asked to provide specific first-year mathematics and physics mechanics knowledge and skills students should have mastered prior to enrolling in the course in the form of example problems that illustrated these skills. The researcher thought that asking for problems would be more helpful than asking for a list of topics and getting back a very long list from which it would be difficult to then assess student knowledge of these topics. Also, the problems would illustrate contexts into which students would be expected to transfer their mathematical and physics mechanics knowledge. Sometimes students may know the mathematical or physics concept or procedures, but they may not recognize that the problem requires what they know because the context of problem is unfamiliar or different from the context in which they learned the concept or procedure. Asking for five problems focused the faculty members on their specific expectations for student mathematical or physics mechanics knowledge and skills instead of providing a laundry list of expectations.

After receiving sample problems from five faculty members, the questions were analyzed to develop a set of learning outcomes that would reflect the knowledge and skills required to solve the problems, which would then be compared with two faculty members independent from the group of statics and dynamics faculty members providing problems. When the problems were submitted, there was significant overlap among the problems, with respect to the knowledge and skills expected. In addition, while faculty members provided several problems related to mathematics skills necessary for the course, fewer problems related to physics mechanics skills were submitted. In fact, several of the physics mechanics problems submitted were mathematics-related skills and not directly physics mechanics skills. An example of one of these problems is shown in Figure 7. The resulting set of mathematics and physics mechanics topics for which engineering faculty members expected student mastery determined from the list of problems submitted are listed in Table 5.

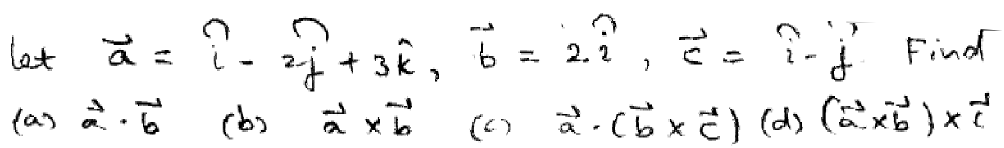


Figure 7. Example physics mechanics problem submitted by engineering faculty member with mathematics-related skills instead of physics mechanics skills.

Table 5

First-year Mathematics and Physics Mechanics Topics Determined by Engineering Faculty

Mathematics Topics
Projection
Vector Components (2-D)
Derivative (using Chain Rule)
Second Derivative
Area Under a Curve
Integration (using Substitution)
Cross Product (definition)
Simultaneous Equations

Physics Topics
Free Body Diagram
Linear Momentum
Newton's Second Law
Newton's Third Law
Conservation of Energy

Using the set of topics and the original problems to determine the expectations of the engineering faculty members, the researcher created a 10-question, alpha version of a mathematics instrument and a 16-question, alpha version of a physics instrument to assess student abilities with respect to expectations. Several of the problems came directly from the MBT since faculty had provided a limited set of direct physics mechanics-related questions. The instrument was then reviewed by two of the engineering faculty members who submitted problems, and they agreed the instrument contained the skills necessary to be successful in the course. The questions from the instruments were also given to two undergraduate students to work and help refine the answer selections with potential common errors in calculations. The researcher thought it would take about 30 minutes for students to complete, and the engineering faculty member who taught the Statics and Dynamics course during the summer of 2010 was willing to allocate 30 minutes of class time to administer the instrument. Students were not allowed to use their calculators, and each of the questions on the two instruments was multiple choice. For each question, students were given space to work the problems. The fifth answer on each question on the mathematics instrument was intentionally left as ”none of the above” to further refine the answer selections on the instrument.

Method for analyzing results

Once results from each instrument are obtained, the item difficulty index will be used to measure the difficulty of each test question. Calculated by taking the ratio of the number of correct responses on each question to the total number of students who attempted the particular question, the index ranges from 0 to 1. A larger value for the index signifies that a higher percentage of respondents answered the question correctly, so the item was easier for this population. If the index value is 1, this signifies that all of the participants answered the question correctly. If the index value is 0, no one was able to answer the question correctly. Therefore, a value of 0 or 1 does not discriminate very well. While there are a number of different possible criteria for acceptable values of the item difficulty index, a widely adopted criterion requires the value to be between 0.30 and 0.70 within+/-.20 of the optimum value of 0.50 (Craighead & Nemeroff, 2000). The item difficulty index was selected to provide an indication of the difficulty level of the questions for further refinement purposes.

Reliability and validity

To obtain a sense of the variability of the data from the mathematics and physics instruments, reliability and validity of each of the instruments will be determined. Reliability provides information on the extent the data is obtained in a systematic, repeatable manner (Walsh & Betz, 2001). Validity, on the other hand, provides information on whether or not the instrument assesses the content desired (Anastasi, 1982).

Reliability

While there are various forms of reliability that can be conducted, some methods were not conducive to this study. For example, each instrument was only administered once within the semester, so test-retest reliability was not appropriate. In addition, there was only one version of each instrument, so alternate forms reliability was not possible. Internal consistency reliability, on the other hand, involves a single administration of the instrument. This form of reliability, also known as inter-item consistency, compares the average correlation among the items on the instrument. If there is a lack of correlation among the items, the reliability value will be low as this potentially indicates the items are not measuring a consistent attribute. Anastasi (1982) details that:

> The more homogeneous the domain, the higher the inter-item (sic) consistency. For example, if one test includes only multiplication items, while another comprises addition, subtraction, multiplication, and division items the former test will probably show more inter-item (sic) consistency than the latter. In the latter, more heterogeneous test, one examinee may perform better in subtraction than in any of the other arithmetic operations" (Anastasi, 1982, p. 115)

While the inter-item consistency was determined based on the instruments as a whole, further review could determine the consistencies between sub-section of questions if desired. Cronbach's alpha, a measurement of internal consistency reliability was used to determine the reliability for each of the instruments. Comparisons were made using the widely accepted criterion values of index values greater than 0.7 being considered reliable (Thorndike, 1997). Another form of reliability, which can be considered, is split-half reliability. This form of reliability is similar to alternate forms of reliability, but instead of having two versions of the instrument, the instrument is divided into two halves with the relationship between the two halves then being examined (Anastasi, 1982). This type of reliability determines if the items are measuring a consistent attribute by evaluating the scores on one half of the instrument and comparing them to the scores on the other half.

Validity

The degree in which an instrument measures the content it is designed to measure is described by content validity (Sireci, 1998). To assist in verifying content validity, faculty members and a graduate student not associated with the statics and dynamics course were asked to evaluate the instruments to determine the skills measured by each of the questions. To describe the relation of test questions to skills, the item-objective congruence index was used, which uses content specialists, or reviewers, to determine how well each question measures a certain objective (Crocker, Miller, & Franks, 1989; Rovinelli & Hambleton, 1976; Turner & Carlson, 2003). Developed by Rovinelli and Hambleton (1976), item-objective congruence is based on previous work by Hemphill and Westie (1950) who had determined the index of homogeneity. While similar in method, the main advantage to item-objective congruence formula was the fact that the index value computed was no longer a function of the number of content specialists and objectives. Therefore, easily interpreting the index across studies was now possible (Rovinelli & Hambleton, 1976). In their 1986 work, Crocker and Algina provided a simplified version of the index-objective congruence index formula, and it is shown in Equation 1.

$$I_{ik} = \frac{N}{2N-2}(\mu_k - \mu) \qquad (1)$$

where I_{ik} is the item-objective congruence for item *i* on objective *k*, *N* is the number of objectives, μ_k is the content specialists' mean rating of item *i* on objective *k*, and μ is the content specialists' mean rating of item *i* on all objectives (Crocker and Algina, 1986).

To determine how well each question measures a particular skill, content specialists rate each item according to the degree in which the question pertains to the particular skill. The three possible ratings are 1, 0, and -1. The corresponding definitions of each rating are: 1, the item measures the topic area; 0, the item is an unclear measure of the topic area; and -1, the item does not measure the topic area. For example, if a content specialist determines question #1 measured integration by substitution and question #2 had an unclear measure of three-dimensional vectors, it would be represented by the values shown in Table 6. Note that a value of -1 is included for each item in which the skill was clearly not measured.

Table 6

Example of Ratings Used by Content Specialists in Item-Objective Congruence

	Vectors (3-D)	Integration (Substitution)
Question 1	-1	1
Question 2	0	-1

This index value is based on the assumption that a test question corresponds to one and only one objective (Crocker, Miller, & Franks, 1989). When this occurs, the item-objective congruence index value calculated will be +1. If the item is matched to multiple items or not clearly regarded as being related to the particular skill or objective, the index value will be less than +1.

In this study, four content specialists reviewed each of the items on the instruments and rated them according to the skills they believe the items were measuring. The content specialists for the mathematics instrument were a mathematics faculty member, two engineering faculty members not associated with the study, and a graduate student in engineering also not associated with the study. Content specialists for the physics instrument included a physics faculty member, two engineering faculty members not associated with the study, and a graduate student in engineering also not associated with the study. The assessment forms provided to the content specialists are provided in Appendix B.

Analysis

Administering the alpha instruments

The physics instrument was administered to 41 sophomore-level engineering majors on the first day of class in the summer of 2010 semester with 37 sophomore-level engineering majors in the course completing the mathematics instrument on the second day of class in that same semester.

With such a small number of participants, responses could be evaluated for common mistakes to help in the revision process. While the work submitted was anonymous, an interested student could include an email address in order to receive an individualized personal summary. A detailed summary of the results on the topics was sent to the faculty member. Instead of simply including percent correct and incorrect or the numbers broken down by each item, the topics were summarized, and input was provided on where students were generally strong and where students failed to have an understanding. Administering the alpha instruments provided an indication of student performance in terms of the expected concepts and skills (see Table 7). The resulting set of first-year mathematics and physics mechanics topics for which engineering faculty members expected student mastery are denoted by an asterisk in the table. A problem on friction was included even though it has not been specified as a needed skill to determine the performance of students on a skill used in the statics and dynamics course.

Table 7

Student Performance in Terms of Expected Mathematics and Physics Mechanics Concepts and Skills on Alpha Versions of Instruments

Mathematics Topic	*Number of Questions on the Instrument Assessing this Topic*	*Percentage of Students that got all of these Questions Correct*
Projection*	1	15
Vector Components (2-D)*	1	77
Derivative (using Chain Rule)*	2	27
Second Derivative*	1	62
Area Under a Curve*	1	41
Integration (using Substitution)*	2	0
Cross Product (definition)*	1	74
Simultaneous Equations*	1	65

Physics Topic	*Number of Questions on the Instrument Assessing this Topic*	*Percentage of Students that got all of these Questions Correct*
Free Body Diagram*	4	22
Linear Momentum*	4	29
Newton's Second Law*	5	5
Newton's Third Law*	1	45
Friction	1	93
Conservation of Energy*	1	44

Note: First-year mathematics and physics mechanics topics determined by engineering faculty members are denoted with an *.

After results from the alpha versions of the instruments were analyzed, the instruments were then revised. In addition, item responses and work shown from students were evaluated to determine if students properly understood what the question asked of them, how the responses compared to expectations, and what appropriate answers should be included in the next prototype.

As will be detailed in the next section, Faculty Expectations – Research Question #2, homework and exam problems from the statics and dynamics course were dissected to gauge the knowledge and skills in mathematics and physics mechanics that were needed to answer the questions. Analyzing homework and exam problems allowed the analysis to be based on actual evidence from an offering of the course instead of perceptions faculty members might have about the skills they wanted. The list of knowledge and skills in mathematics and physics mechanics was then compared to the original list (Shryock, Srinivasa, & Froyd, 2011).

Administering the beta instruments

In fall of 2010, a beta (second) version of the instrument was given to three sections of the Statics and Dynamics course whose instructors would allow class time to administer the instrument. Given that students randomly select a section of the course in which to register and most names of instructors are not added until after students have registered for the course, there is every reason to believe this was a good, representative sample of students completing a statics and dynamics course. There were 271 students who completed the mathematics instrument and 264 students that completed the physics instrument from the three Mechanical Engineering sections. In addition, the instruments were administered to students in the Aerospace Engineering Statics and Aerospace Engineering Dynamics courses. As previously mentioned, the first Aerospace Engineering course is equivalent to the first half of Mechanical Engineering's Statics and Dynamics course, while the second Aerospace Engineering course is equivalent to the second half of Mechanical Engineering's course. There is only section offered for the Aerospace Engineering versions of statics and dynamics within a given semester. Including the Aerospace Engineering students, the total number of students completing the mathematics instrument was 368 students with 362 students completing the physics instrument. As with the alpha version, the physics instrument was given on the first day of class in the fall semester in each of the sections, and the mathematics instrument was given on the second day of class in the semester.

While the plan had been to administer the instrument with scantrons, they were not used for fear of time limitations in the classroom. Therefore, each question was multiple-choice, but students were allowed to denote their answers on each instrument. Students were given 20 minutes to complete the instrument and again were not allowed to use their calculators. Decreasing the amount of class time needed to administer the instruments seemed to make a difference in the willingness of faculty members to allow class time for the instrument to be administered. For example, while the faculty member who had allowed time in the summer to administer the alpha instruments saw value in the results he had obtained, he was hesitant to allow basically a class period of time, 60 minutes for the two instruments, to the administration of both instruments in the fall. By having each instrument only take 20 minutes of each class time, he felt this would still allow him time to cover material on the days when the instruments were administered. Other faculty members were comfortable as well with only having 20 minutes of each class period being devoted to the administration of the instrument. Once refinements to the instruments were complete, the beta version of the mathematics instrument had 9 questions, and the physics instrument consisted of 17 questions. Administering the beta instruments provided an indication of student performance in terms of the expected concepts and skills (see Table 8).

Table 8

Student Performance in Terms of Expected Mathematics and Physics Mechanics Concepts and Skills on Beta Versions of Instruments

Mathematics Topic	*Number of Questions on the Instrument Assessing this Topic*	*Percentage of Students that got all of these Questions Correct*
Vector Components (2-D)	1	72
Vector Components (3-D)	1	20
Derivative (using Chain Rule)	2	42
Second Derivative	1	78
Area Under a Curve	1	58
Integration (using Substitution)	1	33
Simultaneous Equations	2	25
Physics Topic	*Number of Questions on the Instrument Assessing this Topic*	*Percentage of Students that got all of these Questions Correct*
Free Body Diagram	7	2
Friction	1	91
Newton’s Second Law	8	8
Newton’s Third Law	1	72

As with the alpha versions, a detailed summary of the results on the topics was sent individually to each faculty member with specific details included on their students. Each student was given the opportunity to receive an individualized personal summary by email.

Results

Once the instruments were administered, results from both the alpha and beta versions were evaluated in more detail. Evaluation of item difficulty index, overall results, and results on individual questions were addressed in greater detail.

Mathematics instrument – alpha instrument

As viewed in Figure 8, the mean difficulty index of the responses in the alpha version of the mathematics instrument given in summer of 2010 is 0.50. Simply because responses to a question fall outside of the optimum range of 0.30 to 0.70 does not nullify the question, but it does cause concern for closer inspection. The three questions that show warrant for further review are item #1 with an index value of 0.15, item #8 with an index value of 0.09, and item #4 with an index value of 0.94. Table 9 lists the three questions on the opposing ends of the histogram.

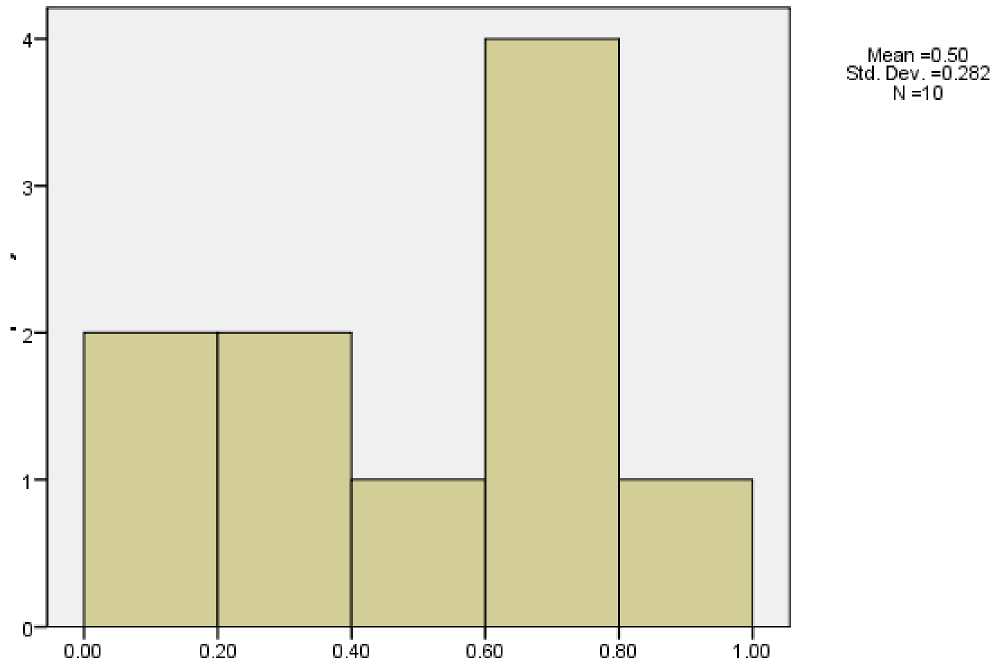


Figure 8. The number of items versus the item difficulty index for alpha mathematics instrument.

Table 9

Questions from Alpha Version of Mathematics Instrument with Highest and Lowest Item Difficulty Index Value

Question #	Item Difficulty Index Value	Question Statement	Details
8	0.09	Find an equivalent integral using the cosine or sine function. $\int \sqrt{16 - x^2}\ dx$	Students had trouble solving this problem. 50% of the students answered $4\int \cos^2 \theta\ d\theta$, while 30% answered $4\int \cos \theta\ d\theta$.
1	0.15	Two vectors are given: $\vec{a} = (-\vec{\imath} + 2\vec{\jmath})\, ft$ and $\vec{b} = (8\vec{\imath} + 6\vec{k})\, ft$ What is the projection of $\vec{a}$ onto the direction of $\vec{b}$?	Each of the answer selections had a large number of responses, which signified that students did not know how to solve this problem. There was not a particular common error.
4	0.94	Find the derivative of the following function with respect to *t*. $\sin(2t^2 + 6)$	Students overwhelmingly answered this question correctly. The largest error made by 9% of the students who answered $4\, t \sin(2\, t^2 + 6)$.

Mathematics instrument – beta instrument

After minor changes to the alpha version of the instrument, the following results were found in the administration of the second version of the instrument. Figure 9 contains the item difficulty index for the items in the beta mathematics instrument. The range of index values for item difficulty index was pretty uniform with the lowest value obtained on item #4 with 0.24 and the highest value on item #3 with 0.81. Table 10 lists the two questions on the opposing ends of the histogram.

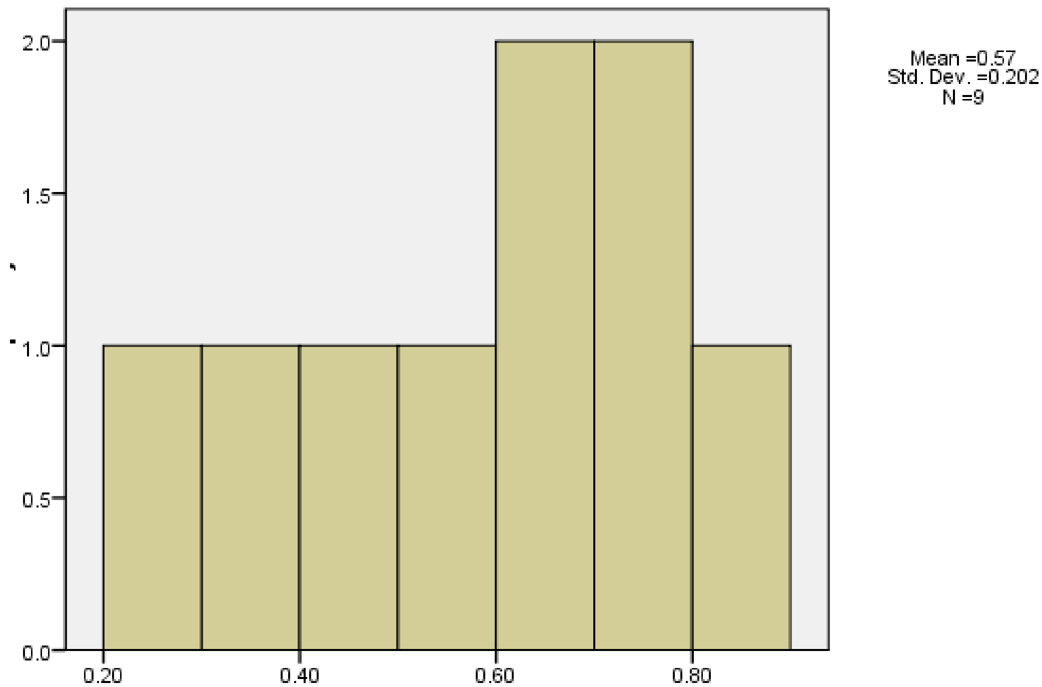


Figure 9. The number of items versus the item difficulty index for beta mathematics instrument.

Table 10

Questions from Beta Version of Mathematics Instrument with Highest and Lowest Item Difficulty Index Value

Question #	Item Difficulty Index Value	Question Statement	Details
4	0.24	A heavy sign (not drawn to scale) is supported by the following configuration. What is the $\vec{\imath}$ component of the force in cable BC where $\vec{\imath}$ is in the positive x direction? Assume the F_{BC} is a known force equal to 500 N, and the force acts along its axis. (Figure 10 displays the sign configuration.)	Each of the answer selections had a large number of responses, which signified that students did not know how to solve this problem. There was not a particular common error.
3	0.81	A point *P* travels on a path given by $x(t) = -\frac{1}{6}t^3$. The term x is in meters, and t is in seconds. Find the acceleration.	Most students answered the problem correctly. There were two common errors. 11% of students differentiated the position equation once to find acceleration. 7% of students integrated the position equation twice to find acceleration.

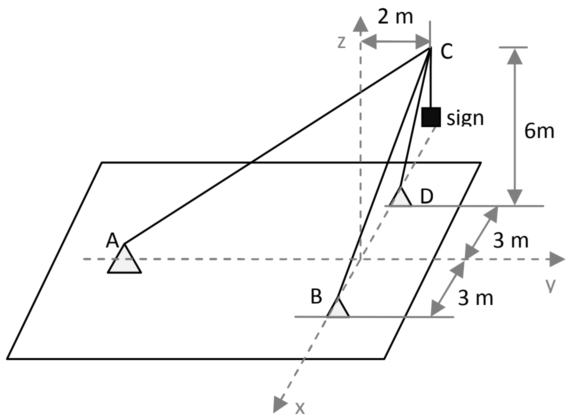


Figure 10. Sign configuration from question #4 on beta mathematics instrument.

The three questions from the alpha version that were investigated further were changed on the beta version. For example, after further review of the actual homework and exam questions, projection and integrals using trigonometry substitution were removed from the beta instrument as they had not been specific topics asked of the students. Question #4, which involved derivatives using chain rule, was adjusted slightly. A variable was added, and the new question is shown in Figure 11. Even with the adjustment, students overwhelmingly still answered the question correctly.

Find the derivative of the following function with respect to *x*: $\cos(x\,t^2 + 6)$

Figure 11. Revised question on derivative using chain rule from beta mathematics instrument.

Three areas on the mathematics beta instrument had less than 50% average of correct answers identified by students, an outcome which causes concern. The lowest average received was on three-dimensional vector components in question #4, which was discussed above in Table 10. Students also had a difficult time with integration by substitution. As with the problem on vector components, all of the answer choices received nearly the same weight, which signifies no clear indication on how to solve the problem. The third area causing concern was with two simultaneous equations where one equation contained a parameter. The problem statement specifically stated to solve for x and y in terms of a. Problematic is the fact that 25% of students selected an answer choice solving for x and a. Another 16% of students answered that the problem could not be solved because there are three unknowns and only two equations.

The average response from 368 students on the beta version of the instrument is 54%. This value was considered much lower than the targeted 75% number. Looking at the results, four students scored a perfect score with two students answering each question on the instrument incorrectly.

Physics instrument – alpha instrument

As viewed in Figure 12, the mean difficulty index of the responses in the alpha version of the physics instrument given in summer of 2010 is 0.52. Simply because responses to a question fall outside of the optimum range of 0.30 to 0.70 does not nullify the question, but it does cause concern for closer inspection. The two questions that show warrant further review are item #8 with an index value of 0.25 and item #2 with an index value of 0.93. Table 11 lists the two questions on the opposing ends of the histogram.

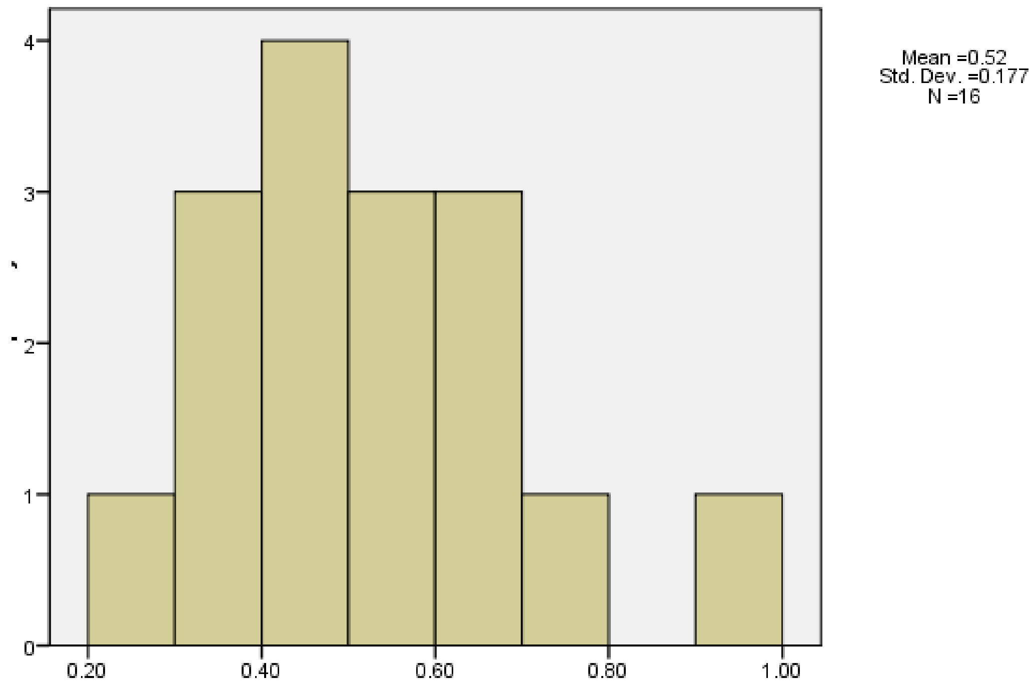


Figure 12. The number of items versus the item difficulty index for alpha physics instrument.

Table 11

Questions from Alpha Version of Physics Instrument with Highest and Lowest Item Difficulty Index Value

Question #	Item Difficulty Index Value	Question Statement	Details
8	0.25	A small metal cylinder rests on a circular turntable, rotating at a constant speed as illustrated in the diagram below. Which of the following sets of vectors best describes the velocity, acceleration, and net force acting on the cylinder at the point indicated in the diagram? (Figure 13 displays the cylinder on the circular turntable.)	Each of the answer selections had a large number of responses, which signified that students did not know how to solve this problem. There was not a particular common error.
2	0.93	A person pulls a block across a rough horizontal surface at a constant speed by applying a force F. The arrows in the diagram correctly indicate the directions, but not necessarily the magnitudes of the various forces on the block. Which of the following correctly describes the friction force on the block? (Figure 14 displays the configuration detailed.)	Most students answered the problem correctly. There were two common errors. 5% of students answered the friction force has the same line of action as the applied force F but in the opposite direction because every force on a free body diagram should have an equal and opposite force shown. 2% of students answered there was not a friction force because the block is moving at a constant speed.

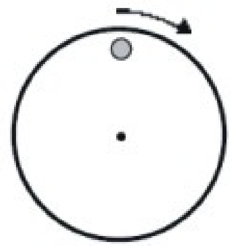


Figure 13. Cylinder on a circular turntable from question #8 on alpha physics instrument.

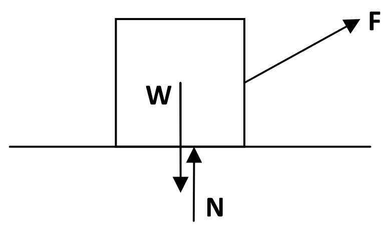


Figure 14. Block being pulled across a rough surface from question #2 on alpha physics instrument.

