ANALYSIS OF THE IMPACT, COURSE ALIGNMENT, & POTENTIAL IMPROVEMENT OF INTRODUCTORY PHYSICS

A Dissertation

by

JONATHAN DREW PERRY

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DOCTOR OF PHILOSOPHY

Chair of Committee,	William H. Bassichis
Committee Members,	Tatiana L. Erukhimova
	A. Lewis Ford
	Luis San Andres
Head of Department,	Grigory Rogachev

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ABSTRACT

Introductory Physics (IP) forms part of the foundational knowledge necessary to success in an undergraduate engineering degree. Here, the impact of IP is studied to address three research questions: 1) What is the correlation of performance in IP with institutionally relevant metrics? 2) How well is IP course content aligned with subsequent engineering coursework? and 3) Does a new online supplemental resource improve student learning in the IP sequence?

Impact of a student's IP Mechanics grade on the metrics of subsequent academic performance, retention, and matriculation rate is analyzed using two decades of academic records of engineering students at Texas A&M University (TAMU). Correlations are quantified using the Spearman Correlation Coefficient, with separate analyses performed for three versions, called flavors, of IP Mechanics available to TAMU students.

Alignment of content between courses is examined using a set of q-matrices developed for three flavors of IP Mechanics and two subsequent engineering courses. The strength of alignment between each flavor of IP Mechanics with each course is examined for the courses as a whole, along with specific physical concepts and mathematical skills. The procedure employed here may be an effective evaluative tool for service based courses to ensure adequate coverage of material for client departments.

Supported by a grant from TAMU Provost's Office and Instructional Technology Services, a new online supplemental resource was created for the IP sequence titled Freshman Physics Classroom (FPC). Development and results from the first deployment of this resource will be discussed, including quantitative analysis of exam scores and conceptual assessments along with qualitative analysis from student surveys. Initial results show positive results from use of the resource and high student approval.

DEDICATION

To all the doctorate degrees in my family that inspired me, and of whom I shall now be a part.

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Contributors

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Data analyzed in Chapter 2 was provided, via request, from the Enterprise Information Systems office of Texas A&M University. Part of the data analyzed in Chapter 4 was provided by Dr. Emanuela Ene and Professor Bob Webb.

All other work conducted for the dissertation was completed by the student independently.

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NOMENCLATURE

BEMA	Brief Electricity & Magnetism Assessment
CBK	Common Body of Knowledge
CSEM	Conceptual Survey of Electricity & Magnetism
DFQ	The percentage of students receiving a grade of D or F, or dropping a course (Q)
DP	Don't Panic Physics
E&M	Introductory Physics: Electricity & Magnetism Course
EDM	Educational Data Mining
FCI	Force Concept Inventory
FPC	Freshman Physics Classroom
IP	Introductory Physics
IPLS	Introductory Physics Life Sciences
IRB	Institutional Review Board
IVV	Interactive Video Vignettes
MLM	Multimedia Learning Modules
RSS	Residual Sum of Squares
STEM	Science, Technology, Engineering & Mathematics
TAMU	Texas A&M University
THECB	Texas Higher Education Coordinating Board
UP	University Physics

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1. INTRODUCTION AND LITERATURE REVIEW

1.1 Physics Education Research

Research conducted under the umbrella of Physics Education Research (PER) seeks to develop and implement those theories and techniques which characterize, influence, and measure the learning of physics by students. This can include, according to the PER group at the University of Washington's website, identifying student difficulties, developing methods to address difficulties and measure learning gains, develop surveys to measure student performance, investigate student attitudes, and more [8]. This definition may be broadened, borrowing from the PER group at the University of Colorado-Boulder, to include the uses of technologies in physics education, theoretical models of students' learning of physics, examination of successful education reforms, and aspects of problem-solving [9]. In short, PER can study all components of and influences on the process of learning physics.

There is evidence that many physicists were concerned with the state and quality of physics education in the United States in the early and mid 20^{th} century, including Enrico Fermi, Richard Feynman and others. Beichner, in 2009, stated that PER as a field began later, around the 1970's with the hiring of Lillian McDermott at the University of Washington by Arnold Arons [10]. Since then, the PER group at the University of Washington has grown into a significant research endeavor, currently with approximately a dozen members and a lengthy list of former members [8]. Since that time, many other PER groups have become established in the field, including Kansas State (started by Dean Zollman), the University of Nebraska (started by Bob Fuller), Arizona State (with David Hestenes), Rutgers University (anchored by Eugenia Etkina), and the University of Colorado- Boulder. Other PER groups exist in the US and around the world, but these mark some of the largest groups that have made significant contributions to the field.

Topics of study within PER cover a broad range of subject matter related to education. Docktor and Mestre identify six categories of current PER research as: 1) conceptual understanding, 2) problem solving, 3) curriculum and instruction, 4) assessment, 5) cognitive psychology, and 6) attitudes and beliefs about teaching and learning [11]. Others such as Beichner identify some additional categories of research including instructional materials, evaluation of specific instructional interventions, technology, and epistemology as focuses of ongoing research [10]. Early research in each of these areas relied primarily on empirical evidence as opposed to theoretical frame work, a bibliographic summary of which may be found in McDermott and Redish 1999, with theoretical frameworks beginning to emerge in recent years [12]. Particular focus for new theoretical frameworks includes understanding student misconceptions, how they form, and how they are encoded into memory [13].

Areas of research mentioned in the previous paragraph, which tie directly or indirectly to this body of work, will be expanded on for a deeper understanding of their current state. Concerning curriculum and instruction, research and development of materials has been conducted to provide new methods for teaching in all settings in the classroom: lecture, recitation, and laboratory. Many of the early successes in this area are well summarized in several texts, such as Redish's *Teaching Physics with the Physics Suite* and Knight's *Five Easy Lessons: Strategies for Successful Physics Teaching* [14, 15]. Ongoing research in this area tends to focus on the answering the questions "Did it work? If so, under what conditions" for each new intervention. Many of the successful engagement strategies fall under the umbrella of what is termed *interactive engagement* [16]. Instructional changes in the classroom which have been seen to have a positive impact include use of classroom polling technologies, interactive lecture demonstrations, collaborative learning in discussion sessions, employing a workshop environment to instruction, and others

[17, 18, 19, 20, 20, 21, 22]. Much of the body of literature associated with this area of research is strictly focused on the impact of changes to a single course. This has left room for more global studies about the impact of changes to a single course on the flow of the curriculum as a whole.

As technology advances and is developed into new and more readily available forms, its impact on the classroom and the learning environment increases. Many research efforts have sought to leverage technology to benefit in the classroom, instead of letting it remain solely a distraction. The PER group at University of Colorado-Boulder is well known for having developed a set of physics simulations of laboratory type experiments for use by both students and instructors [23]. Other efforts have seen the development of web-based systems for labs and problem solving, including WebAssign (recently acquired by Cengage), and VPython (a visual programming tool) [24, 25]. Recent years have seen a significant increase in the use of video to explain or demonstrate physics concepts. These are discussed in depth later.

1.1.1 Assessment Tools

One of the first assessment tools developed in PER was the Force Concept Inventory (FCI) published in 1992 by Hestenes, Swackhammer, and Wells [26]. This assessment covers the topics of Newtonian mechanics, and its relation to motion, and was based on the dissertation work of Ibrahim Halloun [27]. Originally, the FCI was comprised of 29 items, though this was revised to 30 items in 1995 [1]. Each item is a multiple choice question targeted towards a particular topic of Newtonian mechanics. One of the most significant studies performed with the FCI was conducted by Hake, examining more than 6000 students, which concluded that interactive engagement shows greater gain in conceptual understanding versus traditional lecture style [16]. An example item from the FCI is shown in Figure 1.1.