Physics instrument – beta instrument

After changes to the alpha version of the instrument, the following results were found in the administration of the second version of the instrument. Figure 15 contains the item difficulty index for the items in the beta physics instrument. The three questions that show warrant further review are item #13 with an index value of 0.11, item #2 with an index value of 0.91, item #6 with an index value of 0.83, and item #11 with an index value of 0.80. Overall, items on the beta version were more difficult than items on the alpha version. Table 12 lists the three questions on the opposing ends of the histogram.

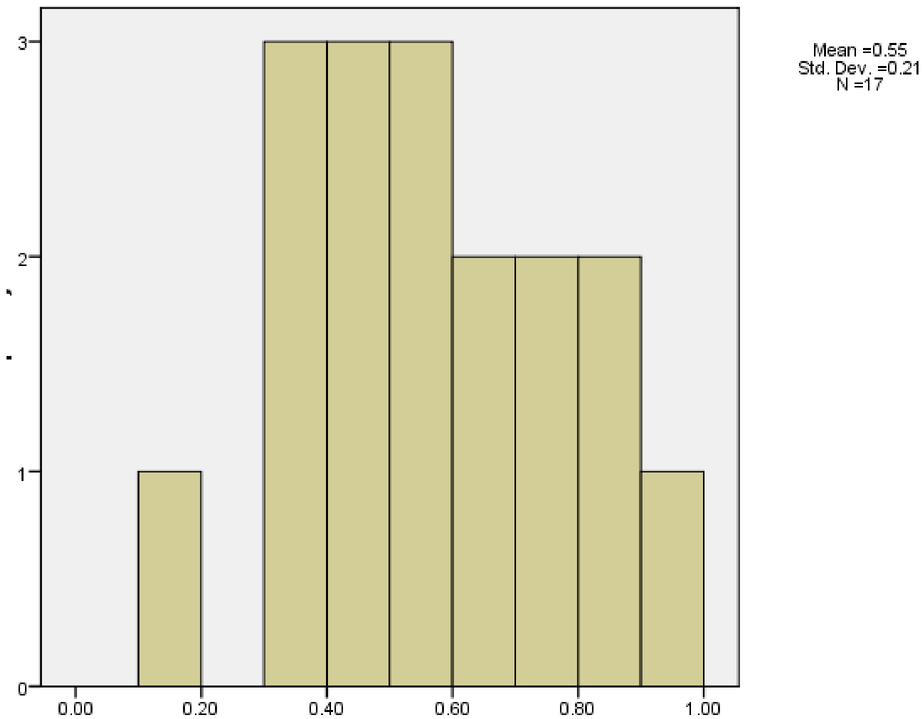


Figure 15. The number of items versus the item difficulty index for beta physics instrument.

Table 12

Questions from Beta Version of Physics Instrument with Highest and Lowest Item Difficulty Index Value

Question #	Item Difficulty Index Value	Question Statement	Details
13	0.11	Different signs hang together outside a doctor's office. Each sign is denoted by a different letter. Each cable is labeled with a different number. Which is the most correct free-body diagram for the system containing signs B and D and the cable connecting them? (Figure 16 displays the sign configuration.)	60% of students included a force in between the two parts within the overall system. 29% of students solved for the value of the variable and put it on the FBD instead of leaving it in terms of T for example for a cable.
2	0.91	A person pulls a block across a rough horizontal surface at a constant speed by applying a force P. The arrows in the diagram correctly indicate the directions, but not necessarily the magnitudes of the various forces on the block. Select the most nearly correct answer from the options below to describe the friction force on the block. (Figure 17 displays the configuration detailed.)	Most students answered the problem correctly. In this version, the answer choices were changed slightly. There were two variations on the friction force moving to the left to see if students could correctly identify why the friction force moved to the left. 3% of students answered that the friction force moved to the left because friction acts in the opposite direction to the externally applied force (instead of correctly stating it is because it opposes the direction of motion). Another 3% of students answered the friction force has the same line of action as the applied force F but in the opposite direction because every force on a free

Table 12 continued

Question #	Item Difficulty Index Value	Question Statement	Details
2 cont			body diagram should have an equal and opposite force shown. 2% of students answered there was not a friction force because the block is moving at a constant speed.
6	0.83	A tennis ball moves such that its velocity as a function of time is described by the graph below. Which of the following graphs most accurately represents the ball's net force versus time association? (Figure 18 displays the graph detailed.)	Most students answered the problem correctly. The most common error made was by 11% of students who answered that the force versus time graph would be identical to the velocity versus time graph.
11	0.80	A crate containing two ornamental pieces, piece A and piece B, is picked up by an overhead crane. The cables holding the pieces are denoted by numbers 1 and 2. Each ornamental piece weighs 10 kg. If the pieces in the crate are moving upward at a constant speed of 3.0 m/s, how (if any) would the answer above in question #10 differ? (Question #10 asked when the pieces in the crate are not moving, what is the magnitude of force exerted on piece A by rope 2?) (Figure 19 displays the crate configuration for both questions.)	Most students answered the problem correctly. 14% of students selected the answer in #10 would be multiplied by 3 and then given in N. 3% of students answered it should be multiplied by $3^2$and then given in N. 2% of students selected the answer would be equal to 3 N, and a final 1% felt it would need to be divided by 3 and then given in N.

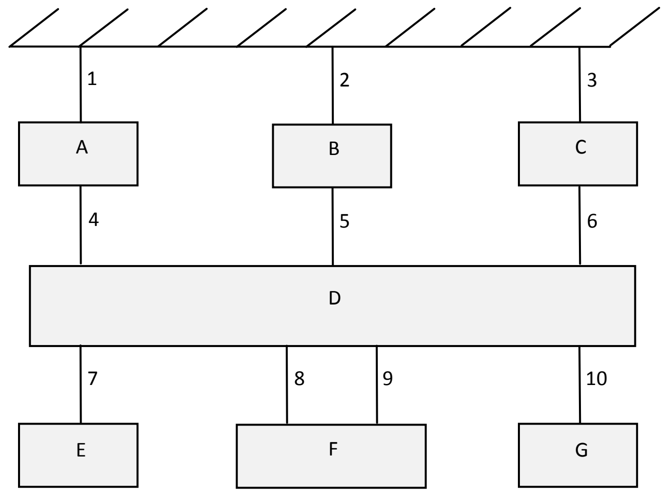


Figure 16. Sign configuration from question #13 on beta physics instrument.

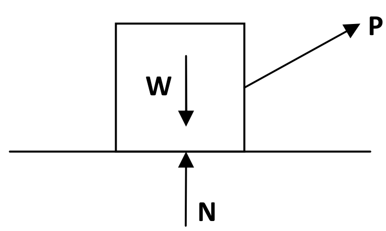


Figure 17. Block being pulled across a rough surface from question #2 on beta physics instrument.

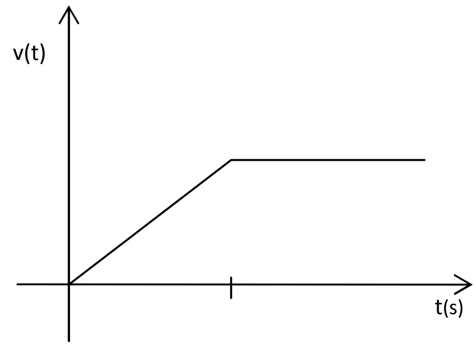


Figure 18. Graph from question #6 on beta physics instrument.

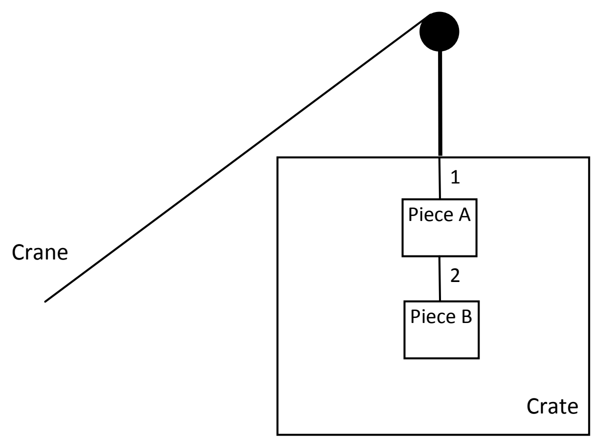


Figure 19. Crate configuration in question #11 on beta physics instrument.

The two questions from the alpha version of the physics instrument that were investigated further were changed on the beta version. Question #8 had asked students to select the correct direction for velocity, acceleration, and force on a cylinder. To gain further insight as to where students had trouble with circular motion and if they could accurately explain why they selected a particular direction, this problem was changed on the beta version. Students were required to not only select a direction for force on one question and acceleration on a second question but also distinguish between two possible reasons for the direction selected. This same format was used on the problem dealing with friction, which was question #2 on the alpha version. Even with the adjustment, students overwhelming still answered the question on friction correctly.

Three areas on the physics mechanics beta instrument had less than 50% average of correct answers identified by students, an outcome which causes concern. The lowest average received was on a stationary free-body diagram in question #13, which was discussed above in Table 12. Students also had a difficult time with the two circular motion problems on the instrument. Only 34% of students could correctly identify the direction of force of a child sitting on a merry-go-round turning clockwise at a constant speed. Problematic is the fact that 37% of students felt acceleration would be zero because the circular object is turning at a constant speed. The third area causing concern dealt with free-body diagrams including a free-fall condition. Approximately 17% of students selected an answer choice that included a normal force. Answer selections including a velocity vector was selected by 39% of students.

The average response from 362 students on the beta version of the instrument is 52%. This value was considered much lower than the targeted 75% number. Looking at the results, two students scored a perfect score with a student answering only two questions on the instrument correctly and earning a score of 12%.

Reliability and validity

Performing the calculations in SPSS, the beta mathematics instrument was determined not to be reliable (Cronbach’s alpha = .451). The beta physics instrument would be considered reliable (Cronbach's alpha = .745). Using split-half reliability in SPSS to determine if any further information could be provided, both instruments displayed lower values for reliability than calculated using internal consistency reliability (split-half coefficient for mathematics instrument = .388 and split-half coefficient for physics instrument = .642).

Item-objective index values were computed for each question based on the reviews of the four content specialists for each instrument. Table 13 provides the details of the review for the mathematics instrument, and Table 14 includes the results for the physics instrument.

Table 13

Item-Objective Congruence Index Values Measured by the Assessment of the Mathematics Instrument

		Objectives								
Questions	*Index of Item-Objective Congruence*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	1.00	1.00*	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
2	1.00	-1.00	-1.00	1.00*	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
3	1.00	-1.00	-1.00	-1.00	-1.00	1.00*	-1.00	-1.00	-1.00	-1.00
4	0.83	-0.25	0.75*	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
5	0.44	-1.00	-1.00	0.00	0.00*	-1.00	-1.00	-1.00	-1.00	-1.00
6	1.00	-1.00	-1.00	-1.00	-1.00	-1.00	1.00*	-1.00	-1.00	-1.00
7	0.61	1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.50*	-0.75	-1.00
8	0.97	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-0.50	1.00*
9	1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	1.00*	-1.00

Table 14

Item-Objective Congruence Index Values Measured by the Assessment of the Physics Instrument

		Objectives							
Questions	*Index of Item-Objective Congruence*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	0.86	1.00*	-1.00	-1.00	-1.00	-0.25	0.00	-1.00	-0.75
2	0.71	-0.25	-1.00	-1.00	-0.50	0.75*	-0.25	-1.00	-0.75
3	0.39	0.00*	-1.00	-1.00	-1.00	-0.75	0.00	-0.75	-1.00
4	0.54	0.25*	-1.00	-1.00	-1.00	-0.75	-0.25	-0.75	-1.00
5	0.38	-0.50	0.00*	-1.00	-1.00	-0.75	0.00	-1.00	-1.00
6	0.50	-1.00	-1.00	-1.00	-1.00	-1.00	0.00*	-1.00	-1.00
7	0.88	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.75*	-1.00
8	0.88	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	0.75*	-1.00
9	0.48	-0.50	-1.00	0.25*	-1.00	-0.25	-0.50	-1.00	-0.75
10	0.55	-1.00	-1.00	-1.00	0.50	-1.00	0.25	-1.00	0.50*
11	0.96	-0.50	-1.00	-1.00	-1.00	-1.00	1.00*	-1.00	-1.00
12	0.80	-1.00	-1.00	0.75*	-1.00	-1.00	-0.25	-1.00	-0.75
13	0.89	-1.00	-1.00	-1.00	1.00*	-1.00	0.00	-1.00	-0.50
14	0.84	-0.75	-1.00	-1.00	-1.00	-0.75	0.75*	-1.00	-1.00
15	0.86	-0.75	-1.00	-1.00	-1.00	-1.00	0.75*	-1.00	-1.00
16	0.84	-0.50	-1.00	-1.00	-1.00	-1.00	0.75*	-1.00	-1.00
17	0.86	-0.75	-1.00	-1.00	-1.00	-1.00	0.75*	-1.00	-1.00

While a common value for effectively meeting the criterion has not been established in the literature, Rovinelli and Hambleton (1976), suggested an index value of 0.5 be considered, which would correspond to one-half of the content specialists in full agreement of an item match and the other half unsure of the clarity of the match. Others in the field have instituted an index value of 0.75 to show acceptance, which would correspond to three of four content specialists in agreement, for example, (Turner& Carlson, 2003). The value of 0.5 seems to be a minimum accepted value in the literature. While questions with item-objective congruence index values below 0.5 do not necessarily need to be discarded, they do warrant further review to ensure they are measuring the intended skills. This review would be necessary for question #5 on the mathematics instrument and questions #3, 5, and 9 on the physics instrument.

Validity was also determined by correlating the scores from the beta instruments to the final grades in the course. Note: a limitation of this method is the fact that it is assumes the instrument adequately measures the intended skill. Further details would need to be verified for this, but it is beyond the scope of this study. This process was used to provide an indication of the affect of the scores earned on the instruments on final grades received in the course.

Correlation of scores on beta instruments and final grades

To provide some indication of the correlation of the scores from the mathematics instrument and physics instruments on the final grade earned by the student in a sophomore-level statics and dynamics course, the corresponding variables were plotted in Microsoft Excel. Figure 20 displays the average score received on the mathematics instrument versus the final grade earned in the statics and dynamics course. As shown, there seems to be a linear relationship between the instrument and the final grade, and it appears as the mathematics instrument score increases, the final grade does as well. The error bars shown detail mean average values within a 95% confidence interval.

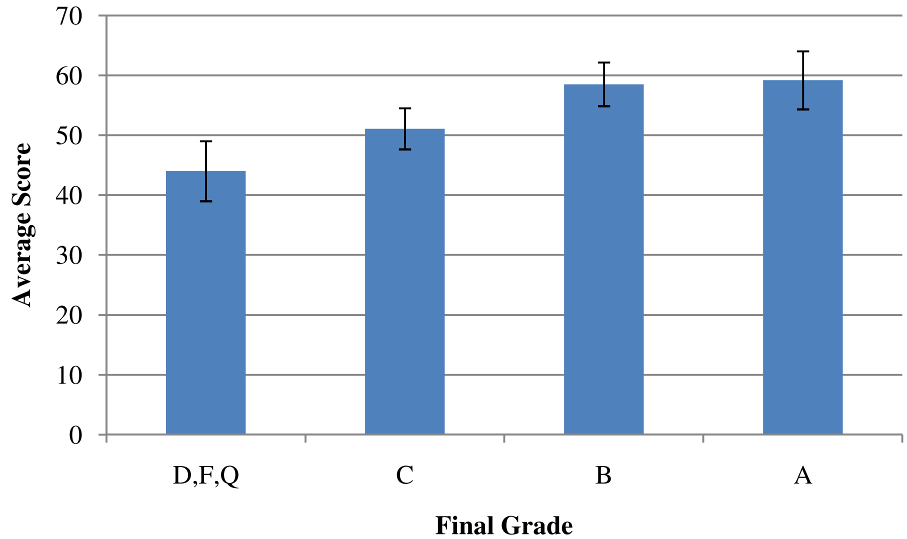


Figure 20. Average score (percent correct) received on the beta mathematics instrument versus final average grade (out of a four-point scale) in a sophomore-level statics and dynamics course. Error bars detail mean average values within a 95% confidence interval.

However, when the axes are reversed and final grade is shown on the dependent variable axis with average score on the independent variable axis as shown in Figure 21 it becomes visible that with any score on the mathematics instrument, the average score within the 95% confidence interval for the mean provides a passing grade of at least a C grade in the statics and dynamics course. At TAMU, a four-point scale is utilized where a grade of an A is four points, and on the other end of the scale, a grade of an F is worth zero points. The vertical line suggests that scores received on the mathematics instrument below 78 result in final grades below B for a sophomore-level statics and dynamics course.

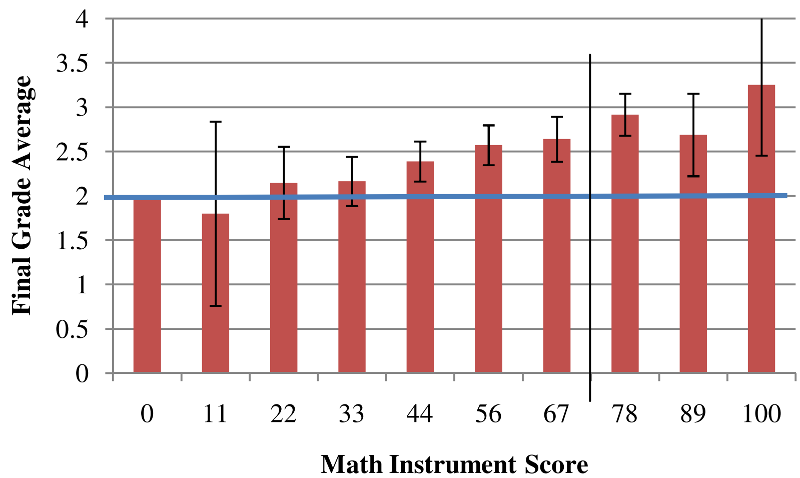


Figure 21. Average final grade (out of a four-point scale) in a sophomore-level statics and dynamics course versus average score (percent correct) received on the beta mathematics instrument. Error bars detail mean average values within a 95% confidence interval.

Similar graphs can be shown for the breakdown of the number of the four linear algebra questions on the mathematics instrument answered correctly. The four questions relating to linear algebra were specifically separated due to the large number of homework, exam, and quiz problems in statics and dynamics that covered this particular skill. Figure 22 displays a linear relationship between the average correct score received out of the four linear algebra questions on the mathematics instrument versus final grade in the course. Figure 23 shows the average final grade in the class was passing, at least a C average of 2.0, whether students answered zero linear algebra questions correctly or all four of the linear algebra questions correctly. Answering less than four of the four linear algebra questions resulted in final grades on average less than B as shown by the vertical line.

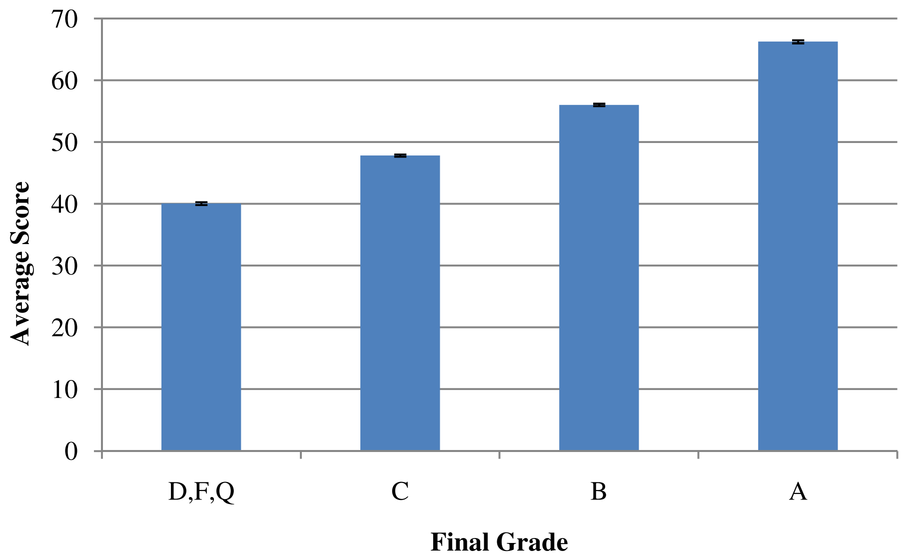


Figure 22. Average score (percent correct) received on the four linear algebra questions on the beta mathematics instrument versus final average grade (out of a four-point scale) in a sophomore-level statics and dynamics course. Error bars detail mean average values within a 95% confidence interval.

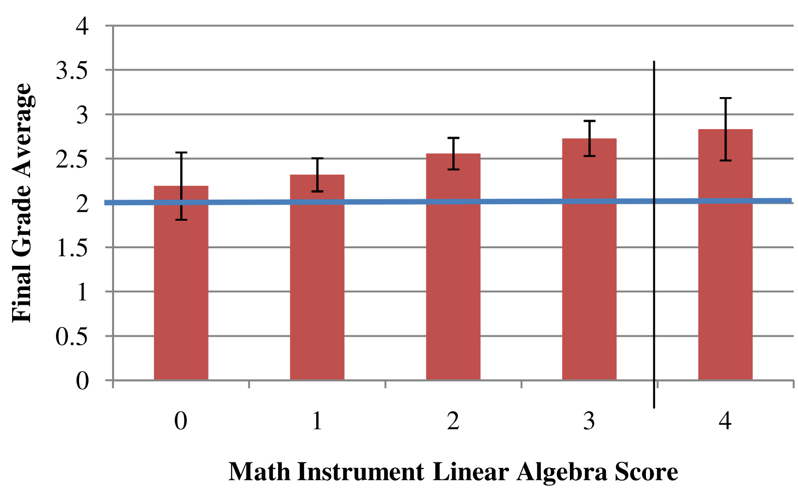


Figure 23. Average final grade (out of a four-point scale) in a sophomore-level statics and dynamics course versus average score (correct number of answers) received on the four linear algebra questions on the beta mathematics instrument. Error bars detail mean average values within a 95% confidence interval.

When evaluating average scores on the physics instruments versus final grades in the statics and dynamics course, a linear relationship appears to exist as shown in Figure 24.

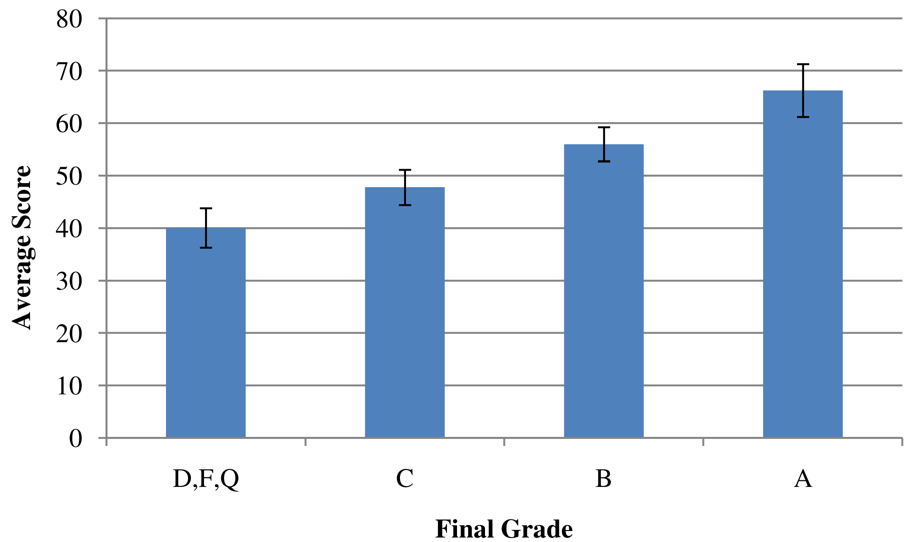


Figure 24. Average score (percent correct) received on the beta physics instrument versus final average grade (out of a four-point scale) in a sophomore-level statics and dynamics course. Error bars detail mean average values within a 95% confidence interval.

When the axes are reversed as shown in Figure 25 the average final grade was at least a C, or 2.0, for all scores of at least 18 on the physics instrument. The vertical line depicts scores below 59 results in final grades below B.

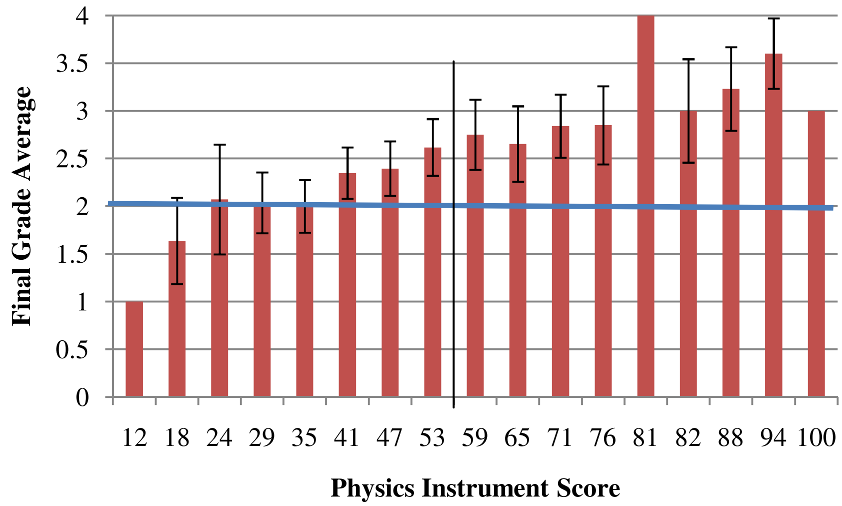


Figure 25. Average final grade (out of a four-point scale) in a sophomore-level statics and dynamics course versus average score (percent correct) received on the beta physics instrument. Error bars detail mean average values within a 95% confidence interval.

When comparing average scores on the seven free-body diagram questions on the physics instrument, a linear relationship exists between average scores on the free-body diagram questions versus final grade in the course as shown in Figure 26. The seven questions relating to free-body diagrams were specifically separated due to the large number of homework, exam, and quiz problems in statics and dynamics that covered this particular skill. Similar to the mathematics linear algebra questions analysis, an average final grade of at least a C is achieved by each group within the 95% confidence interval from answering zero of the free-body diagram questions correctly to answering all seven questions correctly. Answering less than four of the seven questions correctly resulted in final grades below B as shown by the vertical line in Figure 27.

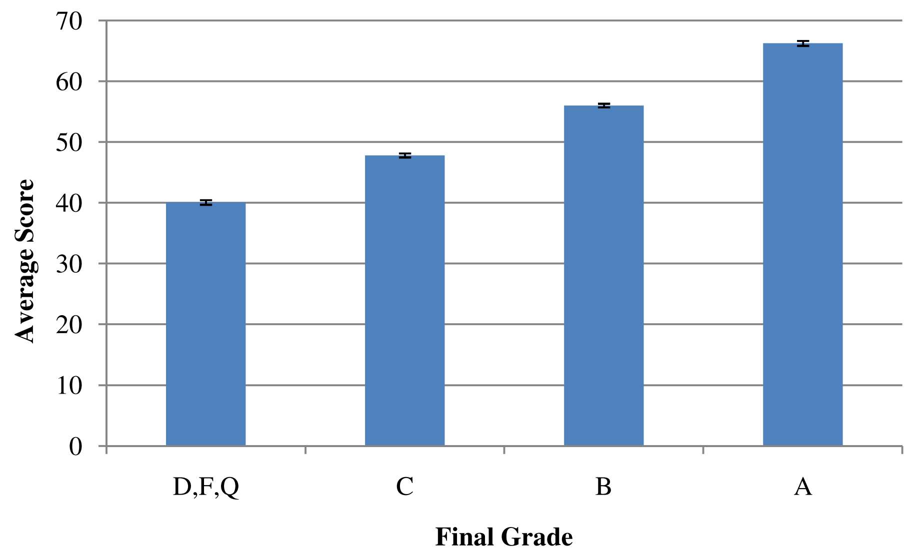


Figure 26. Average score (percent correct) received on the seven free-body diagram questions on the beta physics instrument versus final average grade (out of a four-point scale) in a sophomore-level statics and dynamics course. Error bars detail mean average values within a 95% confidence interval.

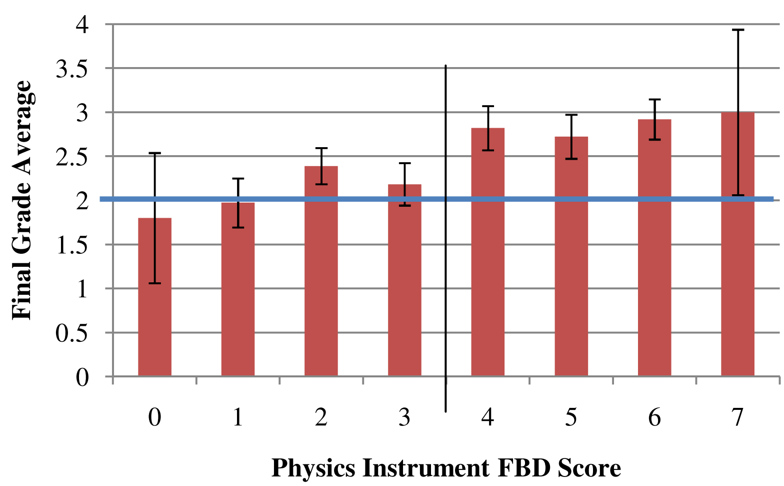


Figure 27. Average final grade (out of a four-point scale) in a sophomore-level statics and dynamics course versus average score (correct number of answers) received on the seven free-body diagram questions on the mathematics beta instrument.

In summary, the expected skills from first-year mathematics and physics mechanics courses determined by engineering faculty members as necessary for a sophomore-level statics and dynamics course were detailed in Table 5. After further refinement by evaluating actual content from the statics and dynamics course, the resulting skills are shown in Table 15.

Table 15

Final List of Expected First-Year Mathematics and Physics Mechanics Skills Determined by Engineering Faculty after Alignment Process

Mathematics Topics
Vector Components (2-D)
Vector Components (3-D)
Derivative (using Chain Rule)
Second Derivative
Area Under a Curve
Integration (using Substitution)
Simultaneous Equations

Physics Topics
Free Body Diagram
Friction
Newton's Second Law
Newton's Third Law

The first-year mathematics and physics mechanics skills were evaluated using the newly developed mathematics and physics instruments, which are included for reference in Appendix B. While a linear relationship was visible when the average scores of percent correct were graphed versus the final grade received in the sophomore-level statics and dynamics course, a reverse of the graph showed that there was not much correlation between the average score of percent correct received on the instrument versus earning at least a grade of C. The data showed that students who earned an average grade of B in the course had a range of scores of percent correct of at least 78 for the mathematics instrument and at least 59 for the physics instrument. When the four linear algebra problems on the mathematics instrument and the seven free-body diagram problems on the physics instrument were separated, the data showed that students who earned an average grade of B in the course had a range of correct number of answers of 4 for the linear algebra questions and at least 4 for the free-body diagram questions.

FACULTY EXPECTATIONS – RESEARCH QUESTION #2

The second research question in this study looks at the alignment of the expectations engineering faculty members have of the first-year mathematics and physics mechanics skills necessary for a sophomore-level statics and dynamics course and the actual skills utilized in the course. Determining the alignment between expectations and actual teaching of the material helps students determine the skills they may need to refresh and helps faculty members ensure they do not have unrealistic expectations for the students. The purpose of this research question was to determine if the skills engineering faculty members had identified as being necessary for success were essentially part of the material taught in the course.

Methodology

Before alignment can be compared between expected skills and actual skills taught, senior-level faculty members down to junior-level faculty in a Mechanical Engineering Statics and Dynamics course were asked to provide problems that would showcase skills they thought their students needed to be successful in their class. These skills were discussed in the Skills from First-Year Courses – Research Question #1 section and summarized in Table 5.

To gauge the level of alignment between faculty expectations of the knowledge and skills related to first-year mathematics and physics mechanics that students should have to be successful in the sophomore-level statics and dynamics course and the actual course content taught in their class, a q-matrix was used to compare the mathematics and physics mechanics skills required for each of the problems.

A q-matrix represents the relationship between observed variables and observations in a matrix format (Tatsuoka, 1983). In the implementation in this study, the columns contain the observed variables, which are specific homework or exam problems. The rows represent the possible observations, or specific skills. Table 16 provides an example of a q-matrix. Values of one in the entry designates the homework problem contains that particular concept with zero indicating that it does not contain that particular concept.

Table 16

Example Q-Matrix Showing the Relationship between Homework Problems and Concepts

	Question #1	*Question #2*	*Question #3*	*Question #4*
Concept #1	0	1	1	0
Concept #2	1	1	0	0
Concept #3	1	0	0	1

In this study, the q-matrix method was applied to homework, exam, and quiz problems from two sections of the Mechanical Engineering Statics and Dynamics course. A q-matrix has been applied to various situations, including determining how well correlated students knowledge of a concept allows them to answer the respective question on a test (Barnes, Bitzer, & Vouk, 2005), testing different scoring methods of exams (VanLehn, Niu, Siler, & Gertner, 1998), and representing the performance of a test-taker (Roussos, Templin, & Henson, 2007). The purpose of using a q-matrix in this study was to provide a visual representation of skills utilized in homework, exam, and quiz problems. While problems where more than one set of skills could be used to solve a single homework problem as in our case, the q-matrix still serves as a good baseline to show where differences can then be discussed and a consensus obtained.

Analysis

A q-matrix was used in this study to analyze 151 homework and exam problems from the section of Statics and Dynamics in which the alpha mathematics and physics instruments, described in the previous section, Skills from First-year Courses – Research Question #1, were given. Validity of this analysis was performed using two randomly generated subsets of 15 problems each from the homework and exam problems. Each subset represented 10% of the total number of 151 homework and exam problems from the course. Because the subsets were randomly generated, there was one common homework problem between the two subsets. Two doctoral students in mechanical engineering were then asked to analyze each subset of problems and evaluate each problem based on the first-year mathematics and physics mechanics skills needed. The purpose was to determine to what extent their analysis agreed with the original analysis. By having each graduate student analyze the two subsets of problems, a comparison could be made between three observations of each subset of problems. Figure 28 depicts this process of having two subsets of problems receiving three separate analyses for comparison.

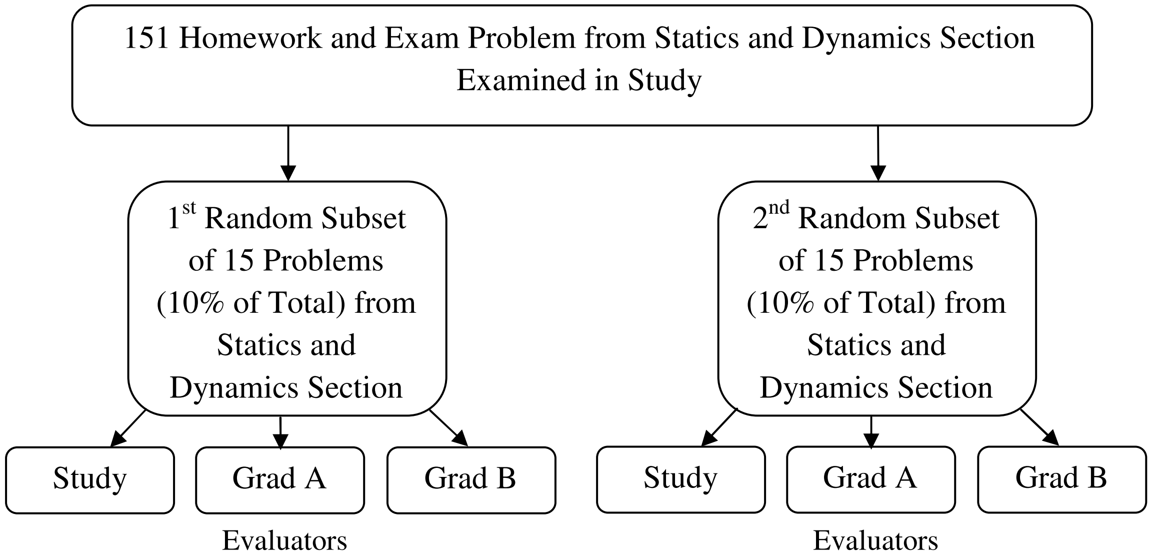


Figure 28 Analysis of homework and exam problems from a section of Statics and Dynamics.

The results between the three observations were very close. There was a direct match between all three observations for 24 of the 30 problems, although only 29 unique problems, in the two subsets. With the remaining six problems, at least two of the three observations were a complete match. In each of the six cases, the problem was examined, and it was determined that the differences occurred when multiple methods could be used to solve a problem when the problem statement did not dictate what method to use. For example, one of the homework problems related to finding the magnitude and angle of a resultant force. One of the doctoral students chose to use projection to solve this problem and listed projection as the mathematics skill needed. The other two observations resolved the forces into vectors components and listed this mathematics skill on the analysis. The two methods are virtually the same, and since the problem did not state a particular method to use, it was up to the observer to select.

While exams are typically common between the different sections of Statics and Dynamics, the homework and quiz problems assigned are usually not consistent. To provide further evidence that the results obtained from the analysis were consistent with the Statics and Dynamics course in general, one of the two doctoral students that assisted with the analysis of the two subsets of problems from the first section, analyzed 158 homework, exam, and quiz problems from another section of Statics and Dynamics to see what first-year mathematics and physics mechanics skills were needed to answer the questions. This time, the researcher in the study analyzed a subset of 15 randomly selected problems for comparison. Again, the only difference occurred on two of the problems. As before, the differences occurred in the tool used to solve the problem when a lack of specifics was provided. The first-year mathematics and physics mechanics skills determined earlier in the study were compared for each of the problem sets from the two Statics and Dynamics sections. As shown in Figure 29 and Figure 30, nearly identical results for the percentage of homework problems related to the specific first-year mathematics and physics mechanics skills were received for the two sections.

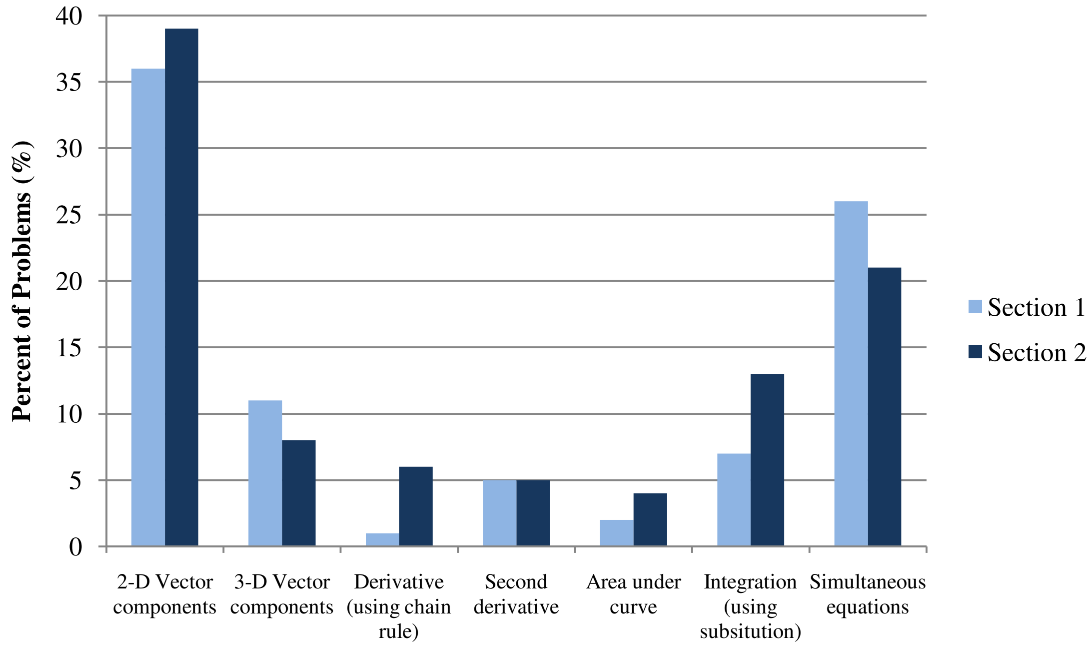


Figure 29. Comparison of percentage of homework problems versus first-year mathematics skills evaluated using a q-matrix for two different sections of Mechanical Engineering's Statics and Dynamics course.

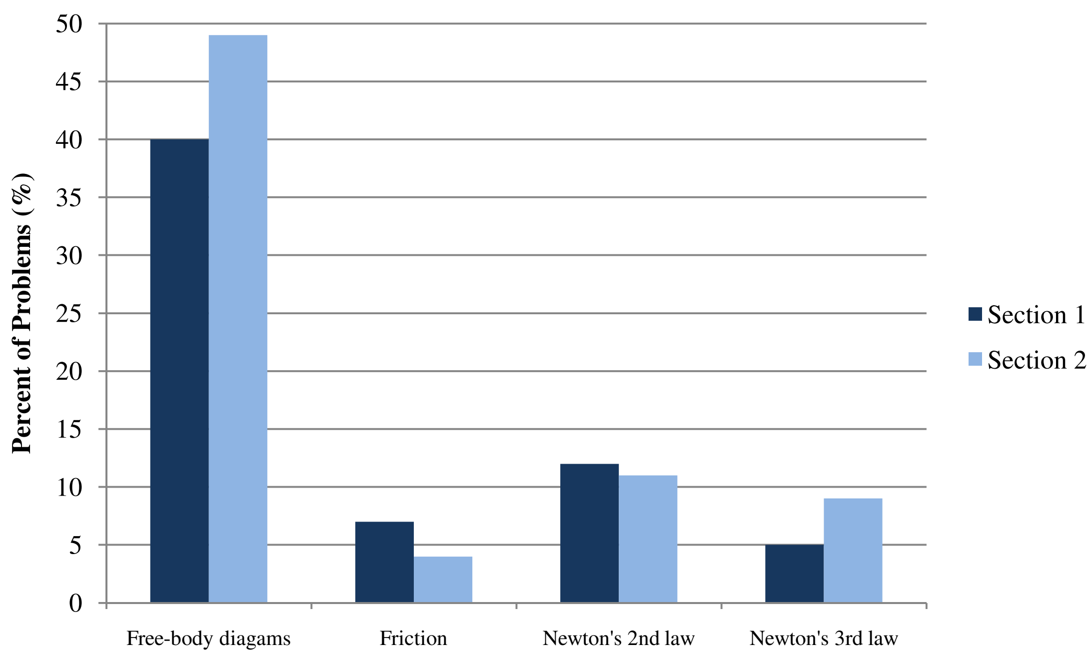


Figure 30. Comparison of percentage of homework problems versus first-year physics mechanics skills evaluated using a q-matrix for two different sections of Mechanical Engineering's Statics and Dynamics course.

Results

When the skills originally identified by the engineering faculty members (Table 5) were compared with homework and exam problems assigned by the faculty members in the statics and dynamics course, a misalignment was evident. Analyzing homework, exam, and quiz problems allowed the analysis to be based on actual evidence from an offering of the course instead of perceptions of faculty members about what they might want. From this analysis, a list of skills in mathematics and physics mechanics was constructed. Figure 31 contains a partial list of findings from the q-matrix developed for the first section of the statics and dynamics course with an example of the entire matrix available in Appendix C.

Skills	**Homework Problems**			
MATH	3-1	3-5	3-6	3-47
resolve vectors into components (2-D)	1	1	1	0
resolve vectors into components (3-D)	0	0	0	1
simultaneous equations	0	1	1	1
PHYS				
free-body diagram	1	1	1	1
circular motion	0	0	0	0
pulleys	0	0	0	0
friction	0	0	0	0

Figure 31. Portion of q-matrix used to determine skills in homework, exam, and quiz problems. Values of one represent the homework problem contains that particular skill. Values of zero represent the homework problem does not contain that particular skill.

As shown in Figure 29 and Figure 30, the three most utilized skills on the homework and exam problems were two-dimensional vector components, simultaneous equations, and free-body diagrams. Because of this, additions were incorporated into the corresponding beta instrument as shown in the previous section.

This process brought to light the issue of engineering faculty members having the course material they teach being aligned with their expectations. For example, multiple engineering faculty members had included problems involving solving for projection of vectors and had indicated projection was a key skill students needed for the statics and dynamics course. When the analysis of the homework, exam, and quiz problems was completed, there was not a single problem that specifically asked students to find the projection between two vectors in the questions related to mathematics topics. While it was definitely a tool that could be used and one of the doctoral student reviewers had listed it as a skill used in several of the homework problems, students were not explicitly asked to use it, based on the homework, exam, and quiz problems. Based on this analysis, additional skills were identified as not being aligned for similar reasons, including integrals using trigonometry substitution and definition of cross product. On the other hand, the process brought to light that three-dimensional vector components and simultaneous equations with a parameter had not been included, and several of the problems related to these skills. Therefore, they were added to the list of skills. The process also identified misalignment between physics mechanics skills that had been listed by engineering faculty as necessary for the course and homework and exam problems related to the skills. These included conservation of energy and linear momentum.

In summary, engineering faculty members were not aligned with the topics they felt were necessary to be successful in the statics and dynamics course and the topics that were required in homework and exam questions they assigned. Using a q-matrix to carefully analyze each problem highlighted this misalignment. Homework, exam, and quiz problems were compared to the previously identified skills. A misalignment was discovered on three of the eight first-year mathematics skills and two additional skills were identified as having a substantial amount of problems addressing the topics compared to the other topics. In addition, two of the six first-year physics mechanics skills demonstrated a misalignment when the q-matrix was analyzed. Finally, the importance of three skills had not been fully identified until after the large numbers of problems associated with them were identified in this process.

ALIGNMENT OF FIRST-YEAR AND SECOND-YEAR CONTENT – RESEARCH QUESTION #3

The third research question in this study looks at the alignment of the first-year mathematics and physics mechanics courses with a sophomore-level statics and dynamics course. Analyzing alignment can occur in different formats; as already discussed, alignment was considered between the expectations an instructor has about needed skills the students entering the course should have to be successful and the course content covered. In addition, one might consider the degree that material from one required course aligns with the next course for which it is a prerequisite. Another example is the alignment of grades received in a prerequisite course and the success of the student in completing the follow-on course. The purpose of this third research question was to determine if the skills students learn in the first-year mathematics and physics mechanics courses, which serve as prerequisites for a sophomore-level statics and dynamics course, are aligned with success in the engineering course.

Methodology

To see whether skills previously identified are covered in the prerequisite courses, course syllabi from the prerequisite courses can be analyzed. In addition, final grades received in the follow-on courses can be compared to the grades received or credits received from the prerequisite courses.

Course content from syllabi

When analyzing course syllabi, basically topic coverage is sought for each of the identified skills. It is important to note that even though the topic might be listed on the syllabus for the course and even possibly in the table of contents for the textbook used in the course, differences in coverage are still possible. For example as mentioned previously with the vector example, the notation used in teaching the material might be very different. This difference and the exact amount of time spent covering the information in reality is beyond the scope of the analysis of this study. Another example of differences in concept description is showcased by the difference in representation of the information. A quick review of the material in the textbook utilized in the physics mechanics class related to free-body diagrams reveals further information on the importance of notation. Figure 32 depicts a free-body diagram similar to one pictured in the University Physics textbook by Young and Freedman (2008), used currently in many of the physics mechanics courses at TAMU. Because the physics mechanics class teaches mainly kinematics in the class, most of the free-body diagrams have objects that are moving. In addition, most all of the free-body diagrams in the physics textbook include the acceleration vector.

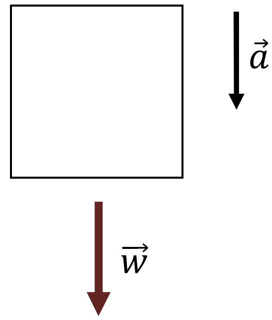


Figure 32. Free-body diagram depiction of a box that is falling vertically downward similar to those found in a physics mechanics textbook. Notice the inclusion of an acceleration vector.

Traditional engineering statics and dynamics textbooks refrain from including the acceleration vector information on the free-body diagram. Students are instructed to only include forces acting on the body in question on the free-body diagram. Figure 33 shows a typical engineering free-body diagram similar to one in Vector Mechanics for Engineers statics and dynamics textbook by Beer, Johnston, Eisenberg, and Clausen (2004). This simple illustration helps explain why 39% of students completing the physics mechanics instrument, previously describe in the Skills from First-year Courses – Research Question #1 section selected an answer choice for free-body diagram questions that contained a velocity vector.

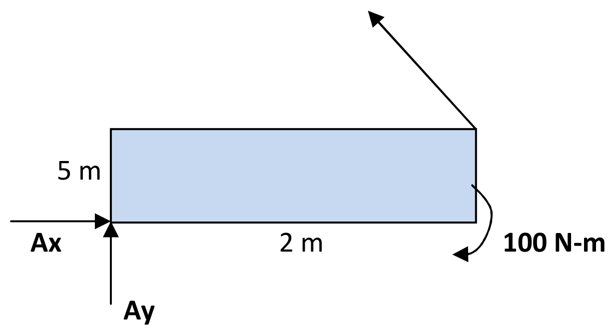


Figure 33. Free-body diagram depiction of a crane arm similar to those found in an engineering textbook. Notice the lack of an acceleration vector included.

Therefore, even though comparison of topics or syllabi can be made, relation to actual notation used in the classroom and time spent teaching the topic may not be reflected in this analysis. The desire is still for better alignment of the material in courses to hopefully provide better results for students. An example of how proper alignment between course content influence the success of a student was previously shown when comparing a typical pre-calculus to an engineering pre-calculus class.

Course grades or completion

Correlation

Course content is not the only means with which to gauge alignment between courses. Using final grades received or the method in which credit was obtained in a course can also be used. To do this, Spearman's rank correlation and mutual information calculations were performed as a means of judging alignment. Both methods, while different in implementation, measure the corresponding strength of the association, which allows reinforcement of results received if shown to be correlated or cause for further investigation if not.

Mutual information measures dependencies between variables (Battiti, 1994). The measure of the average uncertainty when the outcome of an information source is not known is defined as entropy of the system. It provides a quantifiable amount of how much information is not known or can be gathered from the factor being examined. Entropy is defined in Equation 2.

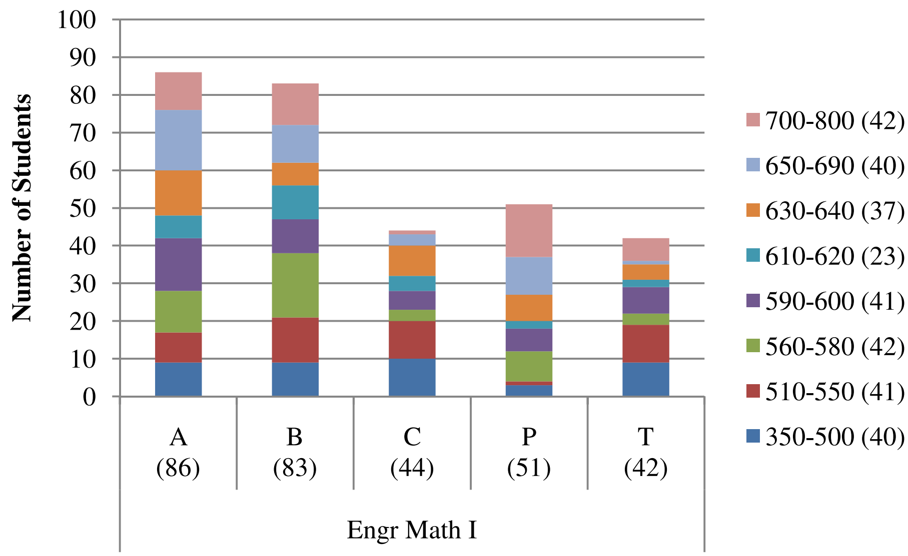
$$H(x) = \sum_{i=1}^{N} p_i \, log_2 \left(\frac{1}{p_i}\right) \quad (2)$$

where p_i is defined as the probability of factor *i*. The mutual information (I), or the dependencies between the variables, obtained from the calculations is the uncertainty before minus the uncertainty after the outcome. This information is illustrated in Equation 3.

$$I(x, y) = H(x) + H(y) - H(x, y) \quad (3)$$

For example, information can be obtained by considering two factors, *x* and *y*. The entropy of the first factor is calculated, along with the entropy of the second factor. These two values are then summed, and the entropy of their interactions is computed to determine if correlation exists. Computed entropy values above one-half a bit of information, or 0.5, are considered high (Battiti, 1994).

There are some factors that are not expected to be correlated. To provide a visual representation of low correlation and subsequently a low value for mutual information, the mutual information was calculated for final grade in Engineering Mathematics I and the score received on the SAT verbal section. Again, these two variables would not be expected to be highly correlated. The calculated mutual information value between these two factors was a low value of 0.14. Graphical details of this correlation are displayed in Figure 34.

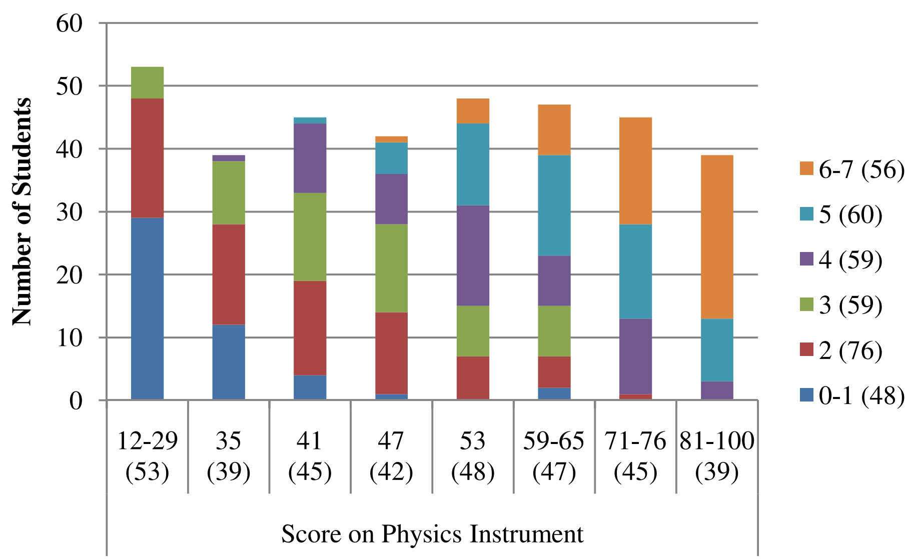


Mutual Information = .14

Figure 34. Mutual information received when grade in Engineering Mathematics I and score on the SAT verbal section was compared.

The lack of a strong correlation can be viewed by the depiction that almost all SAT verbal scores are included for each grade in Engineering Mathematics I. Therefore, this picture depicts very little correlation between the grade earned on the SAT verbal section and the final grade received in a first-year mathematics course.

On the other hand, an example of two factors having a high correlation through mutual information calculations and visual inspection is depicted by comparing the correct number of responses on the seven free-body diagram questions contained on the physics instrument with the total score on the instrument. With the free-body diagram questions representing seven of the total 17 questions, this correlation is not a surprise. Mutual information calculations show there is a high correlation between these two factors with 0.75 bits of information being received when the correct number of free-body diagram questions answered is compared to the score received on the physics instrument. Details of this correlation are shown in Figure 35.



Mutual Information = .75

Figure 35. Mutual information received when the score on the physics instrument and the number of correct answers on the seven free-body diagram questions on the instrument was compared.

The strong correlation is visible by the "banding effect" evident in the figure. For example, a large number of students who received none or one of the free-body diagram questions correctly received between 12% and 29% of the physics instrument questions correct. On the other end of the graph, a large number of students who answered six or seven of the free-body diagram questions correctly received between 81% and 100% of the physics instrument questions correct.

One example of usefulness that information on final grades can be used is for administrators to determine if policies for admitting students into upper-level departmental specific courses should be altered. As previously discussed, currently CBK grade point average and overall TAMU grade point average are the only factors, in addition to ensuring certain courses have been completed, used in admitting a student to the upper-level program in an engineering department at TAMU. For many departments, administrators feel their grade point average limits should be altered, but most do not have corresponding data to support such a change. Therefore, a closer look to determine if certain CBK and overall TAMU grade point averages performed differently was executed. This study utilized final rank in class in a sophomore-level statics and dynamics course and the grades received in Engineering Mathematics I, Engineering Mathematics II, Physics Mechanics, and Foundations of Engineering I for four different grade point average ranges to make a determination of the correlation on success in a sophomore-level statics and dynamics course. Looking at grades included not only letter grades received at TAMU for the courses but also outcome if a student used transfer credit or advanced placement credit because all of the grade types are used when making decisions on promoting students to the upper-level program.