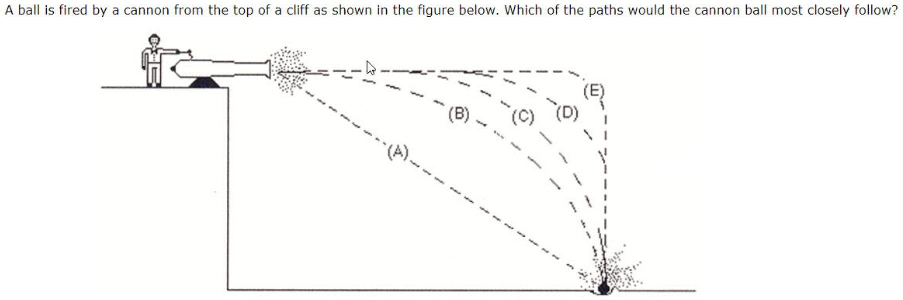
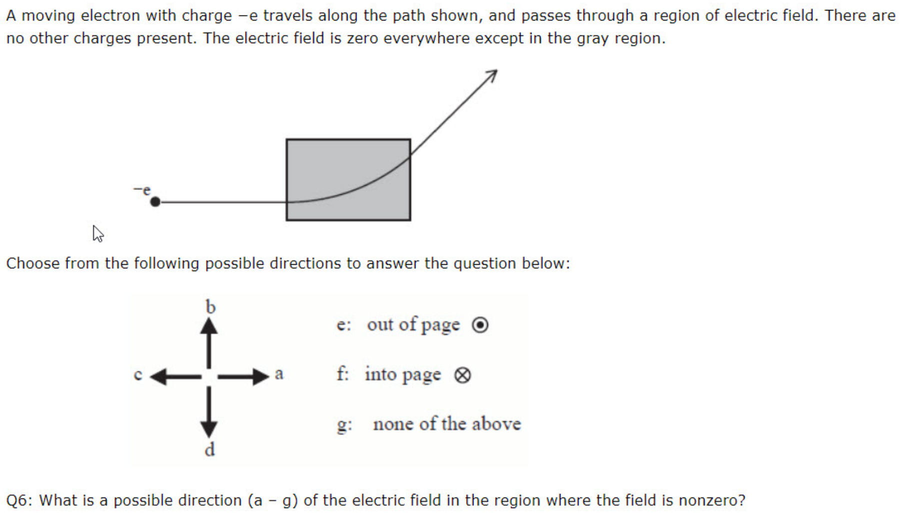

A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?

Figure 1.1: An example item from the FCI, adapted PhysPort [1].

Another common assessment tool is the Brief Electricity & Magnetism Assessment (BEMA) developed by Chabay and Sherwood in 1997 [1]. This assessment tool covers a broad range of topics from a traditional E&M course including electrostatics, electric and magnetic fields, through electromagnetic induction [28]. BEMA is comprised 30 multiple choice items that are predominantly qualitative, though a few semi-quantitative items are included [29]. Work by Ding *et. al.* 2006 and Pollock 2008 have shown the BEMA to be a well discriminated assessment tool to measure student learning, well correlated with post-test knowledge at the end of a course [29, 30]. An example item from BEMA is shown in Figure 1.2.

These previous assessments are two of the most commonly employed tools by researchers for measuring conceptual learning gains. Other assessments exist for these areas, and others. A more complete listing of more then 80 assessment tools is available on PhysPort [1].

One alternative assessment for mechanics is the Force and Motion Conceptual Evaluation (FMCE). This 43 item multiple choice assessment covers a slightly broader range of topics compared to the FCI. It relies heavily on qualitative questions based on a series of diagrams within the assessment, with multiple questions being asked of each diagram [31]. While the FMCE is not used as widely as the FCI, it has been tested for its validity



A moving electron with charge −e travels along the path shown, and passes through a region of electric field. There are no other charges present. The electric field is zero everywhere except in the gray region.

Choose from the following possible directions to answer the question below:

e: out of page ⊙

f: into page ⊗

g: none of the above

Q6: What is a possible direction (a – g) of the electric field in the region where the field is nonzero?

Figure 1.2: An example item from BEMA, adapted from PhysPort [1].

and reliability as a measurement for student learning with positive results, according to Ramlo 2008 [32].