Several quantitative factors were considered to help classify how successfully a student completed the sophomore-level statics and dynamics course. These included final grade, final numerical average, and final rank in class. The most common way to classify the success of a student would be to use final grade received in the course. A problem can arise, however, when multiple sections taught by different instructors are evaluated. For example, one instructor might provide a curve at the end of the course to have a certain number of students achieve certain grades. In addition, a cut-off used for an A or B in one section might vary greatly from that used in another section. Another mechanism would be to consider the actual final numerical grade received in the course. For the same reasons previously described, the researcher felt this would not be an appropriate mechanism to compare across sections. The cut-off used for certain grades in one section differed quite a bit from those used in another section. Therefore, the researcher decided to use rank in class to make proper comparisons across sections. For rank in class, each section evaluated was individually sorted by final numerical grade and then the students were divided into eight equal bins. By using the bins instead of simply using final grade, factors, such as grade inflation between sections and differences in cut-offs for different grades, were removed as previously discussed. The reason to divide each section into eight different bins based on final rank in class was to be able to compare the information based on halves and quartiles for comparison purposes. The number of students in each of the eight bins used in the study as a whole is shown in Table 17.

Table 17

Number of Students in Each of Eight Bins Utilized for Comparison Purposes

Bin Number	n
1	46
2	45
3	44
4	44
5	44
6	44
7	43
8	45

Note: Total number of students = 355 students

Note that 355 students are considered in this study. While more students completed each of the instruments, this number represents students who completed at least one of the instruments and were still enrolled in the course as of the official twelfth day of class. For the 355 students considered in these comparisons, Table 18 displays the grades received when the sample was divided into upper-half and lower-half with Table 19 depicting the resulting grades when the sample was split into quarters. The final grades received when dividing the sections into bins were nearly identical across the sections, but there was a very slight variation in one of the sections. The grades listed in bold in the following tables are the majority of those received by students in each of the bins in the sections. This designation of bins and correspondence to final grades shown in bold will be utilized throughout the remainder of the discussion.

Table 18

Grades Received in Sample Divided into Two Equal Bins

Grouping of Class	Grades Received
Upper-half (bins 5-8)	**A,B** (92%); C (8%)
Lower-half (bins 1-4)	**C,D,F,Q** (89%); B (11%)

Note: Grades shown in bold are the large majority for that group.

Table 19

Grades Received in Sample Divided into Four Equal Bins

Grouping of Class	Grades Received
First quarter (top – bins 7-8)	**A,B** (100%)
Second quarter (bins 5-6)	**B** (84%); C (16%)
Third quarter (bins 3-4)	**C** (80%); B (20%)
Fourth quarter (lowest – bins 1-2)	**D,F,Q** (66%); C (33%); B (1%)

Note: Grades shown in bold are the large majority for that group.

The four categories utilized for CBK and overall grade point average comparisons were averages below 2.85, 2.85-2.99, 3.0-3.249, and 3.25 and higher. The reason for having one cut-off at an average of 2.85 is because the two largest departments in the representative sample in the study, Mechanical Engineering and Aerospace Engineering, both currently use a CBK grade point average and overall TAMU grade point average of 2.85 as the entrance requirement for upper-level admittance. Anecdotally, the researcher has found through years of serving as an undergraduate departmental advisor in Aerospace Engineering that students who have entered the upper-level courses on a provisional basis with grade point averages below 2.85 have performed poorly. On the other hand, students with an average of 3.25 and above have seemed to perform well in upper-level engineering courses. The researcher has also recognized that differences between students in the 2.85-2.99 range can differ from students in the 3.0-3.249 range at times. Therefore, to determine if there are significant differences in the two ranges, the researcher decided to consider averages of 2.85-2.99 separately from averages of 3.0-3.249.

Other factors

As previously mentioned in Table 3, many factors are useful in describing the preparation and composition of a student. Some of the factors can be easily quantified and compared, such as CBK grade point average, SAT mathematics score, and final grade in Engineering Mathematics II. Other factors cannot be easily quantified, such as the role the environment plays, determination, and high school preparation or experience.

To determine the quantitative factors with the best indication of success in the sophomore-level statics and dynamics course, Spearman's rank correlation and then ANOVA were calculated using SPSS. ANOVA provides a useful test to evaluate the effect of more than one independent variable (Brace, Kemp, & Snelgar, 2009). It provides information not only on the effect that multiple factors have on the dependent variable, but it also determines the effect the interaction between multiple independent variables has on the dependent variable.

Analysis

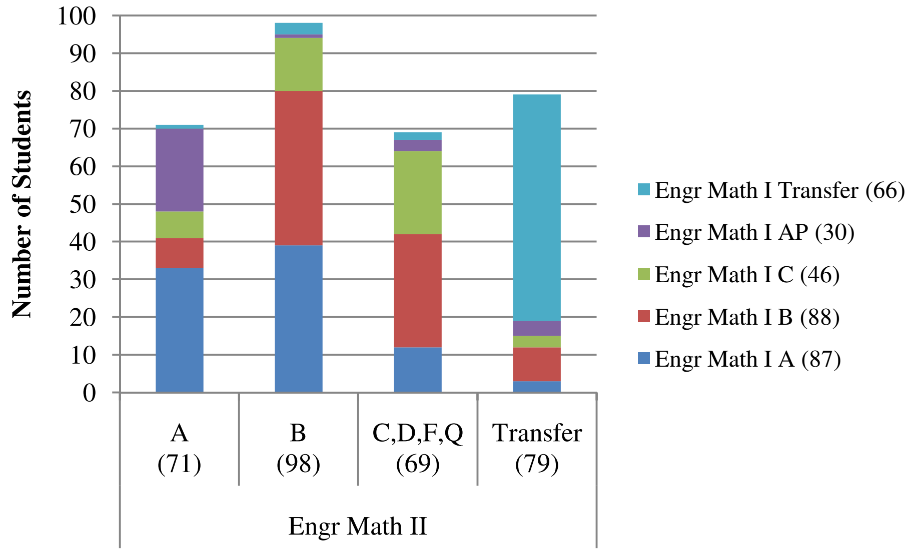
Course content from syllabi

To address whether first-year mathematics and physics mechanics skills identified as being successful for a sophomore-level statics and dynamics course are covered in the prerequisite courses, the course syllabi were compared. At TAMU, all course syllabi for undergraduate courses are available on-line. The first-year mathematics topics were compared to the syllabi for Engineering Mathematics I and Engineering Mathematics II. On the syllabi, a weekly schedule is provided with the listing of topics to be covered. This schedule provided greater detail for the comparison. The first-year physics mechanics topics were compared to the syllabus for Physics Mechanics. In all cases, the researcher looked for exact listings of the particular topic. There were no assumptions made as part of the process of topics that might be related and covered as part of another topic. The weekly schedules for Engineering Mathematics I and Engineering Mathematics II and the listing of topics for Physics Mechanics is included in Appendix C.

Course grades or completion

Correlation

To determine the correlation between final grades of prerequisite courses to follow-on courses, the correlation between final grades received by students in Engineering Mathematics I and Engineering Mathematics II. This analysis used in this case will then be applied to the prerequisites for the statics and dynamics course. The correlation between final grades received by students in Engineering Mathematics I and Engineering Mathematics II is statistically significant at the 99% confidence level (correlation coefficient = .429, $p < .0005$, $n = 337$). The fact that the correlation between final grades received in the two courses is statistically significant is not entirely surprising as the Mathematics Department at TAMU has taken a very organized approach to structuring the two courses. For example, they have organized course content between the different sections of the course taught by different instructors at different times, they have developed standard course topics coverage, they conduct common exams for the different sections, and they even utilize the same book for the two classes. Mutual information calculations performed, which are another form of determining the correlation between variables, signify almost three-quarters of a bit of information are received (mutual information = .68) when the final grades from these two sections were compared (Figure 36).



Mutual Information = .68

Figure 36. Mutual information received when grade in Engineering Mathematics I and grade in Engineering Mathematics II was compared.

As shown in the figure, correlation exists between the final grade received in Engineering Mathematics I and Engineering Mathematics II. Students who earned a grade other than A or by advanced placement credit in Engineering Mathematics I had a lower probability of earning a grade of A in Engineering Mathematics II. Likewise, students who received transfer credit for Engineering Mathematics I largely received transfer credit for Engineering Mathematics II.

Grade point averages

To determine the effect various course grades have on final grades, the decision of whether or not both CBK and overall TAMU grade point averages would have to be compared for each case or if knowing information about only one of the averages would provide significant information about the other one was addressed first. Table 20 depicts the number of students in each of the final grade rank categories for a sophomore-level statics and dynamics course based on both CBK and overall grade point averages. As shown in the table, both CBK and overall TAMU grade point averages appear to correlate well with final rank in class for a sophomore-level statics and dynamics course. Refining this further, the researcher considered if CBK or overall TAMU grade point averages would illustrate things differently. More concisely, it would be helpful to determine if CBK grade point averages and overall TAMU grade point averages independently provide the same outcome or if they need to be considered together. The results obtained by evaluating CBK grade point averages or overall TAMU grade point averages were nearly identical. As shown in the table, the number of students in each final rank category is approximately the same for CBK grade point average and overall grade point average.

Table 20

Number of Students Split into Quarters Based on Final Rank in Class and Both CBK and Overall Averages

	CBK and Overall Grade Point Average Ranges					
Final Rank in S&D	< 2.85	2.85-2.99	3.0-3.249	≥ 3.25	n	Type of Grade Point Average
Bins 7-8	2	2	10	76	90	CBK
A,B	2	3	9	68	82	Overall
Bins 5-6	8	7	27	47	89	CBK
B	12	6	21	46	85	Overall
Bins 3-4	22	15	24	24	85	CBK
C	30	14	24	17	85	Overall
Bins 1-2	42	16	16	17	91	CBK
D,F,Q	47	14	15	10	86	Overall
N	72	40	77	164	355	CBK
	91	37	69	141	338	Overall

Notes. The first column contains final rank in class for the sophomore-level Statics and Dynamics course. The first row of data represents the number of students with the corresponding CBK grade point average. The second row of data represents the number of students with the corresponding overall TAMU grade point average.

Anecdotally, the researcher has observed when students apply for admittance into upper-level, the student's CBK grade point averages and overall TAMU averages seem to be highly correlated. All courses completed at TAMU constitute the overall grade point average, but only nine mainly science based courses comprise the CBK grade point average. For many students, their overall grade point average includes several elective courses. For students that repeat a course, all attempts for a particular course are included in the overall average, whereas only the highest grade received counts in the CBK average. Overall, students who perform well overall at TAMU seem to also perform well in their CBK courses. If the observation is correct, only one of the two grade point averages needs to be considered, and it will provide almost complete information about the other one. A Spearman's correlation in SPSS also shows the high correlation between the two grade point averages, significant at the 99% confidence level (correlation coefficient = .881, $p < 0.0005$, $N = 338$). In addition, looking at Table 20, it appears there are similar numbers contained in each of the bin / range entries. To determine whether or not the difference between the numbers in the two groups was significant, a paired samples t-test was conducted. The paired samples t-test compares the means of two variables. The test determines whether or not there is a difference in the means for a pair of random samples whose differences are approximately normally distributed. The difference between the two variables for each case is computed and then tested to determine of the average difference is significantly different from zero. The null hypothesis, H_o, states there is no significant difference between the means of the two variables with the alternative hypothesis, H_a, being there is a significant difference between the means of the two variables, number of students in each CBK grade point average and overall TAMU grade point average range in this case. A paired samples t-test was used to determine the difference between the amount of students in each of the two types of grade point averages ($t = 0.865$, $df = 15$, $p = .401$, two-tailed). Since the p-value is greater than 0.05, the null hypothesis cannot be rejected; therefore, there is no significance difference between the mean number of students in each range with CBK grade point average and the overall TAMU grade point average, at a 95% confidence level. In addition, the correlation between the number of students in each of the two grade point averages for the different ranges was calculated and determined to be quite strong (correlation = 0.977, $p < .0005$).

When evaluating final class rank in key mathematics, physics mechanics, and more related engineering CBK courses, the researcher found similar results for CBK and overall grade point averages. Whether CBK grade point average or overall grade point average was considered, nearly the same number of students appeared in each of the CBK and overall groupings for each of the four grade point average designations. Therefore, while data was obtained individually for CBK and overall grade point averages, the near identical results obtained for each type of grade point average allow for the discussion to focus on one type of grade point average and provide significant information about the other type. The researcher selected to discuss CBK grade point ratio since the courses used in the comparisons are more directly tied to this value.

Results for different CBK ranges

To evaluate differences in CBK grade point averages compared to final rank in class in a statics and dynamics course, an independent samples t-test was performed in SPSS to determine significance of the data. The null hypothesis that will be used for each CBK grade point average range will be there is no difference between the groups. Another way to state this is that the difference between students who score in the top half of the statics and dynamics course and those who score in the lower half of the statics and dynamics course within a given CBK grade point average range is purely due to chance. The significance of the difference between these two groups will be determined at a 95% confidence level.

As shown in Figure 37, differences exist between entering CBK grade point averages and final rank in class for the sophomore-level statics and dynamics course for students. The statistics test determined there was significance. Therefore, the null hypothesis of no differences between the two groups was rejected, and there is a statistically significant difference between the mean CBK grade point average for students in the top half of the class based on final rank and the CBK grade point average for students in the lower half of the class based on final rank (t = -12.409, df = 350, $p < .0005$). Figure 38 displays the error bar graph for the information. As shown, there is no overlap between the two bars for each group. This lack of overlap is indicative of a significant difference between the groups.

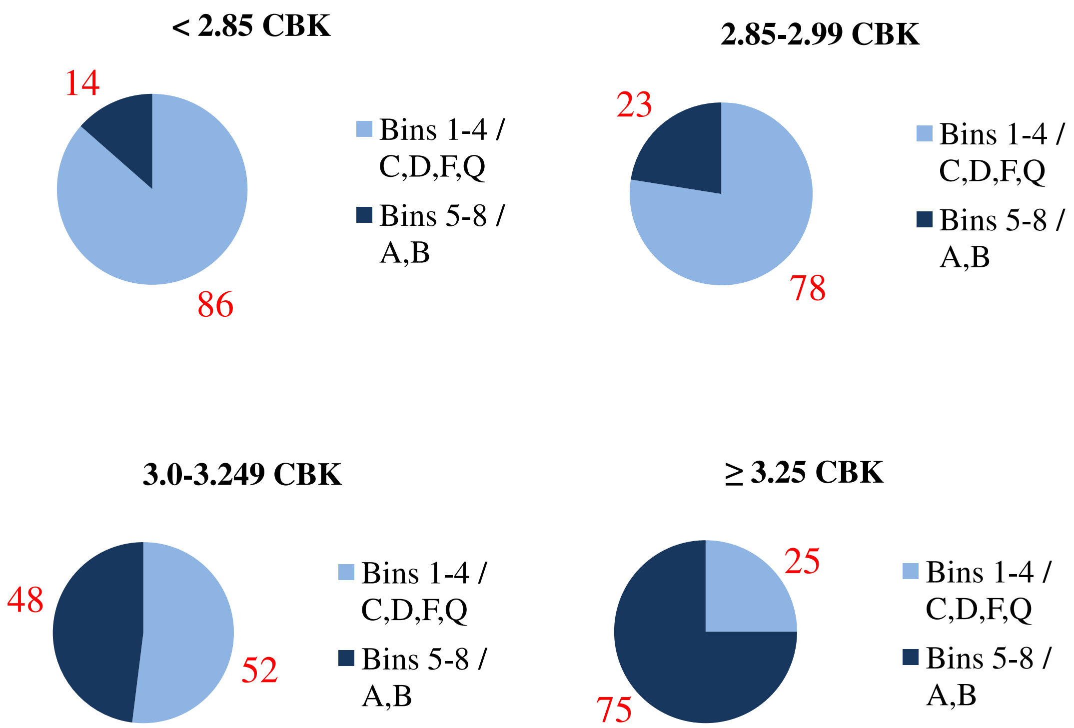


Figure 37. Number of students earning grades of C, D, F, or Q and A or B in a sophomore-level statics and dynamics course divided into four CBK grade point average ranges. For bins 1-4 / C,D,F,Q, n = 176 students. For bins, 5-8 / A,B, n = 179 students.

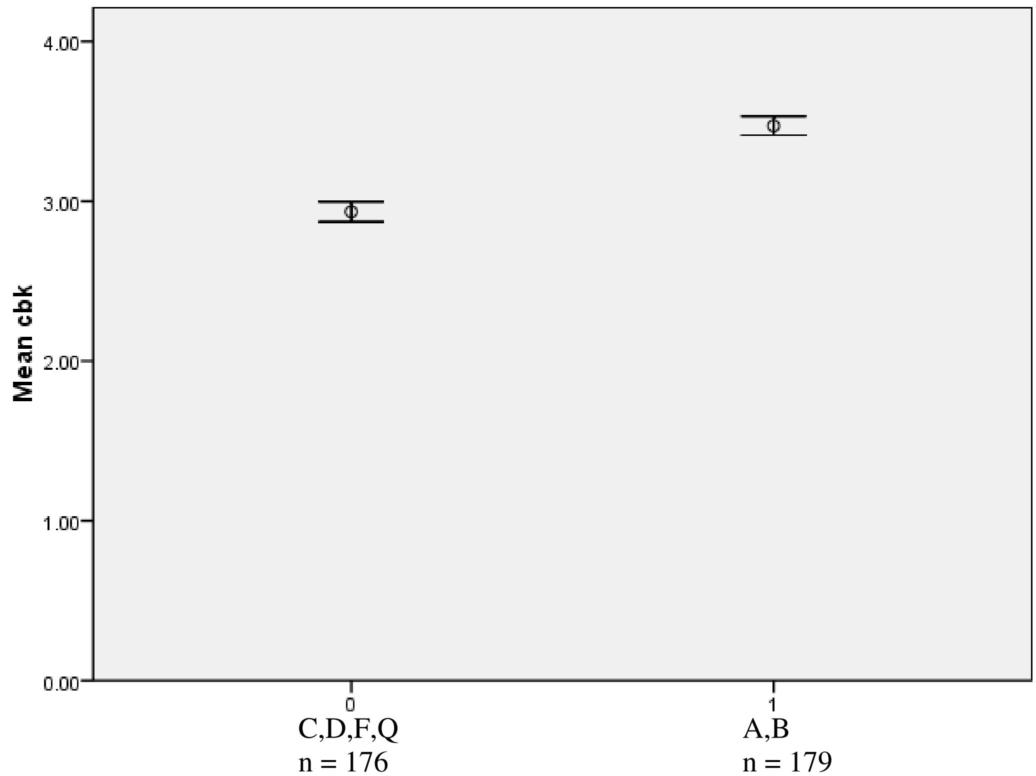


Figure 38. Errors bars at 95% confidence level depict the average CBK grade point averages of students who entered with a CBK average in two final rank in class bins, C, D, F, or Q on the left hand side and A or B on the right hand side. The lack of overlap between the two sets of error bars indicates there is a significant different in the entering CBK grade point averages for students who earn a C, D, F, or Q in the statics and dynamics course and those who earn an A or B. Students who earn a C, D, F, or Q on average have lower entering CBK grade point averages.

If a student had a CBK grade point average in the range of 2.85-2.99, the odds that the student would be ranked by their final grade in a sophomore-level statics and dynamics course in the lower-half of the class at the end of the course is 3:1. On the other hand, if the student had a CBK grade point average of at least 3.25, the odds the student would be ranked by their final grade in the upper-half of the class at the end of the course is 3:1. For students in the CBK grade point average category of 3.0-3.249, the odds are 1:1 that they will be in the upper-half or lower-half rank-wise based on final grade at the end of the course.

Closer inspection is made to determine the significance of each CBK grade point average range. For students who have less than a 2.85 CBK grade point average, an independent samples t-test performed shows equal variances are not assumed for students in the top half based on final rank in class for a sophomore-level statics and dynamics course versus lower half (Levene's test, $p = .033$). The statistics test determined there was significance, however. Therefore, the null hypothesis of no differences between the two groups was rejected, and there is a statistically significant difference for students in the top half of the class based on final rank and students in the lower half of the class based on final rank if their entering CBK grade point average was below 2.850 ($t = -2.769$, $df = 19.057$, $p = .012$). Figure 39 displays the error bar graph for the information. There is a slight overlap between the bars for the two groups, although the extent of the overlap is quite small, which indicates a difference between the groups. Therefore, further evaluation of the data will hopefully provide refinement to understand how these two groups of students differ.

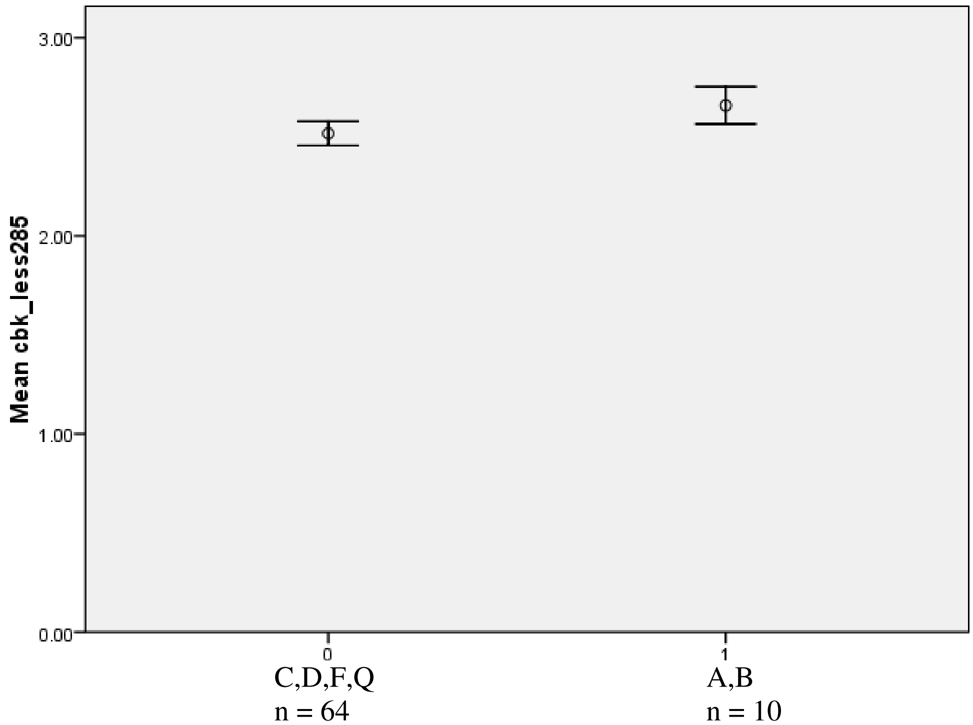


Figure 39. Errors bars at 95% confidence level depict the average CBK grade point averages of students who entered with less than a 2.850 CBK average in two final rank in class bins, C, D, F, or Q on the left hand side and A or B on the right hand side. The lack of overlap between the two sets of error bars indicates there is a significant different in the entering CBK grade point averages for students who earn a C, D, F, or Q in the statics and dynamics course and those who earn an A or B. Students who earn a C, D, F, or Q on average have lower entering CBK grade point averages.

For CBK grade point averages in the range of 2.85 to 2.99, the statistics test determined there was no significance between the two groups. Therefore, the null hypothesis of no differences between the two groups cannot be rejected at a 95% confidence level, and there is no statistically significant difference between the mean CBK grade point average for students in the top half of the class based on final rank and the CBK grade point average for students in the lower half of the class based on final rank (t = -1.058, df = 38, p = .297).

For CBK grade point averages in the range of 3.0 to 3.249, the statistics test determined there was no significance. Therefore, the null hypothesis of no differences between the two groups was failed to be rejected, and there is no statistically significant difference between the mean CBK grade point average for students in the top half of the class based on final rank and the CBK grade point average for students in the lower half of the class based on final rank ($t = -0.638$, $df = 75$, $p = .526$).

For students who have above a 3.25 CBK grade point average, an independent samples t-test performed shows equal variances are not assumed for students in the top half based on final rank in class for a sophomore-level statics and dynamics course versus the lower half (Levene's test, $p = .017$). The statistics test determined there was significance, however. Therefore, the null hypothesis of no differences between the two groups was rejected, and there is a statistically significant difference for students in the top half of the class based on final rank and students in the lower half of the class based on final rank if their entering CBK grade point average was above 3.25 ($t = -5.039$, $df = 82.226$, $p < .0005$). Figure 40 displays the error bar graph for the information. As shown, there is no overlap between the two bars for each group. This lack of overlap is indicative of a significant difference between the groups.

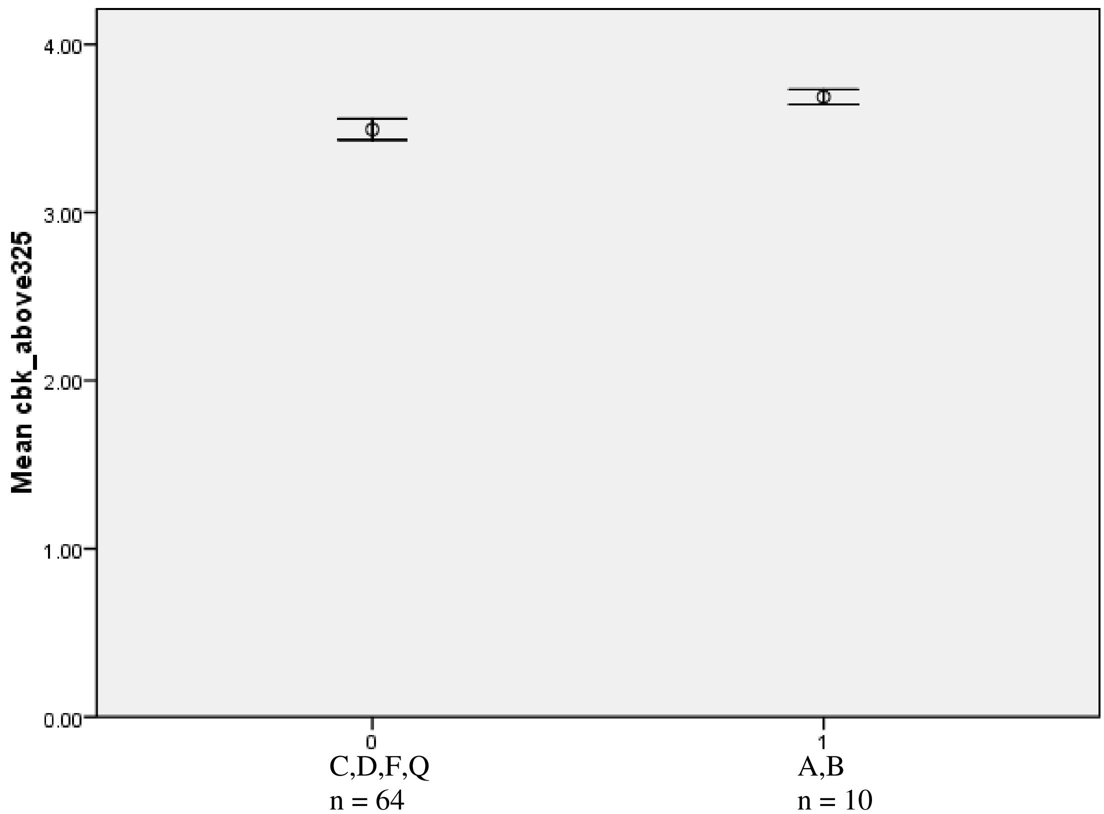


Figure 40. Errors bars at 95% confidence level depict the average CBK grade point averages of students who entered with at least a 3.250 CBK average in two final rank in class bins, C, D, F, or Q on the left hand side and A or B on the right hand side. The lack of overlap between the two sets of error bars indicates there is a significant different in the entering CBK grade point averages for students who earn a C, D, F, or Q in the statics and dynamics course and those who earn an A or B. Students who earn a C, D, F, or Q on average have lower entering CBK grade point averages.

In summary, Table 21 revisits Table 20 and incorporates the results from the independent samples t-tests. As shown in the table, there is significance to be found by evaluating CBK grade point average ranges separately. While some of the ranges do not show significance between the CBK averages of students within that range, other factors will hopefully sort out the information. Since the differences between student grades in statics and dynamics were found to be significant, a comparison can be made of the average final grades received by students in statics and dynamics across the different CBK categories. The average final grade in the statics and dynamics course based on the different CBK grade point average range is depicted in Table 22. As shown in the figure, there is large drop in average final grades in the statics and dynamics course based on the CBK average range, especially for CBK grade point averages below 3.0.

Table 21

Results Based on Mean CBK Grade Point Averages and Final Rank in Class

	Bins							
CBK Range	5-8 A,B	1-4 C,D,F,Q	Levene's Test	Equal Variances	t	df	p	Significant
< 2.85	10	64	0.033	No	-2.769	19.057	0.012	Yes
2.85-2.99	9	31	0.121	Yes	-1.058	38	0.297	No
3.0-3.249	37	40	0.961	Yes	-0.638	75	0.526	No
> 3.25	123	41	0.017	No	-5.039	82.226	< .0005	Yes
All	179	176	0.871	Yes	-12.409	350	< .0005	Yes

Note. The second and third columns contain number of students with final rank in class for the sophomore-level Statics and Dynamics course that corresponds to grades of A or B and C, D, F, or Q, respectively.

Table 22

Average Final Grade in Statics and Dynamics Based on CBK Range

CBK Range	Average Grade in Statics and Dynamics
< 2.85	1.6
2.85-2.99	1.8
3.0-3.249	2.5
≥ 3.25	3.0

Note. Grades have been converted into a numerical format with A = 4 points, B = 3 points, C = 2 points, D = 1 point, and F and Q = 0 points.

Refining this information further, the same groupings of students can be split into quarters instead of halves as is shown in Table 23.

Table 23

Number of Students Split into Quarters Based on Final Rank in Class and CBK Averages

	CBK Grade Point Average Ranges				
Final Rank in S&D	< 2.85	2.85-2.99	3.0-3.249	≥ 3.25	n
Bins 7-8 A,B	0	2	10	76	91
Bins 5-6 B	7	7	27	47	88
Bins 3-4 C	25	15	24	24	88
Bins 1-2 D,F,Q	39	16	16	17	88
n	71	40	77	164	355

Note. The first column contains final rank in class for the sophomore-level Statics and Dynamics course.

As shown in the table and Figure 37, the probability is very small that students with CBK grade point averages less than 3.0 will earn a final rank in class in a sophomore-level statics and dynamics course than enables a grade of A or B. CBK grade point averages greater than 3.25 show a high probability of having the highest ranks in the statics and dynamics course and of earning a grade of A or B.

Transfer credit received

Transfer credit is earned when a student completes a course at an institution other than TAMU. The reasons students obtain transfer credit are varied, including but not limited to failing a course at TAMU and having to repeat it, wanting to advance in the curriculum and get ahead by completing a course back home during a summer, typically paying less tuition by completing a course at a community college rather than at a university, and completing a course on a dual credit basis while in high school, which earns highs school credit and college credit through a local community college simultaneously, for example. This study focuses on students who are TAMU student but take courses elsewhere either during the fall or spring semesters or during the summer between academic years. It does not focus on students who transfer in all of their courses into TAMU to start the engineering courses. Each of the four CBK grade point average ranges will be evaluated to determine what effect transfer credit has on the success of the students in a sophomore-level statics and dynamics course. Spearman's rank correlation was computed in SPSS for credits earned by transfer in Engineering Mathematics I, Engineering Mathematics II, and Physics Mechanics. There was significant correlation at the 95% confidence level for the three courses. Therefore, only details on transfer credit received in Physics Mechanics was evaluated. This course was selected due to the strong correlation of the course in general to final grade in statics and dynamics as will be shown later in this section.

CBK grade point average below 2.85

For CBK grade point averages below 2.85, students who receive transfer credit for core first-year mathematics and physics courses have a higher percentage of much lower grades received in a sophomore-level statics and dynamics course as shown in Table 24. Inspecting bins 1-4 further to breakdown grades of C versus grades of D, F, Q, there is a larger probability of students earning a grade of D, F, Q if they have earned transfer credit in Engineering Mathematics I or Engineering Mathematics II than those students who earned a grade of a C as shown in the table. There was more of an even split in the grade of C versus grade of D,F,Q in Physics Mechanics.

Table 24

Number of Students Below 2.85 Split into Halves who Received Transfer Credit

Final Rank in S&D	Engr Math I	Engr Math II	Phys Mech
Bins 5-8 A,B	2	2	1
Bins 1-4 C,D,F,Q	17	15	14
Bins 3-4 C	5	5	6
Bins 1-2 D,F,Q	12	10	8

Note. The first column contains final rank in class for the sophomore-level Statics and Dynamics course.

Figure 41 compares the ratio of students with less than 2.85 CBK grade point average who earned an A or B in statics and dynamics and those that earned a grade of C, D, F, or Q in the course with the same group of students that also used transfer credit for Physics Mechanics. As shown in the figure, students who earned transfer credit for

Physics Mechanics performed worse than students with less than a 2.85 CBK grade point average in general.

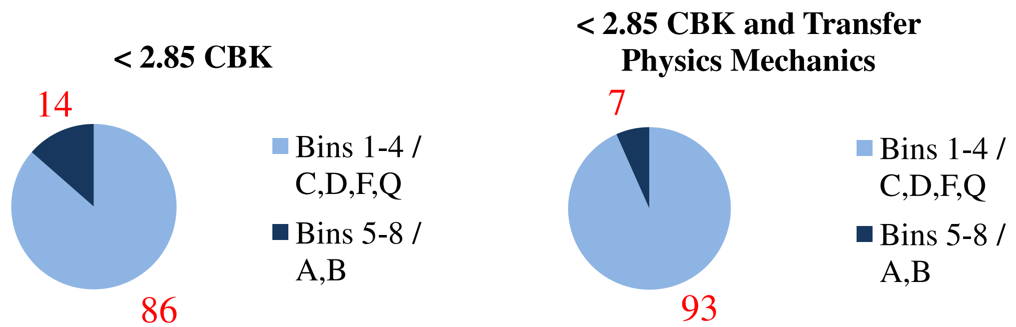


Figure 41. Comparison of CBK grade point average only versus CBK grade point average and transfer credit for Physics Mechanics for students with averages below 2.85.

CBK grade point average in the range of 2.85-2.99

For CBK grade point averages in the range of 2.85-2.99, students who receive transfer credit for core first-year mathematics and physics courses also have a higher percentage of much lower grades received in a sophomore-level statics and dynamics course as shown in Table 25. Inspecting bins 1-4 further to breakdown grades of C versus grades of D, F, Q, a disproportionate amount of students fall in the D, F, Q range for Engineering Mathematics I and Engineering Mathematics II as opposed to the C range as shown in the table.

Table 25

Number of Students in 2.85-2.99 Range Split into Halves who Received Transfer Credit

Final Rank in S&D	Engr Math I	Engr Math II	Phys Mech
Bins 5-8 A,B	1	1	0
Bins 1-4 C,D,F,Q	5	5	5
Bins 3-4 C	1	2	2
Bins 1-2 D,F,Q	4	6	3

Note. The first column contains final rank in class for the sophomore-level Statics and Dynamics course.

Figure 42 compares the ratio of students with CBK grade point averages between 2.85 and 2.99 who earned an A or B in statics and dynamics and those that earned a grade of C, D, F, or Q in the course with the same group of students that also used transfer credit for Physics Mechanics. As shown in the figure, students who earned transfer credit for Physics Mechanics performed much worse than students with CBK grade point averages between 2.85 and 2.99 in general.

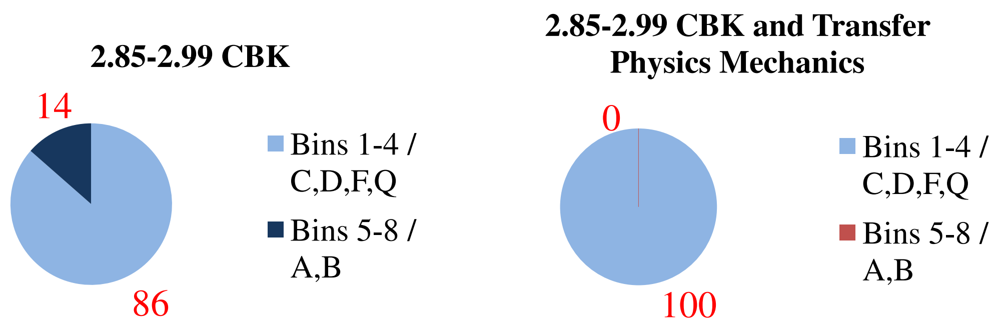


Figure 42. Comparison of CBK grade point average only versus CBK grade point average and transfer credit for Physics Mechanics for students with averages between 2.85 and 2.99.

CBK grade point average in the range of 3.0-3.249

Similarly, students who have a CBK grade point average in the range of 2.85-2.99 and receive transfer credit for core first-year mathematics and physics courses also have a higher percentage of much lower grades received in a sophomore-level statics and dynamics course as shown in Table 26. Inspecting bins 1-4 further to breakdown grades of C versus grades of D, F, Q, there is more of an even split in the grade of C versus grade of D, F, Q in Engineering Mathematics I and Physics Mechanics as shown in the table. However, a larger amount of students who receive transfer credit in Engineering Mathematics II fall in the grade of D, F, Q range than grade of C.

Table 26

Number of Students in 3.0-3.249 Range Split into Halves who Received Transfer Credit

Final Rank in S&D	Engr Math I	Engr Math II	Phys Mech
Bins 5-8 A,B	3	3	1
Bins 1-4 C,D,F,Q	9	9	7
Bins 3-4 C	4	6	3
Bins 1-2 D,F,Q	5	10	4

Note. The first column contains final rank in class for the sophomore-level Statics and Dynamics course.

Figure 43 compares the ratio of students with CBK grade point averages between 3.0 and 3.249 who earned an A or B in statics and dynamics and those that earned a grade of C, D, F, or Q in the course with the same group of students that also used transfer credit for Physics Mechanics. As shown in the figure, students who earned transfer credit for Physics Mechanics performed much worse than students with CBK grade point averages between 3.0 and 3.249 in general. Whereas the number of students in the top half of the statics and dynamics course was pretty split with the number in the bottom half when only CBK grade point average was compared, students who used transfer credit received much lower grades.

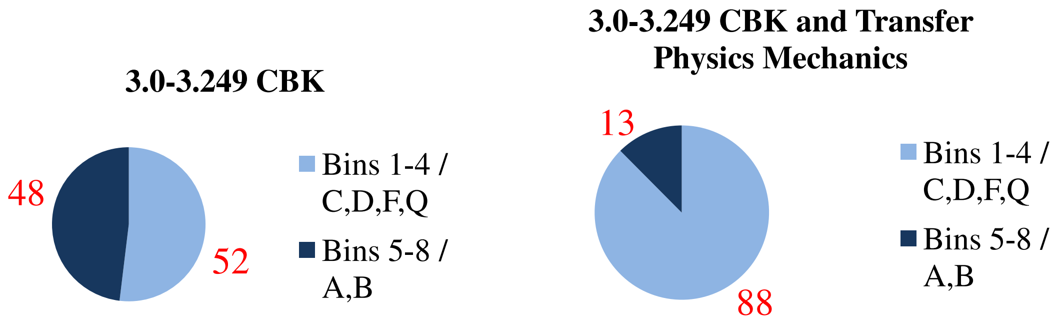


Figure 43. Comparison of CBK grade point average only versus CBK grade point average and transfer credit for Physics Mechanics for students with averages between 3.0 and 3.249.

CBK grade point average above 3.25

For CBK grade point averages of 3.25 and above, there is more of an even split in the number of students who receive transfer credit for core first-year mathematics and physics courses and the grade they receive in a sophomore-level statics and dynamics course as shown in Table 27. While there is still a large number of students who do not perform as well, many top students obtain transfer credit through dual credit received in high school. They do not necessarily fall into the same category of not doing well in a course and retaking it at another institution. Inspecting bins 1-4 further to breakdown grades of C versus grades of D, F, Q, there is still a disproportionate number of students that receive grades of D, F, Q if they have earned transfer credit in one of the three courses as shown in the table.

Table 27

Number of Students in 3.25 and Above Range Split into Halves who Received Transfer Credit

Final Rank in S&D	Engr Math I	Engr Math II	Phys Mech
Bins 5-8 A,B	14	15	11
Bins 1-4 C,D,F,Q	15	18	17
Bins 3-4 C	5	7	7
Bins 1-2 D,F,Q	10	11	10

Note. The first column contains final rank in class for the sophomore-level Statics and Dynamics course.

Figure 44 compares the ratio of students with CBK grade point averages at least 3.25 who earned an A or B in statics and dynamics and those that earned a grade of C, D, F, or Q in the course with the same group of students that also used transfer credit for Physics Mechanics. As shown in the figure, students who earned transfer credit for Physics Mechanics performed worse than students with CBK grade point averages at least 3.25 in general.

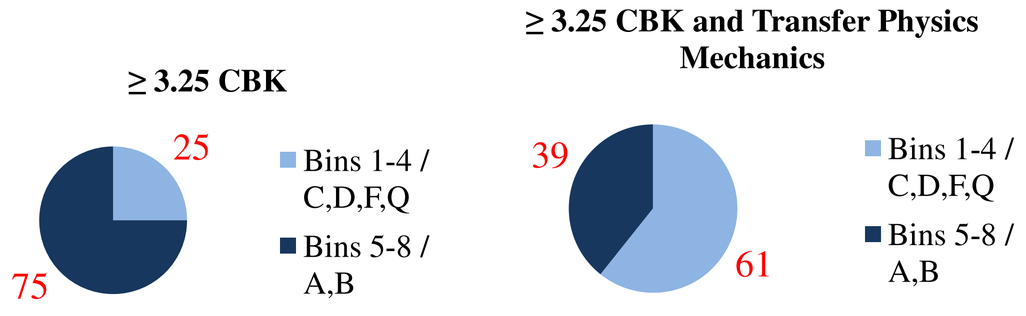


Figure 44. Comparison of CBK grade point average only versus CBK grade point average and transfer credit for Physics Mechanics for students with averages of at least 3.25.

From the pie charts in the corresponding figures, there appears to be a difference in the performance of students if they used transfer credit for Physics Mechanics. This was evident in each of the four CBK grade point average categories. A one-sample t-test was performed in SPSS to determine if the difference was significant. Statistics show that there is a significant different at a 95% confidence level of final grades in a statics and dynamics course based on the use of transfer credit for Physics Mechanics ($t = 9.655$, $df = 354$, $p < 0.0005$). As shown, there are definite differences between the grades students receive by transfer for first-year mathematics and physics mechanics courses and the grades earned in a sophomore-level statics and dynamics course, which contains the three courses as prerequisites. Since the differences between student grades in statics and dynamics were found to be significant, a comparison can be made of the average final grades received by students in statics and dynamics across the different CBK categories when transfer credit was used in Physics Mechanics. The average final grade in the statics and dynamics course based on the different CBK grade point average range is depicted in Table 28. Similar results were found when comparing average final grade in statics and dynamics based on using transfer credit for Physics Mechanics or in addition for Engineering Mathematics I and Engineering Mathematics II. The one difference in comparisons is denoted in the figure. As shown, there is large drop in average final grades in the statics and dynamics course based whether transfer credit was used, especially for CBK grade point averages of at least 3.25.

Table 28

Comparison of Final Grade in Statics and Dynamics Based on Use of Transfer Credit

	Average Final Grade in Statics and Dynamics	
CBK Range	Not Using Transfer Credit	Using Transfer Credit
< 2.85	1.6	1.3
2.85-3.249	2.4	1.8 (1.5 for Physics Mechanics)
≥ 3.25	3.2	2.4

Note. Grades have been converted into a numerical format with A = 4 points, B = 3 points, C = 2 points, D = 1 point, and F and Q = 0 points.

Advanced placement credit received

Advanced placement credit is received by taking an exam in high school, normally after taking an advanced class to help prepare the student and scoring high enough on the exam to show adequate knowledge of the material to earn credit for the course. Incoming freshmen will many times enter with advanced placement credit for courses on different subjects, such as mathematics, physics, English, history, government, economics, just to name a few. Most advanced placement credits were earned by students with CBK grade point averages above 3.25. Table 29 displays the total number of students in the sample who utilized advanced placement credits in Engineering Mathematics I, Engineering Mathematics II, and Physics Mechanics and the number of students who had CBK grade point averages above 3.25 and made use of advanced placement credits in the same three courses. As shown, between 75%-85% of the students who utilize advanced placement credits for the three CBK courses listed have averages above 3.25.

Table 29

Number of Students Overall and in 3.25 and Above Range who Received AP Credit

CBK Range	Engr Math I	Engr Math II	Phys Mech
All	53	28	17
> 3.25	45	21	14
% Difference	85%	75%	82%

Final Rank in S&D	Engr Math I	Engr Math II	Phys Mech
Bins 7-8 A,B	30	13	10
Bins 5-6 B	10	6	3
Bins 3-4 C	4	1	0
Bins 1-2 D,F,Q	1	0	0

Note. The first column contains final rank in class for the sophomore-level Statics and Dynamics course.

Spearman's rank correlation was computed in SPSS for credits earned by advance placement in Engineering Mathematics I, Engineering Mathematics II, and Physics Mechanics. There was significant correlation at the 95% confidence level for the three courses. Therefore, only details on advanced placement credit received in Physics Mechanics was evaluated further. This course was selected due to the strong correlation of the course in general to final grade in statics and dynamics as will be shown later in this section.

Figure 45 compares the ratio of students with CBK grade point averages at least 3.25 who earned an A or B in statics and dynamics and those that earned a grade of C, D, F, or Q in the course with the same group of students that also used advanced placement credit for Physics Mechanics. As shown in the figure, students who used advanced placement credit for Physics Mechanics performed better than students with CBK grade point averages at least 3.25 in general.

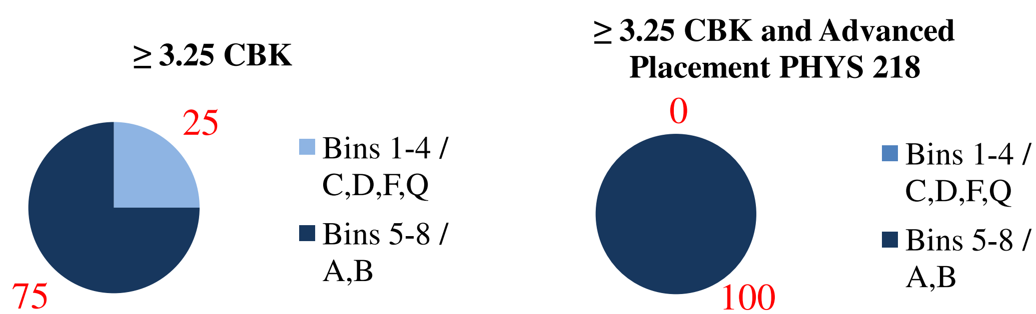


Figure 45. Comparison of CBK grade point average only versus CBK grade point average and advanced placement credit for Physics Mechanics for students with averages of at least 3.25.

From the pie chart in the figure above, there appears to be a difference in the performance of students if they used advanced placement credit for Physics Mechanics. A one-sample t-test was performed in SPSS to determine if the difference was significant. Statistics show that there is a significant different at a 95% confidence level of final grades in a statics and dynamics course based on the use of advanced placement credit for Physics Mechanics (t = 8.143, df = 354, p < 0.0005). Students who have advanced placement credit tend to perform well in the statics and dynamics course. Since the differences between student grades in statics and dynamics were found to be significant, a comparison can be made of the average final grades received by students in statics and dynamics across the different CBK categories when advanced placement credit was used in Physics Mechanics. The average final grade in the statics and dynamics course based on the different CBK grade point average range is depicted in Table 28. Similar results were found when comparing average final grade in statics and dynamics based on using advanced placement credit for Physics Mechanics or in addition for Engineering Mathematics I and Engineering Mathematics II. Accepting advanced placement credit for any of the three courses results in raising the average final grade in the statics and dynamics course from 2.8 to 3.9 for CBK grade point averages of at least 3.25. As in previous comparisons, grades have been converted into a numerical format with grades of A equal to four points down to grades of F and Q equal to zero points.

Grades received in first-year related courses

After considering advanced placement and transfer credits, it is important to see what information letter grades received from individual first-year mathematics, physics mechanics, and related engineering courses provide, which are Engineering Mathematics I, Engineering Mathematics II, Physics Mechanics, and Foundations of Engineering I provided. Therefore, final grade information will be compared for each of the four courses specified to determine the effect the grade received in the prerequisite course had on the success in the sophomore-level statics and dynamics course.

Results

Course syllabi

The percentage of homework and exam problems covering these topics and the percentage of time spent on the topics in first-year mathematics courses on the topics according to the course syllabi is contrasted in Figure 46. The percentage of homework and exam problems was obtained from the q-matrix study of the first Statics and Dynamics section since nearly identical results were received for the two sections, and the first-year mathematics topics were compared to the weekly schedule listed on the course syllabi for the two first-year mathematics courses. The researcher looked for exact listings of the topics for comparison purposes. It is important to note that the figure provides an overall comparison. A percentage of homework problems related to the particular skill is compared to the percentage of time in the course is devoted to the skill. While both values are percentages, they are not directly calculated in the same way. They do, on the other hand, provide an overall comparison of the topic coverage.

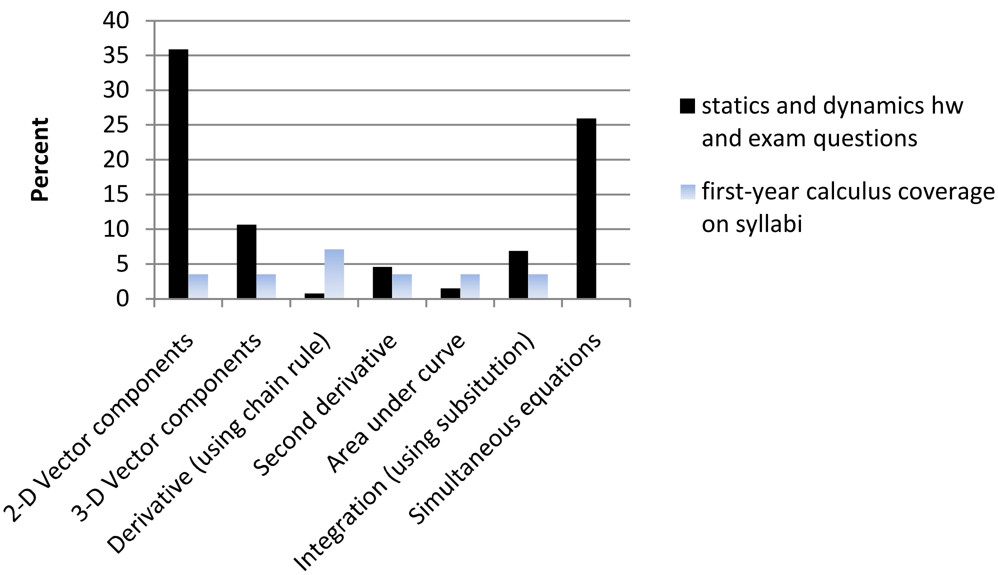


Figure 46. Alignment of first-year mathematics topics comparing percentage of homework and exam problems in Statics and Dynamics and topic list in first-year mathematics courses.

From the figure, serious alignment issues are evident. For example, important mathematics skills in the statics and dynamics homework and exam problems include two-dimensional vectors and simultaneous equations. These two topics are briefly listed as topics on the calculus syllabi, if at all.

Determined using the same method as for the previous figure, Figure 47 depicts the percentage of homework and exam problems covering the physics mechanics topics and the percentage of time spent on the topics in a first-year physics mechanics course on the topics according to the course syllabi. As with the mathematics topics, the percentages provide an overall comparison.

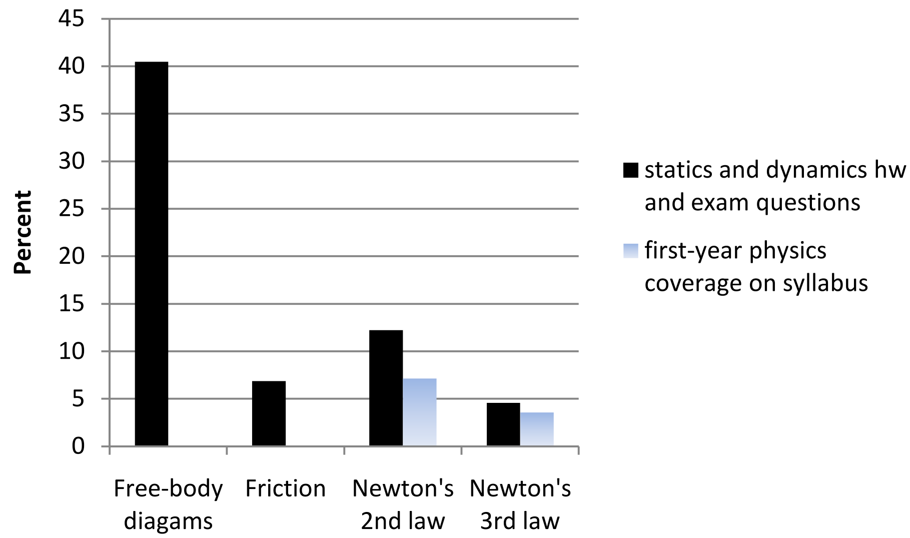


Figure 47. Alignment of first-year physics mechanics topics comparing percentage of homework and exam problems in Statics and Dynamics and topic list in a first-year physics mechanics course.

While many of the topics identified as necessary for a sophomore-level statics and dynamics course were listed on the syllabi for the prerequisite first-year mathematics and physics mechanics courses, there was a difference between the amount of coverage received in the first-year courses and the utilization of these skills based on the number of homework, exam, and quiz problems related to them. In addition, it was shown that simply because a topic is listed on the course syllabus does not provide enough information to determine the notation used when teaching the material or the actual time spent covering the material.

Course grades or completion

Correlation

While the correlation between the two first-year mathematics courses was shown to be strong (correlation coefficient = .429), the correlation of either course to the final grade received in a sophomore-level statics and dynamics course is less strong (Table 30). Values for Engineering Mathematics II, Physics Mechanics, and Foundations of Engineering I are significant at the 99% confidence level, however, the final grade in Foundations of Engineering I depicts the strongest correlation of the four courses on the final grade in the statics and dynamics course.

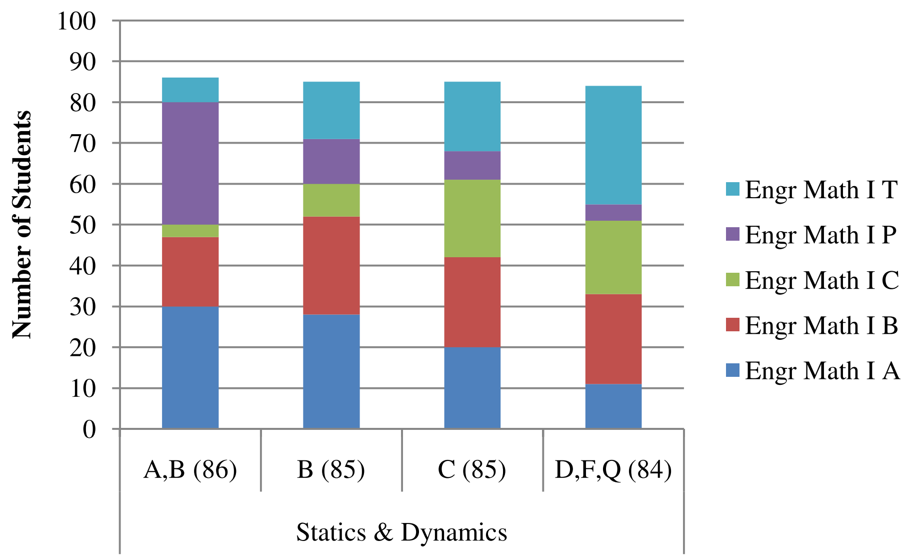
Table 30

Spearman's Rank Correlation Values for Key First-Year Courses Versus Final Grade in Statics and Dynamics Course

	Engr Math I	*Engr Math II*	*Phys Mech*	*Found Engr I*
correlation coefficient	.038	.259	.348	.515
p	.484	< .0005	< .0005	< .0005
n	340	344	340	284

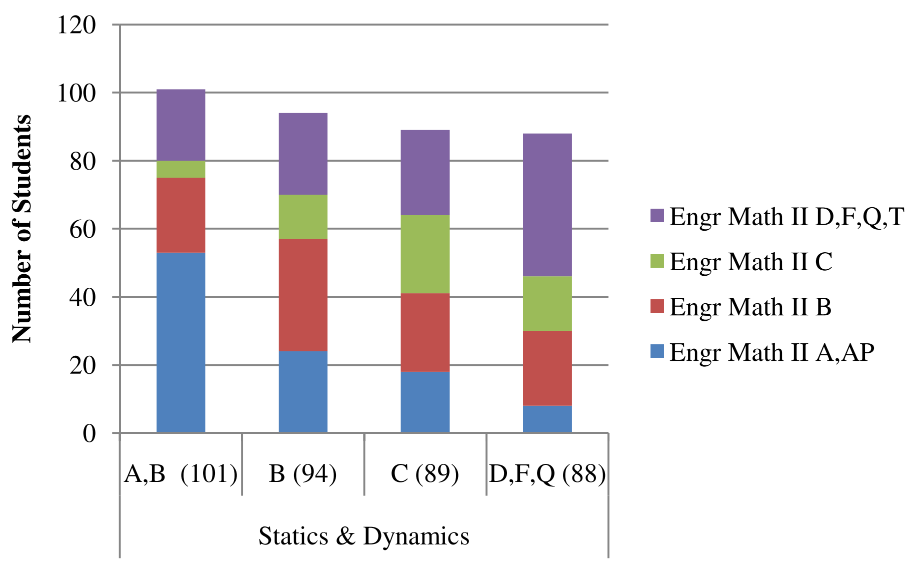
The Engineering Mathematics I and Engineering Mathematics II courses are taught as service courses for engineering students through the Mathematics Department, and the titles imply they are covering mathematics that engineering students need. In reality, the two courses have the least amount of correlation of the first-year mathematics, physics mechanics, and related engineering courses. This is a prime example of good alignment between courses similar in content but not necessarily useful for the intended course. While Engineering Mathematics I and Engineering Mathematics II seem to be properly aligned, the alignment between the courses and the intended engineering courses for which they are preparing students for is less correlated than Physics Mechanics or Foundations of Engineering I.