An alternative assessment for electricity & magnetism is the Conceptual Survey of Electricity & Magnetism (CSEM). This assessment is a 32 item multiple choice test covering topics in electricity and magnetism, like BEMA. Early evaluation of the assessment, given to more than 5000 students at 30 institutions, showed pre-test scores around 25%-31%, with post-test scores rising to the 44%-47% level depending on whether the student was enrolled in an algebra-based or calculus-based E&M course [33]. According to a study by Pollock, the BEMA and CSEM yield roughly equivalent results when measuring student learning [30].

1.1.2 Growth in STEM

It is well known that the STEM job market has exploded in recent years, offering a host of well-paying careers to qualified candidates. This has translated into a dramatic rise in the enrollment of STEM degrees at colleges and universities across the country. In fact, according to the National Center for Educational Statistics Integrated Postsecondary

Education Data System, the number of STEM majors has more than tripled in the past 50 years. This may be seen in Figure 1.3, reproduced here from the Joint Task Force on Undergraduate Physics Programs (JTUPP) Phys21 report from 2016 [2].

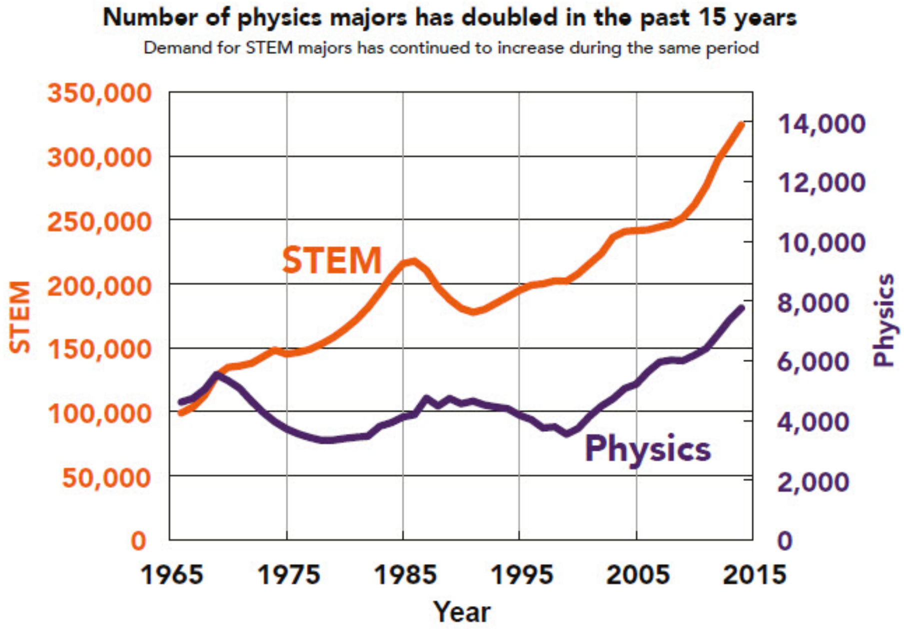


Figure 1.3: Number of total STEM and physics majors in the US 1965-2015, reprinted here from the JTUPP Phys21 report [2].

Demand for well trained scientists and engineerings within the US is very high, leaving it as one of the job sectors with the lowest unemployment rate in the country. According to Congressional Research Service report in 2013, growth and job replacement is estimated to require 2.3 million new science and engineering professionals to enter the workforce between 2012-2022 [34]. At TAMU this has led to a push for increased enrollment within the Dwight Look College of Engineering, as encapsulated in the 25 by 25 program. This program seeks to have 25,000 active undergraduate engineers enrolled at TAMU by the year 2025.

1.2 Engineering Curriculum

Students entering TAMU are not automatically admitted to the engineering major of their choice. Depending on the year, students were either admitted to a lower level version of their engineering major (*e.g* MEEL as opposed to MEEN for Mechanical Engineering), or were listed as general engineering majors, ENGE. Admission to the upper level major requires a secondary admissions-like process. This process must be completed and passed by a student before enrolling in sophomore level or higher courses specific to a particular engineering major. Part of the admissions requirements are is a minimum GPA, which varies by department. The minimum GPA requirements for the 2017-2018 cohort are shown in Table 1.1.