Similar comparisons can be made using mutual information as was computed for the comparison between the two first-year mathematics courses. The results provided are similar to those received with correlation calculations in SPSS. While the mutual information value is indicative of the correlation between the variables, the graphical view provides a better idea of how well correlated final grades in Engineering Mathematics I (Figure 48), Engineering Mathematics II (Figure 49), Physics Mechanics (Figure 50), and Foundations of Engineering I (Figure 51) are correlated with final grades received in Statics and Dynamics.



Mutual Information = .19

Figure 48. Mutual information received when grade in Engineering Mathematics I and grade in Statics and Dynamics was compared.



Mutual Information = .16

Figure 49. Mutual information received when grade in Engineering Mathematics II and grade in Statics and Dynamics was compared.

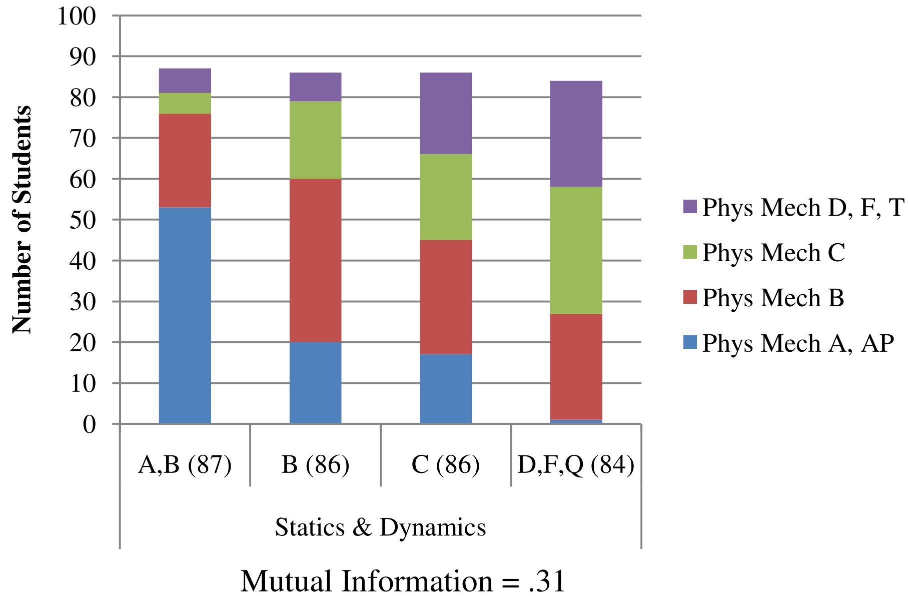


Figure 50. Mutual information received when grade in Physics Mechanics and grade in Statics and Dynamics was compared.

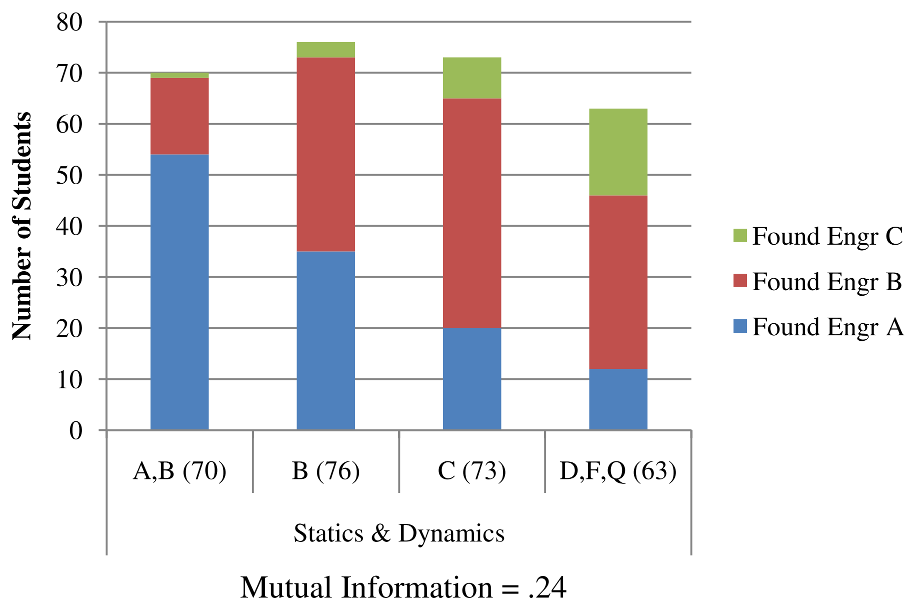


Figure 51. Mutual information received when grade in Foundations of Engineering I and grade in Statics and Dynamics was compared.

Course grades and credits received

The data has shown there are definite differences between the grades students receive by transfer for first-year mathematics and physics mechanics courses and the grades earned in a sophomore-level statics and dynamics course, which contains the three courses as prerequisites. The most critical difference occurred with students who have CBK grade point averages less than 3.0 (Table 23). An area of weakness for students in the CBK grade point average range of 3.0-3.249 is students who have transfer credit for Engineering Mathematics II (Table 26). These students have a 2:1 odds of receiving a grade of D, F, Q in a sophomore-level statics and dynamics course versus a grade of C. Students with a CBK grade point average above a 3.25 are more evenly split between grades of A, B and grade of C, D, F, and Q most likely due in part to dual credit received while in advanced high school courses (Table 27). Students who earned advanced placement credits typically have higher grade point averages and perform well in the statics and dynamics course.

Simply earning a passing grade of at least a C in a sophomore-level statics and dynamics course is not the only thing important to students and administrators, however. As a fundamental course in the curriculum, processes should be in place to assist students with earning a grade of A or B in the statics and dynamics course. Since this is such a fundamental course, the thought is that skills need to be refined to be successful in follow-on courses. Further review outside the scope of this study could examine the success in subsequent engineering courses and the retention of engineering students who earned a grade of A or B versus a grade of a C in a sophomore-level statics and dynamics course.

Figure 52 shows the ratio of students in each course who earned a grade of A categorized by final rank in class for the sophomore-level statics and dynamics course. The ratio percentage was computed and is displayed in the figure instead of the individual number count of students. This allows results to be equally compared to each other. Only students who also had a CBK grade point average are included in this table, so that a comparison breakdown can be shown splitting the numbers out by different CBK grade point average ranges. Three students did not have a CBK grade point average since all of their credits were from advanced placement, which technically does not have a grade associated with it. Since transfer and advanced placement credit have already been evaluated, the table only includes information on grades of A, B, or C in the courses.

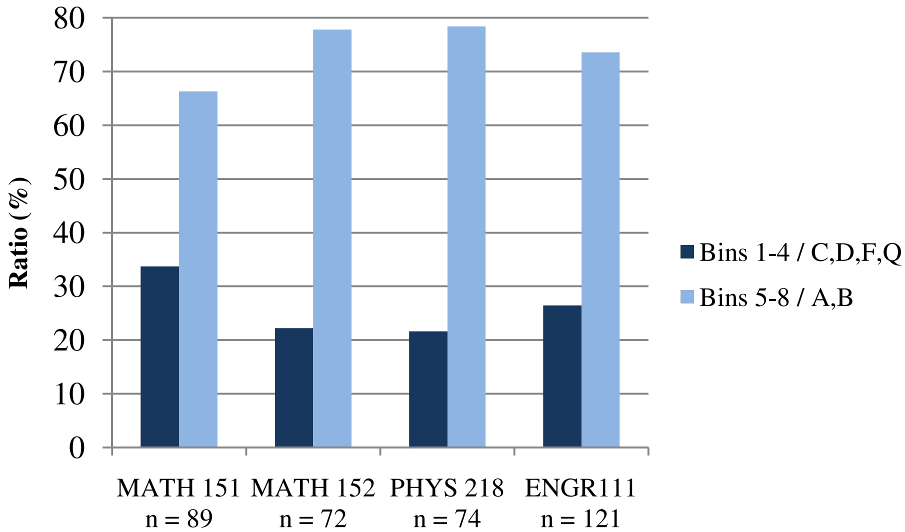


Figure 52. Ratio of students in sample earning a grade of A in first-year mathematics, physics mechanics, and related engineering courses along with number of students in each sample (split into halves).

As shown in the figure, there is a very high probability of students, from 5:1 for Engineering Mathematics II to 2:1 for Engineering Mathematics I, who earn a grade of A in one of the related first-year courses will earn an A in the sophomore-level statics and dynamics course. When the information is analyzed even further as shown in Figure 53, with the exception of Engineering Mathematics I there is a high probability of passing the statics and dynamics course with at least a grade of C, and the likelihood is high the grade will be an A or B. The final ranks for the statics and dynamics course with earning a grade of A in Engineering Mathematics I are much closer, although the probability is still high the final grade in the statics and dynamics course will be passing with at least a C.

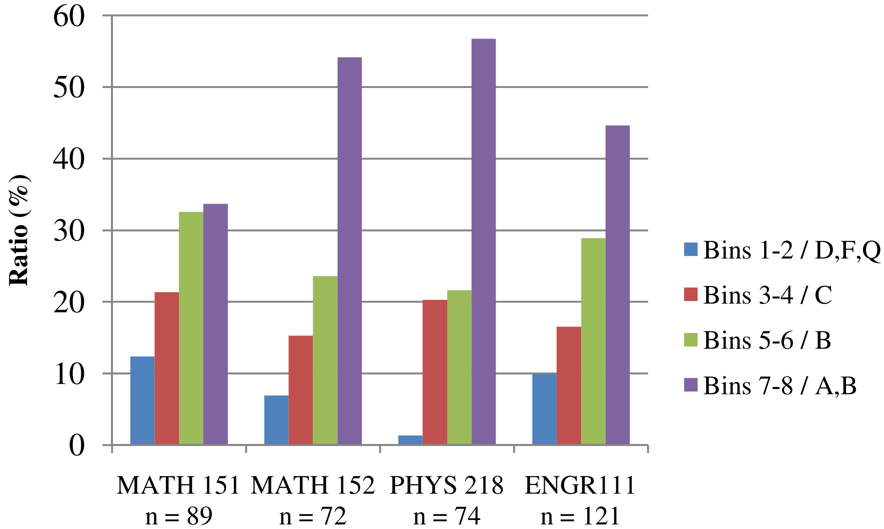


Figure 53. Ratio of students in sample earning a grade of A in first-year mathematics, physics mechanics, and related engineering courses along with number of students in each sample (split into quarters).

Similar information can displayed for grades of B and C received in the related first-year courses. Figure 54 shows the ratio of students in each course who earned a grade of B categorized by final rank in class for the sophomore-level statics and dynamics course.

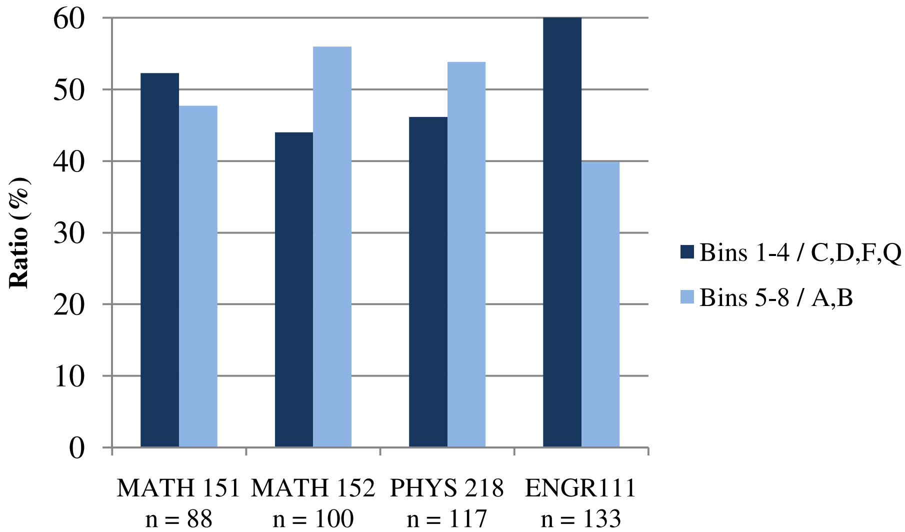


Figure 54. Ratio of students in sample earning a grade of B in first-year mathematics, physics mechanics, and related engineering courses along with number of students in each sample (split into halves).

As shown in the figure, the probability that students who earn a grade of B in one of the related first-year courses will fall into either the top half of students or the lower half of students determined by final rank in class is split. There is not much distinction between the two groups. When the information is analyzed even further as shown in Figure 55, the likelihood of being in any of the four final ranks in class is fairly even. Approximately 25% of the students who earn a grade of B in one of the related first-year courses will earn a D, F, or Q in the statics and dynamics course.

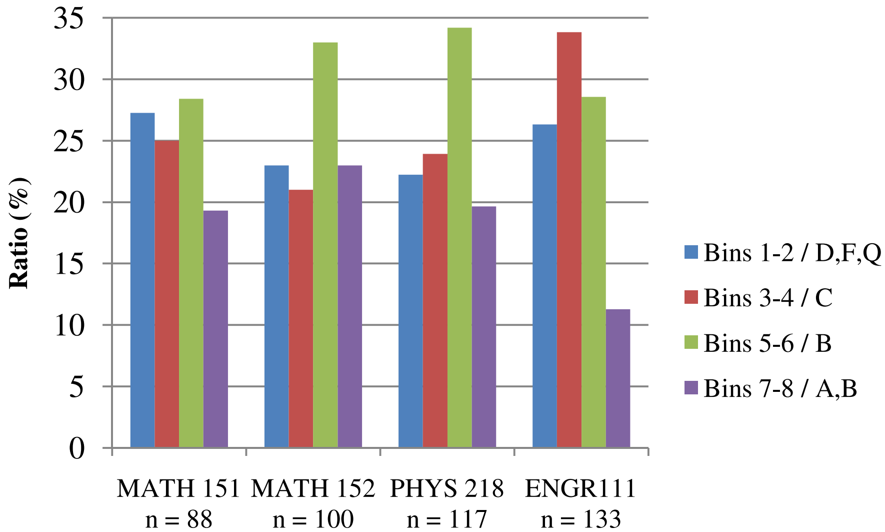


Figure 55. Ratio of students in sample earning a grade of B in first-year mathematics, physics mechanics, and related engineering courses along with number of students in each sample (split into quarters).

Evaluating the outcomes for students who earned a grade of C in the related first-year courses, Figure 56 displays the ratio of students in each course who earned a grade of C categorized by final rank in class for the sophomore-level statics and dynamics course.

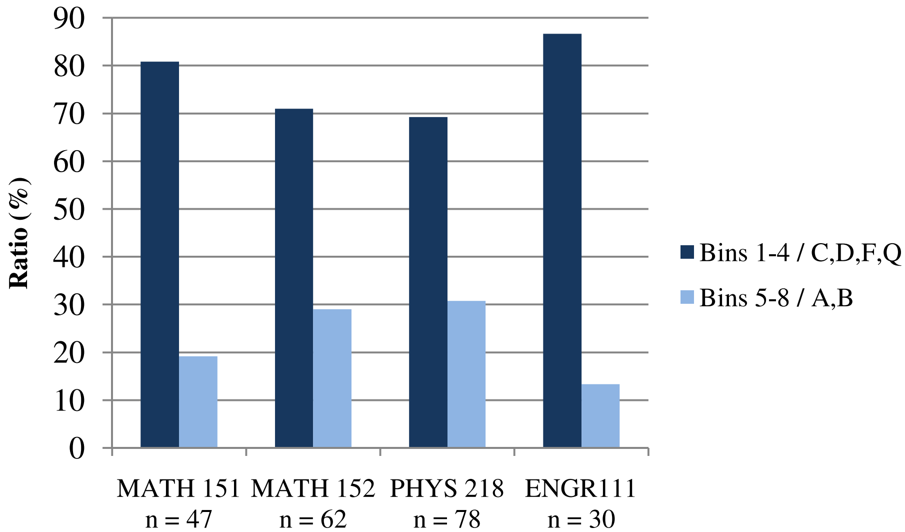


Figure 56. Ratio of students in sample earning a grade of C in first-year mathematics, physics mechanics, and related engineering courses along with number of students in each sample (split into halves).

As shown in the figure, there is a very high probability of students, from 5:1 for Foundations of Engineering I to a little over 2:1 for Physics Mechanics, who earn a grade of C in one of the related first-year courses will fall into the lower half of the class based on final rank in the statics and dynamics course. When the information is analyzed even further as shown in Figure 57, there is a very low probability that the student will earn a grade of A in the statics and dynamics course. With Foundations of Engineering I and Physics Mechanics, the likelihood is high that the final grade in the statics and dynamics course will be D, F, or Q.

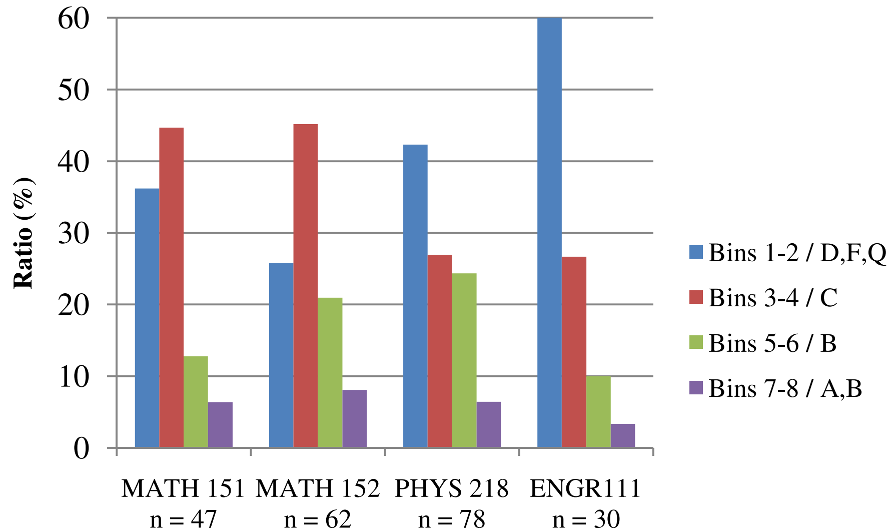


Figure 57. Ratio of students in sample earning a grade of C in first-year mathematics, physics mechanics, and related engineering courses along with number of students in each sample (split into quarters).

To obtain a clearer picture, Spearman's rank correlation was computed in SPSS for credits earned by grades of A received in Engineering Mathematics I, Engineering Mathematics II, Physics Mechanics, and Foundations of Engineering I. There was significant correlation at the 95% confidence level for the four courses. Therefore, only details on grades of A received in Physics Mechanics was evaluated further. This course was selected due to the strong correlation of the course in general to final grade in statics and dynamics and consistency from the details provided on transfer and advanced placement credits.

Figure 58 compares the ratio of students with CBK grade point averages at least 3.25 who earned an A or B in statics and dynamics and those that earned a grade of C, D, F, or Q in the course with the same group of students that also earned grades of A, B, and C for Physics Mechanics. As shown in the figure, students who earned grades of A in Physics Mechanics had a higher ratio of earning an A or B in a statics and dynamics course. Students who earned a B in Physics Mechanics had almost an even split in their success in a statics and dynamics course. Students who earned a grade of C had a much lower ratio of earning an A or B in a statics and dynamics course.

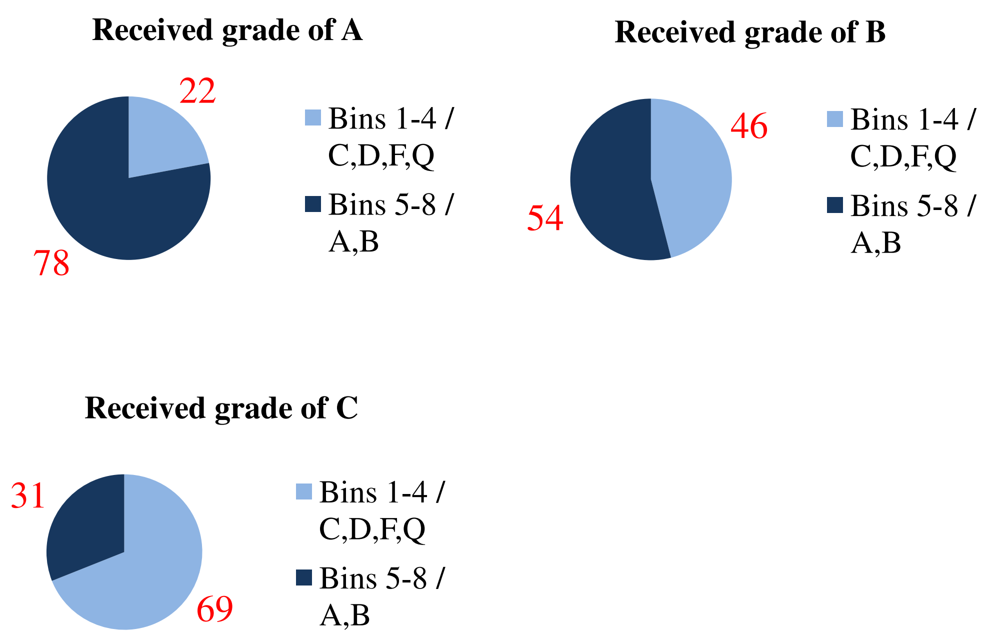


Figure 58. Comparison of final course grades in a statics and dynamics course based on grades of A, B, and C earned in Physics Mechanics.

Figure 59 breaks down the final course grades received in a statics and dynamics course even further to show a comparison of ratio of students in the top and lower half and those same students split into quarters if they earned a grade of A in Physics

Mechanics. The information provided in this figure provides further detail, especially on the C and D, F, Q comparisons. The breakdown of grades by quarters is 57% A, B; 21% B; 21% C; and 1% D, F, Q.

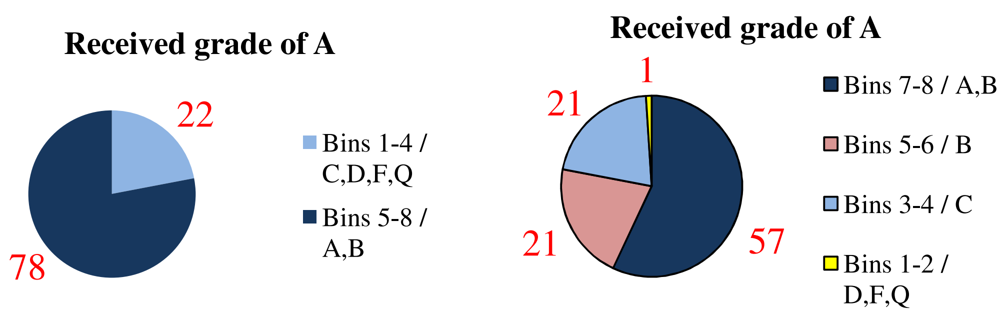


Figure 59. Comparison of final course grades in a statics and dynamics course, split into halves and quarters, based on grades of A earned in Physics Mechanics.

Figure 60 breaks down the final course grades received in a statics and dynamics course even further to show a comparison of ratio of students in the top and lower half and those same students split into quarters if they earned a grade of B in Physics Mechanics. The information provided in this figure provides further detail, especially on the C and D, F, Q comparisons. The breakdown of grades by quarters is 20% A, B; 34% B; 24% C; and 22% D, F, Q.

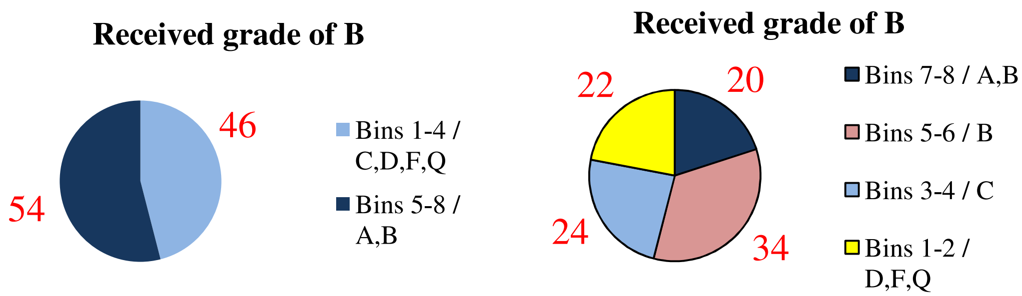


Figure 60. Comparison of final course grades in a statics and dynamics course, split into halves and quarters, based on grades of B earned in Physics Mechanics.

Figure 61 breaks down the final course grades received in a statics and dynamics course even further to show a comparison of ratio of students in the top and lower half and those same students split into quarters if they earned a grade of A in Physics Mechanics. The information provided in this figure provides further detail, especially on the C and D, F, Q comparisons. The breakdown of grades by quarters is 6% A, B; 25% B; 27% C; and 42% D, F, Q.

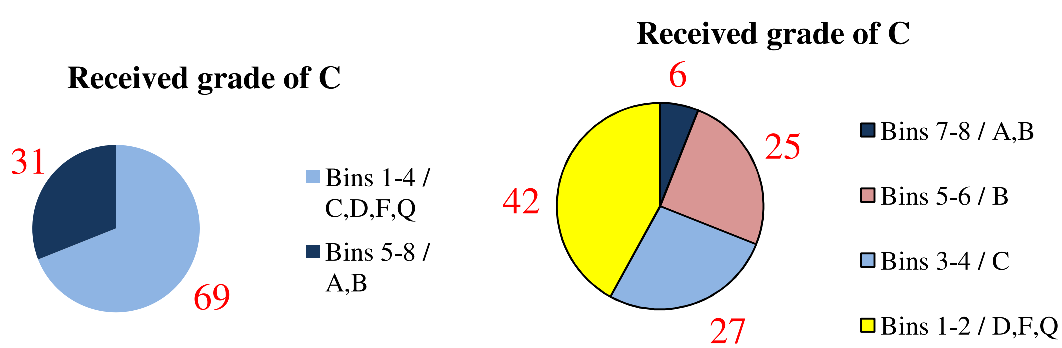


Figure 61. Comparison of final course grades in a statics and dynamics course, split into halves and quarters, based on grades of C earned in Physics Mechanics.

As shown by the previous figures, grades of A received in Physics Mechanics, result in high ratios of being successful and passing the sophomore-level statics and dynamics course. The likelihood is high that the final grade in a statics and dynamics course will be an A or B and at least a grade of C. Earning a grade of B in Physics Mechanics does not provide significant information about the outcome in the statics and dynamics course as the ratio of students in each quarter is relatively the same. Grades of C received in Physics Mechanics indicates a very high probability the final grade of the student in the statics and dynamics course will be a C, D, F, or Q with a large ratio of students earning a D, F. or Q grade.

Grade point averages of less than 3.0

Thus far, students with CBK grade point averages less than 3.0 have been shown not to perform as well in earning a top rank for final grade in a sophomore-level statics and dynamics course. In addition, the students with averages below 3.0 who have utilized transfer credit for Engineering Mathematics I, Engineering Mathematics II, or Physics Mechanics have also shown greater probability for lower final rank in class for the statics and dynamics course. Therefore, this group of CBK grade point averages less than 3.0 was separated to evaluate their experiences in the statics and dynamics course based on final grades received in the related first-year courses.

Figure 62 contains the breakdown by rank in class for a sophomore-level statics and dynamics course for students with less than a 3.0 CBK grade point average who earned a grade of A in one of the related first-year courses. As shown in the figure, there is a very small number of students who have below a 3.0 CBK average and receive a grade of A in one of the courses. There is not much information that can be gained from this group.

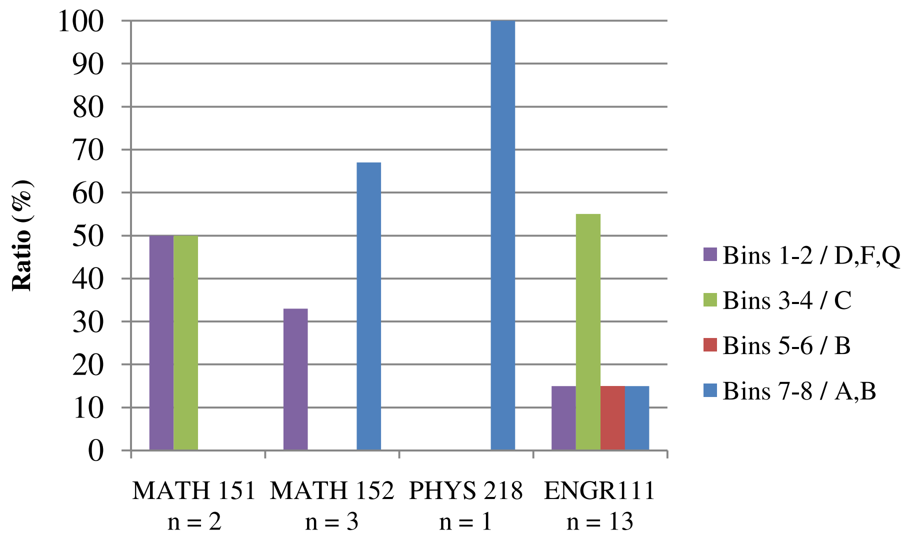


Figure 62. The ratio of students in the sample who entered with a CBK grade point average of below 3.0 and earned a grade of A in first-year mathematics, physics mechanics, and related engineering courses is separated into final rank in class for a sophomore-level statics and dynamics course.

Figure 63 contains the breakdown by rank in class for a sophomore-level statics and dynamics course for students with less than a 3.0 CBK grade point average who earned a grade of B in one of the related first-year courses. As shown in the figure, there is a very high probability that the final rank in class for the statics and dynamics course will be in the C, D, F, or Q range. When all CBK grade point averages were considered, there was an even split between the different four final ranks in class for students who earned a grade of B in one of the related first-year courses. When only averages less than 3.0 are considered, the disparity in the final ranks being in the lower half is highlighted. The probability is quite high in each of the four courses that the final rank in class will correspond to a D, F, or Q received in the statics and dynamics course.

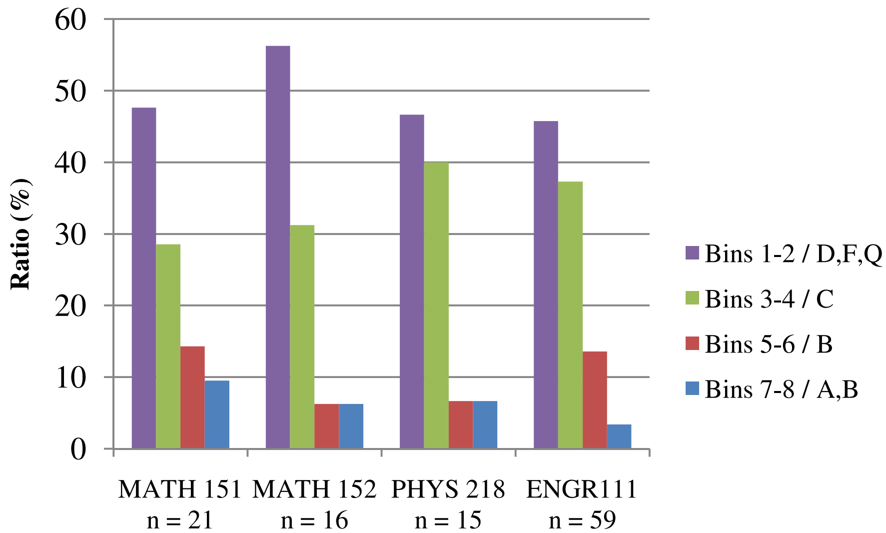


Figure 63. The ratio of students in the sample who entered with a CBK grade point average of below 3.0 and earned a grade of B in first-year mathematics, physics mechanics, and related engineering courses is separated into final rank in class for a sophomore-level statics and dynamics course.

Figure 64 contains the breakdown by rank in class for a sophomore-level statics and dynamics course for students with less than a 3.0 CBK grade point average who earned a grade of C in one of the related first-year courses. As shown in the figure, the probability that the student will then earn a grade of A or B in the statics and dynamics course is very low. There is a high probability the final rank in class for the statics and dynamics course will be in the C, D, F, or Q range. For Physics Mechanics and Foundations of Engineering I, the probability is even higher the final grade will be D, F, or Q.

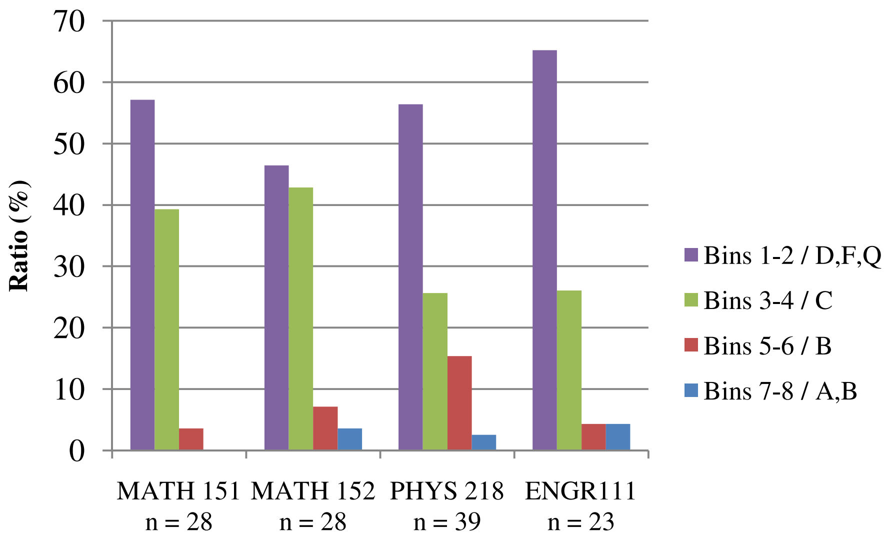


Figure 64. The ratio of students in the sample who entered with a CBK grade point average of below 3.0 and earned a grade of C in first-year mathematics, physics mechanics, and related engineering courses is separated into final rank in class for a sophomore-level statics and dynamics course.

As the information in the figures depict, a student has a very low probability of earning an A or B in a sophomore-level statics and dynamics course if their CBK grade point average is below a 3.0 and the student earned a grade of grade of B or especially C in one of the four first-year related courses.

Students who earned grades of B in Foundations of Engineering I and the possibility of intervention to improve performance

The final rank in class is studied to determine if significant differences occur for students who earn a B in Foundations of Engineering I based on their CBK grade point averages. Table 31 provides a breakdown of how the number of grades of C, D, F, and Q related to the total number of students in that category for grades of B earned in

Foundations of Engineering I. For example, 133 students received a B in Foundations of Engineering I. When the CBK grade point averages were compared using an independent samples t-test in SPSS for students earning an A, B versus C, D, F, Q, there was a significant difference between the means of the two groups. Likewise, the differences of the means were significant for the group with CBK grade point averages less than 3.25. The group with grade point averages less than 3.0 did not have a significant difference in the means of the CBK grade point averages for students who earned an A, B versus students who earned a C, D, F, Q. The difference in the average means of the CBK grade point averages were too close to each other in the tight spread of less than 3.0 to be significant. Basically, it would be advantageous to the 49 students in the C, D, F, Q final rank in class students if proper intervention could assist them with moving from the C, D, F, Q to an A or B category.

Table 31

Determination if Final Rank in Class is Statistically Different for Students Who Earned a B in Foundations of Engineering I Based on Entering CBK Grade Point Averages

CBK Range	n	C,D,F,Q in S&D	Levene's Test	Equal Variances	t	df	p	Significant
All	133	80	0.140	Yes	-5.860	131	< .0005	Yes
< 3.25	87	69	0.004	No	-4.860	84.294	< .0005	Yes
< 3.0	58	49	0.151	Yes	-1.813	56	0.075	No

Note. The third column contains number of students with final rank in class for the sophomore-level Statics and Dynamics course that corresponds to grades of C, D, F, or Q.

Using the instruments as potential intervention tools for grades of B in Foundations of Engineering I

To consider how intervention might be helpful in an Foundations of Engineering I course, the data is mined further to consider first the students who received a final grade of in B in Foundations of Engineering I to determine if their skills on the mathematics instrument, physics instrument, mathematics linear algebra questions, or physics free body diagram questions provide any further clarification. Foundations of Engineering I was selected as it is taught by engineering faculty members, and it contains first-year mathematics and physics mechanics content used in a statics and dynamics course.

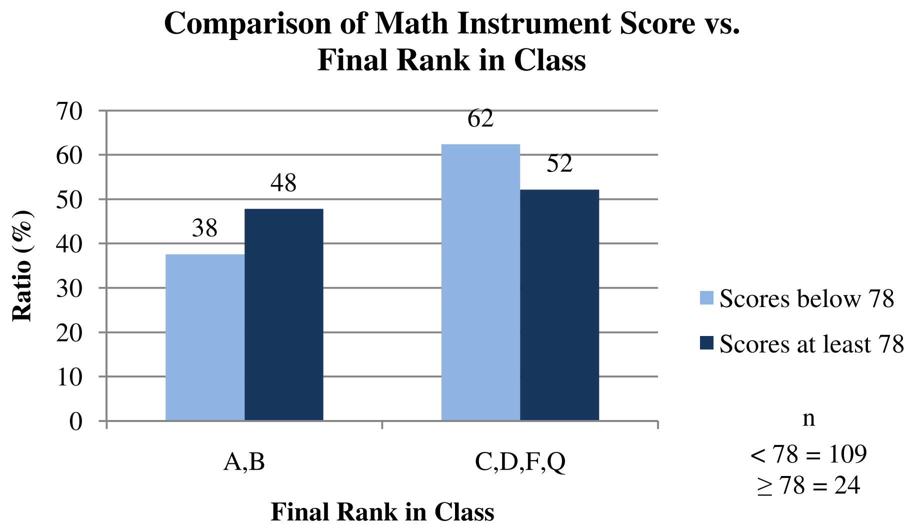


Figure 65. Comparison of percent correct score on the mathematics instrument versus final rank in Statics and Dynamics split into halves. The selection of score cut-offs was determined in Figure 21.

Figure 65 displays the comparison of the score received on the mathematics instrument compared to the final rank in class in a sophomore-level statics and dynamics course for students who received a grade of B in Foundations of Engineering I. Since an unequal amount of students scored in the lower half of the scores versus the top half of the scores, the ratio of students in each category was computed and is displayed in the figure instead of the individual number count of students. This way, results can equally be compared to each other. Using the results obtained earlier in Figure 21, the students were split into two groups based on their scores on the mathematics instrument, scores below 78 and scores of at least 78. As previously shown, students in the first range of scores below 78 on average had final grades in the course of below B, or 3.0 points on a four point scale.

While there does appear to be advantages of scoring at least 78 on the mathematics instrument and then earning an A or B in a sophomore-level statics and dynamics course, it does not necessarily predict where a student will fall in regards to the final grade. An independent samples t-test determined there was no significance (t = -0.677, df = 131, p = 0.500). Since the p-value is greater than 0.05, the null hypothesis cannot be rejected; therefore, there is no significance difference between the means scores of the mathematics instrument related to final grades for a sophomore-level statics and dynamics course for the lower half of the scores on the instrument versus the top half of the scores on the instrument overall, at the 95% confidence level. Figure 66 provides the breakdown into quarters for scores on the mathematics instrument versus final rank in class for the statics and dynamics course.

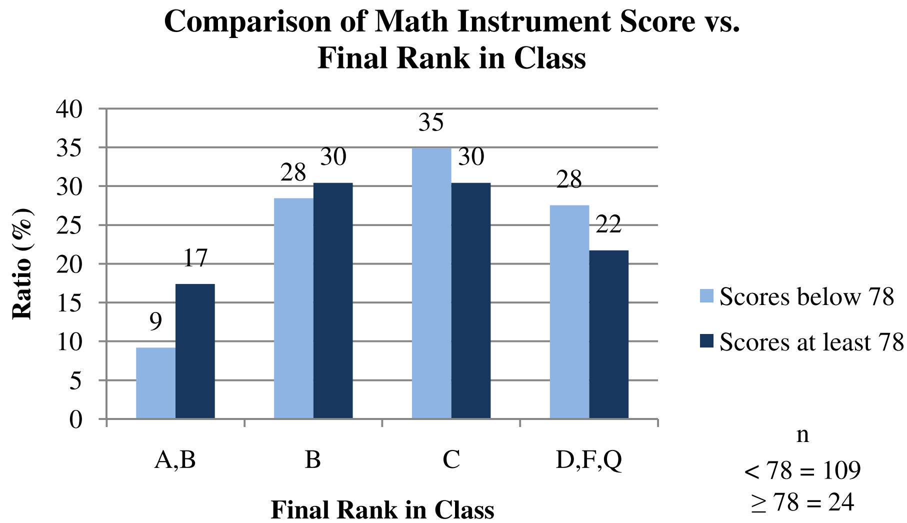


Figure 66. Comparison of percent correct score on the mathematics instrument versus final rank in Statics and Dynamics split into quarters. The selection of score cut-offs was determined in Figure 21.

Figure 67 displays the comparison of the score received on the four linear algebra related questions on the mathematics instrument compared to the final rank in class in a sophomore-level statics and dynamics course for students who received a grade of B in Foundations of Engineering I. Again, the ratio of students in each category was computed and is displayed in the figure instead of the individual number count of students for comparison purposes. Looking at the scores of the linear algebra questions provided even less information than the mathematics instrument as a whole. Performing well on these four questions did not provide much indication of the final grade in the sophomore-level statics and dynamics course at least for students who earned a B in Foundations of Engineering I.

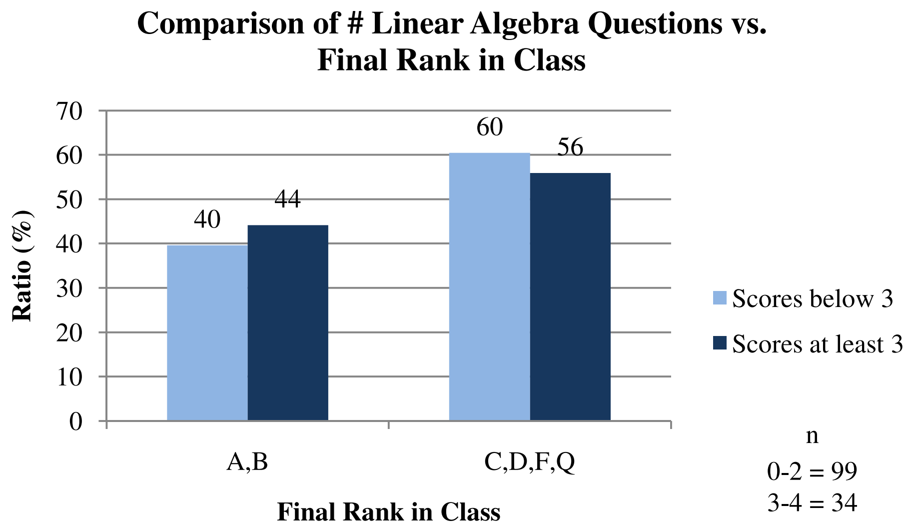


Figure 67. Comparison of correct number of answers on the four linear algebra questions on the mathematics instrument versus final rank in Statics and Dynamics split into halves. The selection of score cut-offs was determined in Figure 23.

An independent samples t-test determined there was no significance (t = -0.257, df = 131, p = 0.797). Since the p-value is greater than 0.05, the null hypothesis cannot be rejected; therefore, there is no significant difference between the means scores of the four linear algebra questions on the mathematics instrument related to final grades for a sophomore-level statics and dynamics course for the lower half of the scores versus the top half of the scores overall, at the 95% confidence level. Note that the breakdown in categories as shown in Figure 23 for a cut-off of 3.0 points, or grade of B, was achieved by students who answered all four linear algebra questions correctly. However, only six students earned a B in Foundations of Engineering I and answered all four linear algebra questions correctly on the mathematics instrument. The error bar signifying the upper bound of the 95% confidence interval was very near 3.0 in the figure. Therefore, a score range of correctly answering less than three linear algebra questions and then at least three linear algebra questions correctly was considered. This provided a more sizable sample of 34 for comparison.

Refining the data even further into quarters show the lack of consistency between answering the linear algebra questions correctly on the mathematics instrument and final rank in class in a sophomore-level statics and dynamics course (Figure 68). The inconsistencies are even more evident in the A, B and D, F, Q ranks.

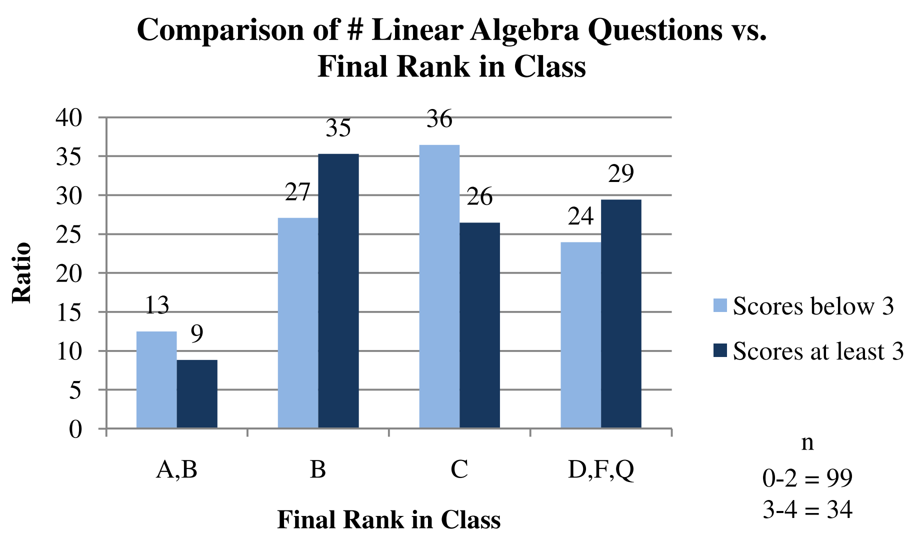


Figure 68. Comparison of correct number of answers on the four linear algebra questions on the mathematics instrument versus final rank in Statics and Dynamics split into quarters. The selection of score cut-offs was determined in Figure 23.

The same set of comparisons will now be made for the physics instrument. Figure 69 displays the comparison of the score received on the physics instrument compared to the final rank in class in a sophomore-level statics and dynamics course for students who received a grade of B in Foundations of Engineering I. The range of scores utilized in the evaluation was the cut-off scores on average obtained from Figure 25 for grades below B and B and above. Again, the ratio of students in each category was computed and is displayed in the figure instead of the individual number count of students for comparison purposes.

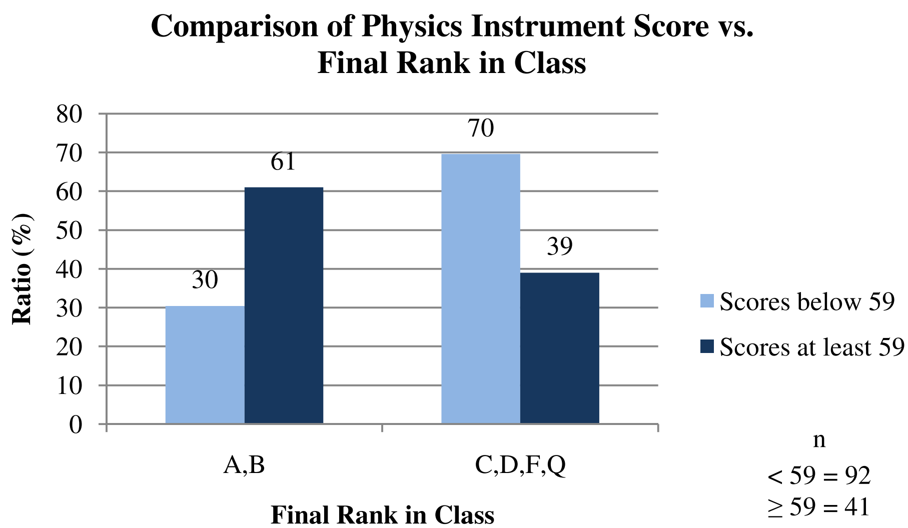


Figure 69. Comparison of percent correct score on the physics instrument versus final rank in Statics and Dynamics split into halves. The selection of score cut-offs was determined in Figure 25.

Unlike the mathematics instrument, there is a significant difference in final rank in class for a sophomore-level statics and dynamics course based on score received on the physics instrument. An independent samples t-test determined there was significance (t = -3.521, df = 131, p = 0.001). Since the p-value is less than 0.05, the null hypothesis is rejected; therefore, there is a significance difference between the means scores of the physics instrument related to final grades for a sophomore-level statics and dynamics course for the lower half of the scores versus the top half of the scores overall, at the 95% confidence level for the range of scores specified.

A refinement of the data into quarters shows even more disparity of results in the A, B final rank in class for students who scored less than 59 on the physics instrument versus students who scored at least 59 as shown in Figure 70.

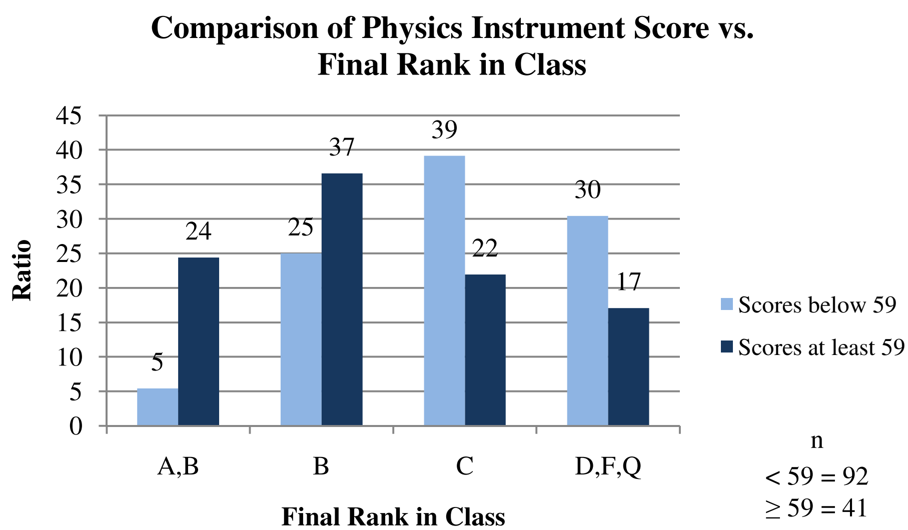


Figure 70. Comparison of percent correct score on the physics instrument versus final rank in Statics and Dynamics split into quarters. The selection of score cut-offs was determined in Figure 25.

Figure 71 displays the comparison of the score received on the seven free body diagram related questions on the physics instrument compared to the final rank in class in a sophomore-level statics and dynamics course for students who received a grade of B in Foundations of Engineering I. Again, the ratio of students in each category was computed and is displayed in the figure instead of the individual number count of students for comparison purposes.

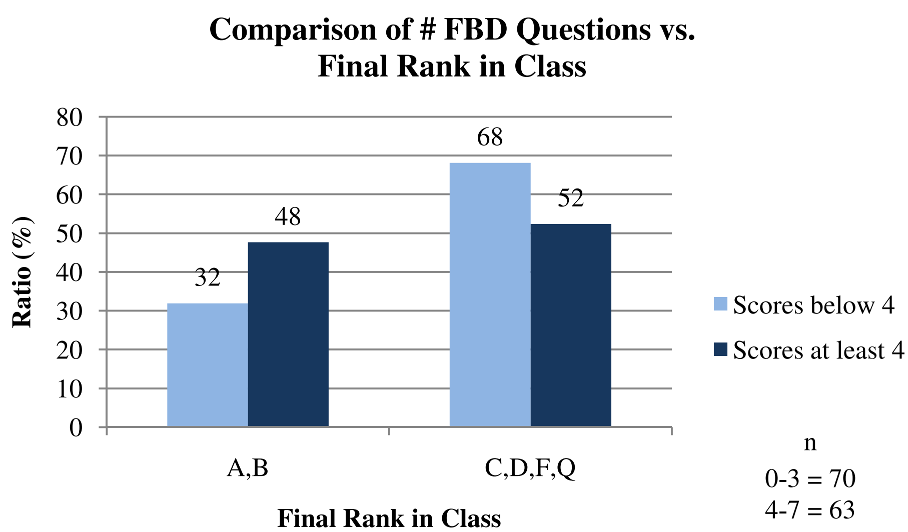


Figure 71. Comparison of correct number of answers on the seven free-body diagram questions on the physics instrument versus final rank in Statics and Dynamics split into halves. The selection of score cut-offs was determined in Figure 27.

The results of evaluating the free body diagram questions were very similar to those received for the physics instrument as a whole. An independent samples t-test determined there was significance (t = -2.022, df = 131, p = 0.045). Since the p-value is less than 0.05, the null hypothesis is rejected; therefore, there is a significance difference between the means scores of the free body diagram related physics instrument related to final grades for a sophomore-level statics and dynamics course for the lower half of the scores versus the top half of the scores overall, at the 95% confidence level for the two ranges of scores.

Again, a breakdown of the data into quarters signify a large difference in results in the A, B rank for students who receive less than four of the seven free-body diagram questions correctly versus those students who answered at least four of the free-body diagram questions correctly as depicted in Figure 72.

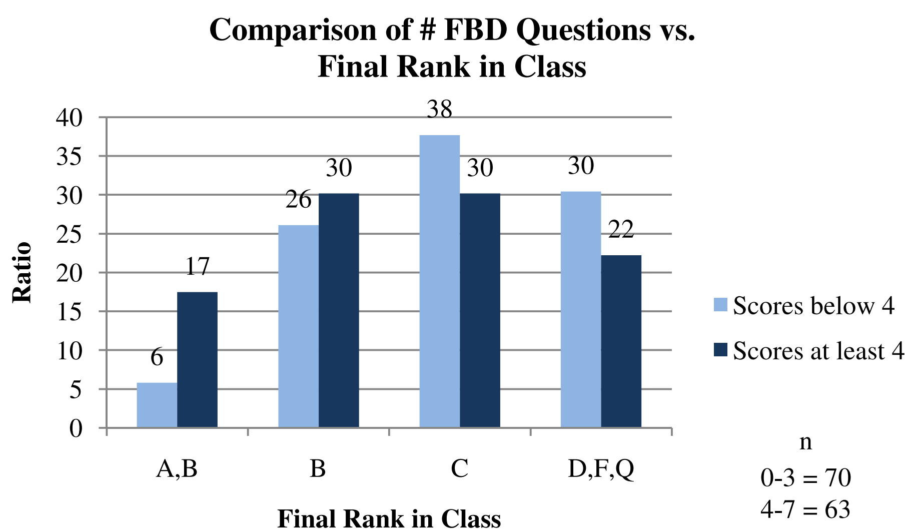


Figure 72. Comparison of correct number of answers on the seven free-body diagram questions on the physics instrument versus final rank in Statics and Dynamics split into quarters. The selection of score cut-offs was determined in Figure 27.

Thus far, there does not seem to be significant information related to the mathematics instrument students completed to help distinguish success in a sophomore-level statics and dynamics course for students who earn a grade of B in Foundations of Engineering I. However, students who earned a grade of B in Foundations of Engineering I and either received a grade below 59 on the physics instrument or answered less than four of the free-body diagram questions correctly on the physics instrument have a significant possibility that their final rank in class in a sophomore-level statics and dynamics course will be in the C, D, F, or Q range.

While all grade point averages were considered in the analysis of students who received a B in Foundations of Engineering I, Figure 73 depicts the percent score received on the physics instrument versus final grade received in statics and dynamics for the subset of CBK grade point averages between 2.85 and 3.249 who earned a grade of B in Foundations of Engineering I. As shown, results are similar to those depicted in Figure 69, which provides further evidence that an intervention focusing on physics skills for students earning a grade of B in Foundations of Engineering I might improve the likelihood of success in a statics and dynamics course.