Table 1.1: Minimum GPA requirements to be admitted to the upper level engineering majors, listed by department. These values are for the 2017-2018 cohort at TAMU, and were taken from the Dwight Look College of Engineering's website [7].

Department	Major	Minimum GPA
Aerospace Engineering	AERO	2.85
Biomedical Engineering	BMEN	3.50
Chemical Engineering	CHEN	2.75
Civil Engineering	CVEN	3.00
Electrical Engineering	ELEN	2.75
Industrial Distribution	IDIS	2.50
Mechanical Engineering	MEEN	2.85
Nuclear Engineering	NUEN	2.50
Petroleum Engineering	PETE	2.50

Freshman engineering majors are required to take a combination of courses designed to lay the foundation of knowledge and skills necessary to their degrees. This coursework includes, but is not necessarily limited to, basic engineering, mathematics, physics, and chemistry. TAMU students in recent years have been required to take seven courses to form their common basic knowledge (CBK) prior to entering their majors. These courses are detailed below in Table 1.2.

Table 1.2: List of required 1^{st} year engineering courses according to TAMU's engineering degree programs.

Course Name	Course ID
Foundations of Engineering I	ENGR 111
Foundations of Engineering II	ENGR 112
Engineering Math I	MATH 151
Engineering Math II	MATH 152
Mechanics	PHYS 218
Electricity & Optics	PHYS 208
Gen. Chemistry for Engineers	CHEM 107

Due to the importance of the content found in the CBK courses, it is vital that the courses themselves have an appropriately strong alignment of content and skills to facilitate student success. Lack of sufficient alignment may make the transition from introductory coursework to the more rigorous major coursework a struggle for students, and may contribute to students migrating to other majors. It would be beneficial to understand the expected (and actual) knowledge and skills gained by students during introductory coursework. This effort focuses only on the physics aspect.

1.2.1 Retention

One of the difficulties within engineering departments and colleges is the high rate at which students migrate from their engineering majors. The Dwight Look College of Engineering at TAMU exhibits this migration. In fact, for the cohort starting in Fall 2010, only 23.8% graduated after four years. At the five and six year marks, the graduation rate improved to 53.1% and 57.7% respectively. Of this more than 40% that migrated out of engineering, the majority did so prior to the start of the second year. Specifically, the

Data and Research Services division at TAMU (`http://dars.tamu.edu`) shows that roughly 75% of enrolled engineering majors were retained after the first year for the Fall 2010 cohort.

While the specific numbers on retention do vary year to year, as discussed in Chapter 2, the relative fraction of students retained, and then graduating after the fourth, fifth, or sixth year is fairly consistent [35]. From these numbers it is understood that there is a significant retention problem in engineering beyond the first year [36, 37]. Attempts to address this retention issue have included efforts such as restructuring the freshman curriculum to integrate mathematics, engineering, and physics as well as introducing freshman design projects [38, 39, 40].

Difficulties in retention of engineering majors is not a new concern. From the 2005 report, *Rising Above the Gathering Storm*, it is evident that the United States has a diminishing fraction of science and engineering graduates [41]. It was reported that only 32% of US graduates obtained a degree in science or engineering, which is comparable to Germany (36%), but far behind China (59%) and Japan (66%). Although there have been increases in undergraduate STEM enrollment, see Figure 1.3, the Congressional Research Service estimates a need for more than 2.3 million science and engineering professionals to enter the workforce between 2012-2022 [34].

1.2.2 Alignment

Many courses which appear in undergraduate curriculum require that another course be taken prior to enrollment in the later course, a prerequisite. Within engineering majors, the courses contributing to the CBK (Table 1.2) act as prerequisites for many of the sophomore, junior, and even senior level courses. As these courses provide a foundation of knowledge for subsequent engineering courses, it is important that their content provide the necessary basis for students to succeed in more advanced courses. This is the concept of alignment between courses.

Previous studies of alignment tend to focus on the extend of agreement or matching between areas that work together to achieve a purpose. In their 2001 study, La Marca defines alignment as "the degree of match between test content and the subject area content identified through state academic standards" [42]. An alternative definition, used by Bhola *et. al.* 2003, says "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" [43]. A third definition comes from Roach *et. al.* 2008, in which alignment is defined as the extent to which curricular expectations and assessments work together as guidance for educators' efforts to facilitate student learning [44]. A majority of the studies referenced above, and others not included in this work, specifically examine alignment in terms of K-12 education. For K-12 education, there is heavy expectation for teachers to conform to state standards and expectations in classroom content, leading to student performance on standardized exams.

In this study, vertical alignment is defined as the quality of similarity for topics to be covered between two distinct courses, one being the prerequisite for the second, appearing within the curriculum. This is similar to a measurement of the degree of agreement between instruction and a standardized test. Here, the content of the engineering courses will be the standard to which the previous course, Introductory Physics (IP) Mechanics, is compared. This is akin to curricular alignment as employed by Martone and Sireci 2009, which is defined as the "degree to which the curriculum across the grades builds and supports what is learned in earlier grades" [45].

To examine the degree to which the curriculum is supported by earlier coursework, an approrpriate tool must be chosen. For this body of work, that tool is the q-matrix. A q-matrix is a two-dimensional array of entries, often binary, developed in the 1980's by Tatsuoka [46]. It provides a method of recording the presence of skills which are encountered by students in items throughout a course.

Examples of skills, relevant to this study, may include a mathematical step such as *vector addition* or *differentiation*, or may be a concept such as *one-dimensional motion* or *angular momentum*. For analysis of courses outside of physics, relevant skills would have to be identified from within the course material. Items are standalone problems that students encounter on assignments throughout a course, such as on homeworks, quizzes, and exams.

The use of the q-matrix yields a new, detailed, quantitative inventory of course content not seen in current literature. Further information about the history, application, and results from this tool are presented in Chapter 3.

1.2.3 Barriers to Completion

As discussed in Section 1.2.1, many students tend to migrate out of engineering. Students who do migrate to another major will tend to do so for a mix of both academic and non-academic reasons.

Academically, students will tend to migrate away from engineering due to low performance and intellectual struggles with the material. Freshman engineering majors are required to take a combination of demanding courses across departments including engineering, mathematics, chemistry, and physics. Depending on a student's background and high school instruction, they may arrive well prepared for demanding coursework with high loads of homework, labs and tutorials; or they may arrive with serious gaps of knowledge in both basic math and science. Students that arrive poorly prepared are forced then to seek remediation for some material, while simultaneously being responsible for new material. This imposes a very demanding work load on students that many are not prepared to handle. This can then lead to lower performance or dropping courses, both of which effect their ability to be admitted to upper level engineering majors and courses.

Beyond the individual student performance, the grade distribution of courses can also be a barrier to completion for students. Often, one or more early courses at an institution has a high rate of failure or drops among students. This is referred to at TAMU as the DFQ rate. That is, the percentage of students achieving a grade of D, a grade of F, or dropping the course, Q. Using data available from Data and Research Services (`http://dars.tamu.edu`) for the Fall 2012 and Spring 2013 semesters, the DFQ rates of the CBK courses listed in Table 1.2 are shown below in Table 1.3. As evident from the table, there are multiple courses with high DFQ rates which can impact students academic progression. Among these courses, physics has the highest DFQ rate, followed closely by the math courses.

Table 1.3: The DFQ rates for freshman engineering courses for the Fall 2012/Spring 2013 terms.