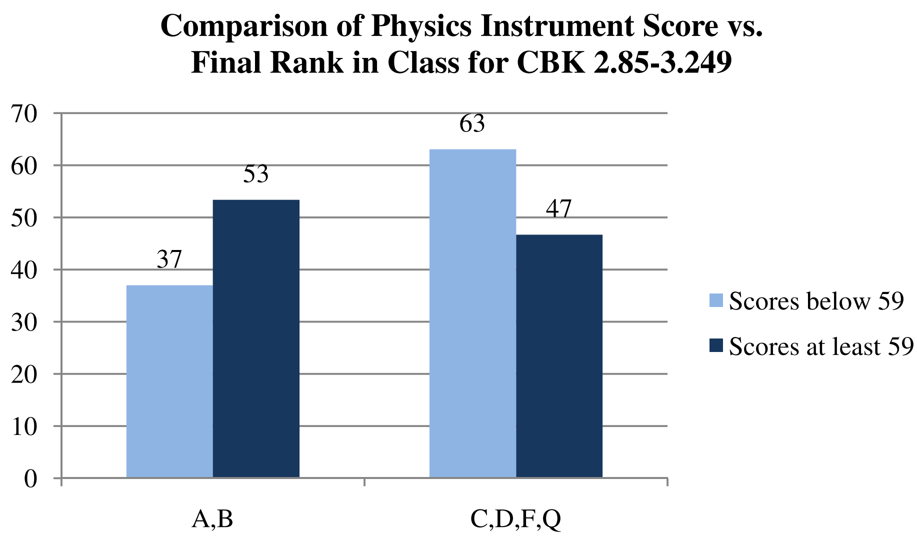


Figure 73. Comparison of percent correct score on the physics instrument versus final rank in Statics and Dynamics split into halves specifically for CBK grade point averages 2.85-3.249. The selection of score cut-offs was determined in Figure 25.

Variance explained

As has been shown through correlation coefficients, charts, and significance t-tests, CBK grade point averages and the grade in Physics Mechanics have shown importance in the success in a statics and dynamics course. Therefore, these two factors were selected for the ANOVA analysis to determine the amount of variance explained from these factors. In each of the models, the dependent variable was final rank in a statics and dynamics course.

In the first model, a one-way ANOVA test was performed with CBK grade point average as the categorical independent variable. CBK grade point averages were categorized into the four ranges used through the study, which were below 2.85, 2.85-2.99, 3.0-3.249, and at least 3.25. These categories will be used for any type of CBK grade point average calculations categorized as independent variables. The independent variable, CBK grade point average was significant at a 95% confidence level ($p < 0.0005$), and the variance explained by the model was 33%.

In the second model, a one-way ANOVA test was conducted with an independent variable of grade received in Physics Mechanics. The categories used for the Physics Mechanics were each of the grade types students earned, which included grades of A, B, C, and D, transfer credit, and advanced placement credit. These categories will be used for any type course grades categorized as independent variables. The independent variable was again determined to be significant ($p < 0.0005$) with the amount of variance explained by this model equal to 29%.

The third model contained grade received in Physics Mechanics and CBK grade point average calculated without the grade in Physics Mechanics. By not including the grade received in Physics Mechanics as part of the CBK grade point average, the two variables are more likely to be independent of each other. When calculating ANOVA, the two independent variables, grade in Physics Mechanics and reduced CBK grade point average, were significant at a 95% confidence level ($p < 0.0005$ for each variable). The interaction between the two variables was not significant. Therefore, the procedure was recalculated with only the two independent variables. The two variables were significant ($p < 0.0005$ for each variable), and the variance explained by the model was 42%.

To compare these results with other prerequisite courses for statics and dynamics, the amount of variance explained by Foundations of Engineering I and

Engineering Mathematics II were considered. Similar to the models related to Physics Mechanics above, results were obtained for the independent variable of grade received in the course and then for independent variables of grade received in the course and the reduced CBK grade point average calculated without including the course.

For the model including independent variable of grade received in Foundations of Engineering I, the independent variable was significant ($p < 0.0005$) with the amount of variance explained by this model equal to 21%. In the next model when reduced CBK grade point average without the grade in the course was added as an independent variable, the variables were significant at a 95% confidence level ($p < 0.0005$ for each variable). The interaction between the two variables was not significant. Therefore, the procedure was recalculated with only the two independent variables. The two variables were significant ($p < 0.0005$ for each variable), and the variance explained by the model was 31%.

Using grade received in Engineering Mathematics II as the independent variable, the variable was significant ($p < 0.0005$) with the amount of variance explained by this model equal to 15%. In the next model when reduced CBK grade point average without the grade in the course was added as an independent variable, the variables were significant at a 95% confidence level ($p < 0.0005$ for each variable). The interaction between the two variables was not significant. Therefore, the procedure was recalculated with only the two independent variables. The two variables were significant ($p < 0.0005$ for each variable), and the variance explained by the model was 29%.

To determine if including more of the prerequisite courses explained more of the variance, two models were developed, which included multiple course grades in the first-year related courses. Since Physics Mechanics and Foundations of Engineering I had higher correlation values to the final grade in statics and dynamics, the grades students received in these courses, along with the reduced CBK grade point average calculated without including the grades from these courses, were used as independent variables. The independent variables were significant at a 95% confidence level ($p < 0.0005$ for Physics Mechanics grade and reduced CBK average, $p = 0.001$ for Foundations of Engineering I), and the variance explained by the model was 39%.

For the next model, the grade received in Engineering Mathematics II was added as an independent variable, and the CBK grade point average was further reduced excluding the information on the additional course. All of the independent variables were significant at a 95% confidence level with the exception of grade received in Engineering Mathematics II ($p < 0.0005$ for Physics Mechanics grade, $p = 0.002$ for Foundations of Engineering I grade, and $p = 0.001$ for reduced CBK average). Therefore, the grade received in Engineering Mathematics II would be excluded as an independent variable, which would reduce down to the previous model.

For the final model, several independent variables were added to previous models to determine if more information would explain more of the variance. Independent variables included all four prerequisite courses from the first year, the reduced CBK grade point average calculated without including information from the four courses, and gender. The independent variables were significant at a 95%

confidence level with the exception of grade received in Engineering Mathematics I, Engineering Mathematics II, and gender ($p < 0.0005$ for Physics Mechanics grade and reduced CBK average, $p = 0.002$ for Foundations of Engineering I grade). Therefore, the three non-significant grades and gender variables would be excluded as independent variables, which would reduce down to a previous model.

After constructing the different models, several determinations can be made. A p-value being significant indicates there is a difference in one of the levels of the factors. The amount of the variance accounted for in the different levels is provided by changing the R^2 value to a percentage. The amount of variance explained by any of the models is less than 50%, so there is more to the success of a student in a statics and dynamics course than what was measured in this study. However, the models do show that more information is not always helpful. For examples, the highest variance was explained by looking at only two independent variables: grade received in Physics Mechanics and reduced CBK grade point average calculated without the grade in Physics Mechanics. Using the information determined, it provides further evidence of the strength of Physics Mechanics as a predictor of success in a statics and dynamics course.

Summary

Evaluating course content using syllabi from first-year mathematics and physics mechanics courses, the topics do not seem to be well aligned with the skills identified for a sophomore-level statics and dynamics course. Grades received in prerequisite courses and CBK grade point averages do provide further information on the probability of success in a statics and dynamics course. While some of the information verified in the study was expected, such as students with high CBK grade point averages performed well in a statics and dynamics course over those with low CBK grade point averages, the importance of course grades and skills in Physics Mechanics over Engineering Mathematics II was not expected. The importance of Physics Mechanics was depicted in the Spearman's rank correlation calculations, mutual information calculations, and ANOVA models calculated. Furthermore, grades of A or C in first-year prerequisite courses show that a student's fate in a statics and dynamics course is pretty much decided positively and negatively, respectively. Students who earn a grade of B in prerequisite courses have an equal chance of being in the upper or lower half of a statics and dynamics course. Focusing more attention on this group of students may prove beneficial in moving them into the upper half of the course. For example, students who earned a grade of B in Foundations of Engineering I were evaluated in more detail, and it appears that scores on the physics instrument and possibly free-body diagrams show some differences in the success in statics and dynamics. If differences can be determined in the students who receive grades of B in prerequisite courses, intervention may be possible to help students be more successful in the follow-on statics and dynamics course.

CONCLUSIONS / RECOMMENDATIONS

The alignment of the expectations of engineering faculty and the preparation engineering students receive in first-year mathematics and physics mechanics courses provides the motivation for the work contained in this study. The primary goal of this study assesses the alignment of the mathematics and physics mechanics knowledge and skills addressed in first-year courses with the knowledge and skills needed for a sophomore-level statics and dynamics course. It is motivated by faculty members in sophomore-level engineering courses being unclear as to the level of preparation students had entering the courses compared to what they thought students needed to have. The development of a set of skills determined by faculty and directly tied to specific first-year mathematics and physics mechanics skills was undertaken. Only once the skills are defined can the process of improving the alignment of these skills from the first-year courses to the sophomore-level engineering courses commence. To address these items, three key research questions formed the basis for this study. The findings related to each question will be summarized below.

Research Question #1

1) Can engineering faculty members teaching a sophomore-level statics and dynamics course identify skills they think students need from first-year mathematics and physics mechanics courses?

Yes, engineering faculty members teaching a sophomore-level statics and dynamics course can identify skills they think students need from first-year mathematics and physics mechanics courses. To fully answer this question, discussions on the skills necessary for success in a statics and dynamics courses went more in-depth than simply stating students need to have sufficient first-year mathematics and physic skills. As shown, the skills must be detailed further into specifics, such as free-body diagrams and Newton's laws for physics and simultaneous equations and vector components, both two-dimensional and three-dimensional, for mathematics. Instead of simply asking faculty for a list of skills, problems were submitted by faculty members and the corresponding skills were generated and then verified with the faculty members to ensure nothing was lost in translation. Table 32 restates the information contained in Table 5 to summarize the skills expected by engineering faculty members.

Table 32

First-Year Mathematics and Physics Mechanics Skills Determined by Engineering Faculty

Mathematics Topics
Projection
Vector Components (2-D)
Derivative (using Chain Rule)
Second Derivative
Area Under a Curve
Integration (using Substitution)
Cross Product (definition)
Simultaneous Equations

Physics Topics
Free Body Diagram
Linear Momentum
Newton's Second Law
Newton's Third Law
Conservation of Energy

Skills were then compared against homework and exam problems from a sophomore-level statics and dynamics course to ensure they were representative of the skills needed for the course. Once the list of skills engineering faculty members expected was refined based on the actual work completed by students in the statics and dynamics course, the performance of students could be determined. A mathematics instrument and physics instrument were completed by the students at the beginning of the statics and dynamics course. The purpose of these instruments was to identify the level of knowledge of students coming into the course in each of these particular skills. For the most part as a whole, the instruments did not provide a significant amount of correlation between the skill levels of students entering the course versus the final grade received in the course if only a passing grade of at least C was desired. However, there were indications that scores of at least 67 on the mathematics instrument and scores of at least 59 on the physics instrument resulted in final grade average of at least B. Furthermore, evaluated for certain subsets of the population the physics mechanics and free-body diagram subset of the physics instrument did provide some detail, which could be utilized as an intervention mechanism for students who earned a B in Foundations of Engineering I. Further work would need to be done to determine if the lower correlation value of the mathematics instrument compared to the correlation value of the physics instrument was a result of the skills included or for example the wording of the questions in the instrument, but this is outside of the scope of this study. Table 33 provides the summary of the refined list of first-year mathematics and physics mechanics skills engineering faculty members determined that are necessary for success in a sophomore-level statics and dynamics course after the alignment process (restated Table 15).

Table 33

Refined List of Expected First-Year Mathematics and Physics Mechanics Skills Determined by Engineering Faculty

Mathematics Topics
Vector Components (2-D)
Vector Components (3-D)
Derivative (using Chain Rule)
Second Derivative
Area Under a Curve
Integration (using Substitution)
Simultaneous Equations

Physics Topics
Free Body Diagram
Friction
Newton's Second Law
Newton's Third Law

Research Question #2

2) Do the expectations of these engineering faculty members align with the classroom implementation in a sophomore-level statics and dynamics course?

No, the expectations that engineering faculty members teaching a sophomore-level statics and dynamics course have of the skills that are necessary for success in the course are not aligned. Detailing over 300 homework, exam, and quiz problems through a careful q-matrix analysis brought to light a misalignment on three of the eight first-year mathematics skills, (projection, integrals using trigonometry substitution, and definition of cross product), with two additional skills being identified as having a substantial amount of problems addressing the topics compared to the other topics even though they had not been included in the original list by faculty, (three-dimensional vector components and simultaneous equations with a parameter). In addition, two of the six first-year physics mechanics skills, (conservation of energy and linear momentum), demonstrated a misalignment when the q-matrix was analyzed. While several of the skills originally identified by faculty members, such as projection and cross product, were tools that could be used in solving some of the problems, students were not directly asked to use the particular skill. Therefore, a student could successfully complete the statics and dynamics course without the knowledge of a skill faculty members had considered to be essential to the course.

Research Question #3

3) Is what students learned in their first-year mathematics and physics mechanics courses aligned with a sophomore-level statics and dynamics course?

When course syllabi were compared between the skills needed for a sophomore-level statics and dynamics course and those covered in first-year mathematics and physics mechanics courses, the content was shown not to be properly aligned. As shown in Figure 74 and Figure 75, (restated from Figure 46 and Figure 47), for the most part the alignment between course content and skills needed is poor. Very little time in the classroom, if any according to course syllabi, is devoted to many of the key skills identified by engineering faculty members. Discussions between engineering faculty members and the mathematics and physics community would benefit both the teaching and learning of students. Engineering faculty members would not have to devote class time to re-teaching topics they felt should have been previously covered, and students would have a clearer indication of the role mathematics and physics comprises in engineering.

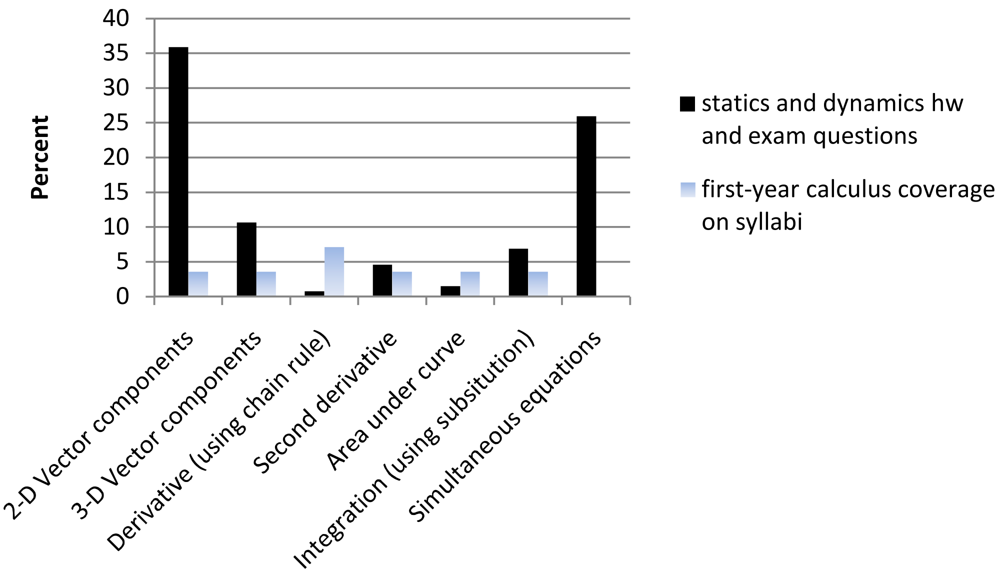


Figure 74. Alignment of first-year mathematics topics comparing percentage of homework and exam problems in Statics and Dynamics and topic list in first-year mathematics courses.

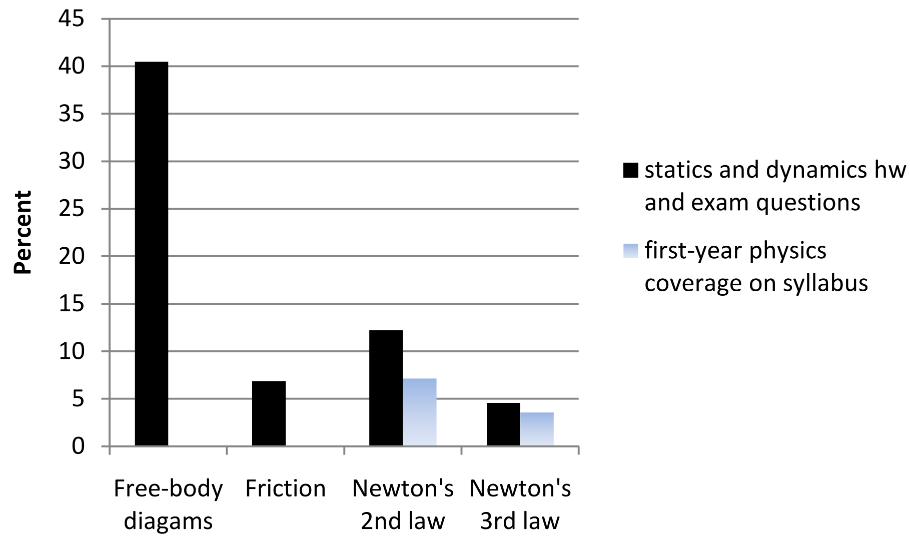


Figure 75. Alignment of first-year physics mechanics topics comparing percentage of homework and exam problems in Statics and Dynamics and topic list in first-year physics mechanics courses.

When final grades in the first-year mathematics and physics mechanic courses were compared to final grades in a sophomore-level statics and dynamics course were compared to determine if what students learned in their first-year courses was aligned with the sophomore-level courses, the results showed that grades received and credits earned were also aligned. Students who had received high grades had a high ratio of earning top grades in statics and dynamics. Students who had earned low grades had a high ration of earning the lowest grades in statics and dynamics.

Another example is evaluating the CBK grade point average, which is comprised mostly of mathematics, physics, and engineering related courses. It has been shown to be a good indicator of success in the statics and dynamics course. Students with grade point averages above 3.25 have a high probability of performing well in the statics and dynamics course. Even students in the range of 3.0-3.249 averages are more likely to perform well in the class, even though more evaluation should be used for this group. Students with grade point averages below 3.0 have a low probability of performing well in the course.

When correlation of grades received in prerequisite courses was compared to final grades in statics and dynamics, the highest correlation occurred with the grade students received in Foundations of Engineering I with the grade in Physics Mechanics and then Engineering Mathematics II following behind. With strong correlation between grades received in the prerequisite courses, the impact of final grades in Physics Mechanics compared to success in a statics and dynamics course was selected to review in further detail. Final grades received in a first-year physics mechanics course show that grades of A received in the courses have a high probability for success in the statics and dynamics course. Grades earned of C in this course have a low probability for success in the statics and dynamics course. For students who earn grades of B in this course, their chance for success in the statics and dynamics course is just as likely to be successful and unsuccessful. The data also showed similar results for the other first-year prerequisite courses.

When transfer and advanced placement credits were considered, students who used these types of credit typically had very different results for the success in a statics and dynamics course. In all four CBK grade point average categories considered, breakdowns of transfer credit exhibited much lower ratios of students being in the top half grade-wise of the statics and dynamics course. For students with CBK grade point averages below 3.0, the extent that transfer credits utilized for the key related courses and the low grades then received in the statics and dynamics course are staggering. Many students either fail one of the first-year related courses at TAMU before taking the course at another institution, or the students intentionally do not attempt the course at TAMU and select to take it another institution instead. The results show much lower ratios of success then in the statics and dynamics course. While advanced placement was typically used by students with CBK grade point averages of at least 3.25, the ratio of students who used the credits and then earned a grade of A or B in statics and dynamics increased over other students in this CBK range who did not use advanced placement credit.

To determine if further information could be gathered on intervention for students who earned a grade of B, details on students who earned a B in Foundations of Engineering I was scrutinized. Foundations of Engineering I was selected for further comparisons because curriculum in the course covers both key first-year mathematics and physics topics utilized in follow-on engineering courses in the one first-year course. Evaluating scores received on the mathematics and physics instruments, a correlation exists between scores received on the physics instrument and then specifically on the free-body diagram subset of the physics instrument. Performing intervention especially at the first-year in Foundations of Engineering I to improve the skill level of at-risk students, or those who earn a grade of B in Foundations of Engineering I, in the physics mechanics and free-body diagram areas shows positive indication for success in the statics and dynamics course.

Summary

In summary, Figure 76 revisits Figure 5 provided earlier to represent the conclusions reached in this study. As shown in the figure with the bold RQ #1 label, engineering faculty members did identify the first-year mathematics and physics mechanics skills necessary for a sophomore-level statics and dynamics course. The expectation of engineering faculty members, on the other hand, did not fully align with the classroom implementation of the material as shown with the broken arrow depiction near the RQ #2 label. Finally, the first year course content when viewed by the corresponding syllabi was not directly aligned with the content needed at the second-year. Grades received by students with high grade point averages correlated well with success in the statics and dynamics course, while students with low grade point averages struggled with the statics and dynamics course. This is depicted in the figure as shown as a connected but non-bold notation for the RQ #3 label.

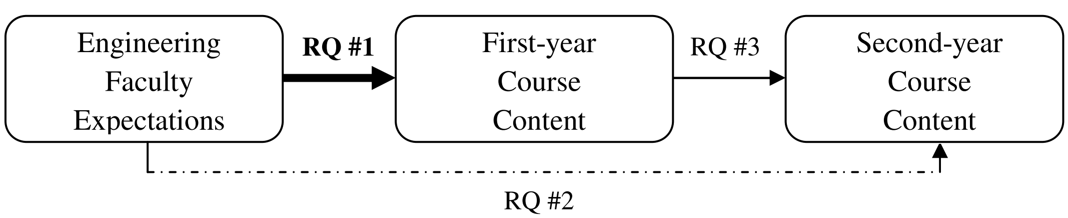


Figure 76. Connections between the three research questions (RQs) in the study.

The relationship of the findings to the alignment system detailed at the beginning of the study (Figure 4) is detailed again in Figure 77. As previously stated, alignment is the extent to which components or constituents of a system are configured to fit together for the system to function as a whole in the desired manner. In this study, the system was the first-year mathematics and physics mechanics courses and a sophomore-level statics and dynamics course, and the function studied was the manner in which the system ensures success in a sophomore-level statics and dynamics course. The components or constituents were: (1) instructors in the statics and dynamics course (alignment area #4 in figure), (2) advisors who promote students into upper-level departmental courses (alignment area #2), (3) prerequisite courses for the statics and dynamics course completed by students (alignment area #1), and (4) mathematics and physics instruments completed as pre-tests by the students in the statics and dynamics course (alignment area #4).

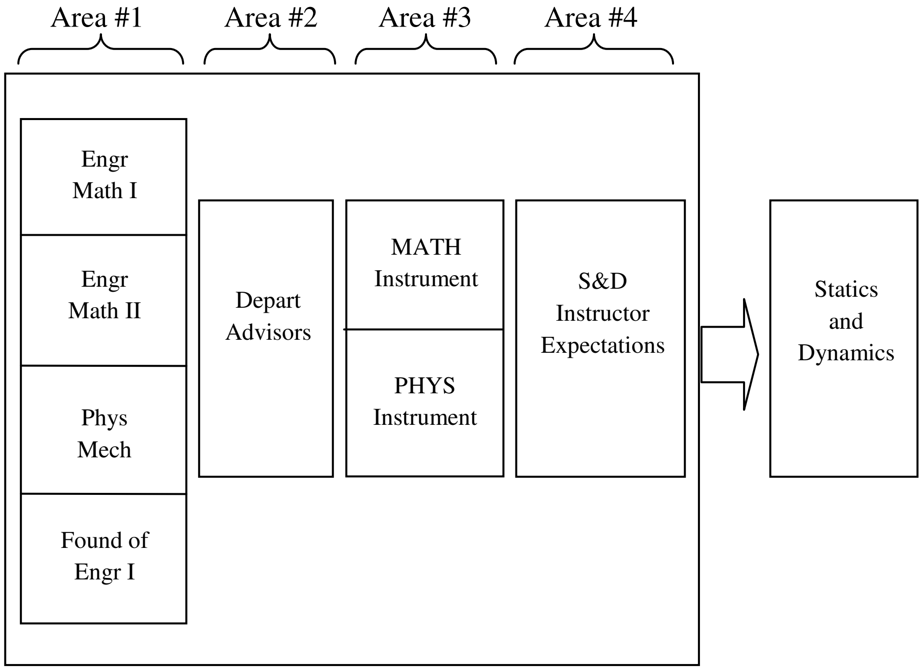


Figure 77. Recap of alignment system used in study.

Alignment area #1 showed a strong alignment in content, skills, and grades received between Physics Mechanics and a statics and dynamics course. Similar results were also found between Foundations of Engineering I and a statics and dynamics course with Spearman's rank correlation coefficient being highest for this course over the other three prerequisite courses when compared to final grades in a statics and dynamics course. Surprisingly though, alignment between Engineering Mathematics I or Engineering Mathematics II and the success of a student in a statics and dynamics course was not nearly as high as that of Physics Mechanics.

Alignment area #2 looked at the alignment of course grades and CBK grade point averages. Students with CBK grade point averages of at least 3.25 had a high ratio of earning a grade of A or B in a statics and dynamics course. Students with CBK grade point average below 3.0 had very high ratios of earning a C, D, F, or Q in a statics and dynamics course. Likewise, a student's fate was pretty much decided if a grade of A or C was earned in prerequisite courses when grades in Physics Mechanics were considered. Students were successful in statics and dynamics if they had earned a grade of A in Physics Mechanics and not as highly successful if they had earned a grade of C in Physics Mechanics. Students who earned a grade of B in Physics Mechanics had equal amounts who then earned an A or B in statics and dynamics and those that earned a C, D, F, or Q. Transfer credits received for prerequisite courses did not show to be helpful for students then completing the statics and dynamics course, whereas, advanced placement credits were advantageous. The alignment determined in this area resulted in results being consistent based on specific grades received or CBK grade point averages. Similar grades and averages showed nearly identical results for success in statics and dynamics.

For the mathematics and physics mechanics instruments developed as part of this study shown in alignment area #3, breakdowns of the scores received by students on the instruments and the success of the students in a statics and dynamics course showed that scores of at least 78 on the mathematics instrument and at least 59 on the physics instrument resulted on average of grades of a least a B in statics and dynamics. In addition, further evaluation of the scores on the physics instrument for students who earned a grade of B in Foundations of Engineering I found potential for helping differentiate success of these students then in a statics and dynamics course. While a content validity study using item-objective congruence demonstrated that further refinement on a couple of the questions on each instrument might need to be refined to ensure the intended skills are represented by the questions on the instruments, over 82% of questions on each instrument received index values of at least 0.5, which is the minimum accepted in the literature.

Alignment area #4 included the use of a q-matrix to measure the alignment of the expectations that instructors teaching the statics and dynamics course have of the first-year mathematics and physics mechanics skills necessary to be successful in a sophomore-level statics and dynamics course. Results from the q-matrix process showed misalignment between the skills instructors expected and those actually used in the homework, exam, and quiz problems in the statics and dynamics course.

Limitations

It is important to note that consideration of factors, such as CBK grade point average and final grades in courses, can play a role in helping to define the potential for students being successful in a sophomore-level statics and dynamics course, but it should be fully understood there are many other factors not included in this study that also can affect the success of a student.

Future Work and Recommendations

The process outlined for determining the alignment of course content, faculty expectations, and skills necessary could be applied to many situations within a curriculum. It is in no way limited to simply first-year mathematics and physics mechanics skills and a sophomore-level statics and dynamics course. In addition, the process outlined for developing the mathematics and physics instruments could also be implemented in other scenarios. To utilize the information contained in the instruments further, more work would need to be done to ensure the questions are fully obtaining the information desired. Now that skills have been identified, recommendations include having discussions with mathematics, physics mechanics, and engineering faculty members to address some of the issues identified in this study. As part of this process, actual course content from the first-year courses would need to be detailed instead of only using the course syllabi, and the notations used in the classroom would need to be determined for proper comparisons to occur. Further evaluation of the impact of Physics Mechanics on a statics and dynamics course should be performed. While faculty have typically focused on the mathematics preparation of students from the first year, this study shows the strong correlation of physics mechanics skills and grades on the success in a sophomore-level statics and dynamics course. Finally, since the first-year engineering courses cover necessary mathematics and physics skills needed for engineering, the faculty members teaching the first-year engineering courses might be able to provide intervention for students struggling with the skills. Further work would need to determine exactly what the intervention would entail, although use of the physics instrument and simply corresponding free-body diagram questions if pressed for time does show promise.

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APPENDIX A

See the supplemental file associated with this dissertation for appendix details.

APPENDIX B

See the supplemental file associated with this dissertation for appendix details.

APPENDIX C

See the supplemental file associated with this dissertation for appendix details.

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Most Recent Related Publications:

- Shryock, K.J., A.R. Srinivasa, and J.E. Froyd. 2011. Alignment of preparation via first-year physics mechanics and calculus courses with expectations for a sophomore statics and dynamics course. In *Proceedings of American Society for Engineering Education.* Vancouver, CA.

- Shryock, K.J., A.R. Srinivasa, and J.E. Froyd. 2011. Assessing first-year calculus knowledge and skills needed for a sophomore statics and dynamics course. In *Proceedings of American Society for Engineering Education.* Vancouver, CA.

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