Course	Term	Number	DFQ
Foundations of Engineering I (ENGR-111)	Fall 2012	1495	4.82%
Foundations of Engineering II (ENGR-112)	Spring 2012	1190	5.46%
Engineering Math I (MATH-151)	Fall 2012	1703	21.67%
Engineering Math II (MATH-152)	Spring 2013	1352	24.63%
Mechanics (PHYS-218)	Fall 2012	1626	26.08%
Electricity & Optics (PHYS-208)	Spring 2013	795	30.57%
Gen. Chemistry for Engineers (CHEM-107)	Fall 2012	872	26.26%

Non-academically, students migrate away from engineering majors for a variety of qualitative reasons, as discussed in Seymore *et al.*. These reasons can include time management skills, motivation, study skills, mental distractions to performance in the classroom and loss of academic self-confidence within a competitive environment [47]. As TAMU automatically accepts the top 10% of students from any school in Texas, there is a consistent comment from students that they did not have to work very hard or study during high school. This directly impacts their preparation in terms of time management and study skills. Simply put, many students have never had to develop them. Motivation is related to a student's reason for attempting an engineering major. While many students have a passion for systems and making things work, many other students are merely following the potential for a high paying job after their undergraduate career. Such students are then more likely to lose their motivation while enduring a demanding and difficult course load without the underlying passion to drive them on. As noted by Seymore *et al.*, loss of academic self-confidence is a significant factor in student migration, and therefore a major obstacle to completion of the engineering degree. Students who begin to exhibit low performance in courses can easily lose their confidence in the face of a large number of high achieving peers. This is particularly true at TAMU where students must achieve a minimum GPA (set by each engineering department, see Table 1.1) to be accepted into their chosen major.

1.3 Educational Data Mining

Educational Data Mining (EDM) is an area of research, defined by Romero & Ventura 2013, as being concerned with the development, research, and application of computerized methods to detect patterns in large collections of educational data that would otherwise be hard or impossible to analyze due to the enormous volume of data in which those patterns exist [3]. EDM as a distinct field is a mixture of education, computer science, and statistics, see Figure 1.4. As a field of research, EDM has recently emerged as a distinct subfield with the specific aim to analyze the unique kinds of data found in educational settings to resolve educational research issues [48]. Application of EDM techniques typically consists of two phases: 1) measurement, data collection, and preprocessing of data, and 2) reporting of data and interpretation of results [49].

Data collection and preparation is an essential and time consuming process in EDM.

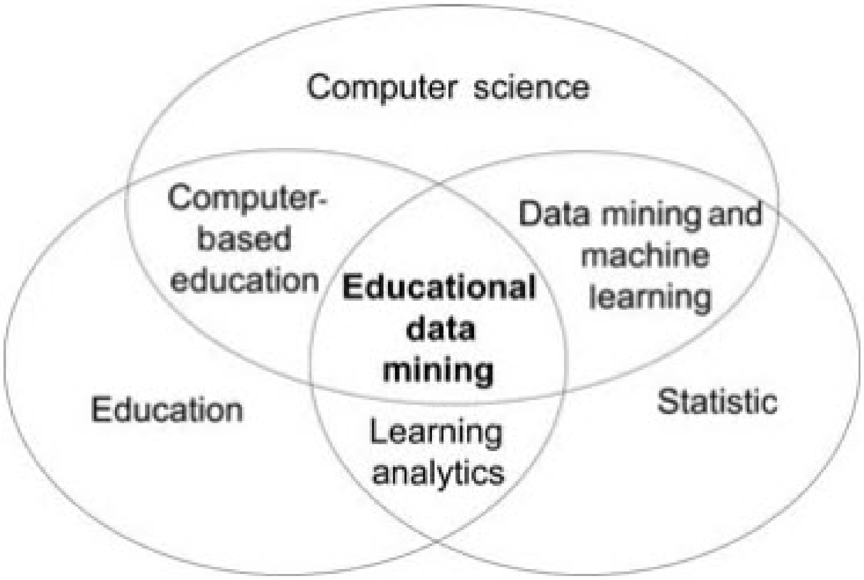


Figure 1.4: The main areas which relate to educational data mining, reprinted here from Romero & Ventura 2013 [3].

Data relevant to EDM is not limited to course grades and interaction times, but includes any other information related to education such as administrative data, demographic data of the school and students, student affectivity (*i.e.* beliefs and attitudes), etc [50]. These data types can have multiple characteristics, such as being hierarchical, context, fine grained, and longitudinal (data recorded over many sessions or semesters) [3]. Once collected, preprocessing of the data can involve considerable effort. This includes organization, grouping, and exclusion of certain data or data points to build the proper dataset. Within EDM, preprocessing of data is extremely important and complicated, sometimes taking up more than half of the total time spent solving the data mining problem [51].

Typical data mining studies employ a number of popular methods such as prediction, clustering, outlier detection, relationship mining, process mining, and text mining [52, 50, 53, 48]. The majority of these data mining techniques, including classification, clustering, and association analysis, have been successfully applied to previous EDM studies [53]. In the context of this study, described in Chapter 2, relationship mining and analysis is predominantly used to explore the link between student performance in one course with other educational metrics. Relationship mining is employed because it specifically seeks to identify relationships in learner's behavior patterns and diagnoses performance difficulties or successes that frequently occur together [54].

The goal of applying EDM techniques to a problem is to be able to inform decision making about how to improve the educational environment of a system [55]. Trends and meaningful relationships that are discovered through data mining have the ability to inform on what aspects of the educational environment are being effective (positive results) and what aspects may need improvement or reform (negative results).

Recent studies employing EDM techniques within PER have tended to focus on questions related to engagement with online courses and student retention. In 2012, Lawton *et. al.* reported on a study comparing two versions of an online course. Using a learning management system for analysis, Lawton *et. al.* concluded that integration of an evidence-based formative assessment promoted higher student learning compared to an online course that did not include this extra assessment [56]. In a 2014 analysis of a Massive Open Online Course (MOOC) hosted by MITx (now edX), Seaton *et. al* used tracking logs and time spent on resources to classify students engaging in the course and how that time spent related to outcomes [57]. Using social network analysis and logistic regression, Brewe *et. al.* examined the persistence (retention) of physics majors, concluded that access to learning communities promoted higher retention of students [58].

Within the scope of this study, EDM will be applied to data related to engineering majors at TAMU to explore the impact of IP on the institutionally relevant metrics of subsequent academic performance, retention, and matriculation rates. At TAMU, IP may be taken one of three ways, depending on if the course is taken on campus (using one of two different textbooks and educational styles) or taken off campus at another institution. Results from EDM will exhibit the relative success of each of these instructional methods compared to the others, and could form the basis of a discussion for any future, potential, education reforms that are made to the IP sequence.

1.4 Multimedia in Education

The use of multimedia resources in education has been on the rise in recent decades. This is aided by the increase in readily available and increasingly affordable electronics which aid in the creation of videos, including cameras, microphones and editing software. As a broad definition, the use of multimedia in education can include any intervention using media such as computers, laptops, podcasts, videos, interactive software, etc. Specifically, this body of work focuses on the video aspect of multimedia and its use in education.

Use of multimedia resources as an educational aid or intervention provides many benefits to instructors. In particular, multimedia technology is a useful tool for capturing the attention of modern students, who grew up in a multimedia environment with frequent (if not constant) visual and auditory stimulus [59, 60]. These resources also provide a measure of control to the student, permitting them to decide when, where, and how to access and review the material, increasing the effectiveness of instruction [61, 62]. Additional research supports student learning from technology enhanced multimedia resources when they are structured to unify concepts and are delivered in an on-demand format online [63, 64, 65].

The use of video and multimedia resources as been found to be an effective tool in physics education [66]. In an early study, Thornton and Sokoloff found that students using real-time graphics with a microcomputer based lab were able to significantly improve their qualitative understanding of kinematics and motion [67]. In 2008, Weiman *et. al.* reported on a program called *Workshop Physics*, in which computer technology was incorporated into real experiences, and was demonstrated to dramatically improve conceptual understanding for students on the topics of kinematics, dynamics, latent heat, and electricity [68]. Clinical studies conducted by the PER group at the University of Illinois Urbana Champaign indicated that students using multimedia learning modules (MLMs) outperformed their peers who were assigned reading assignments from the textbook [69, 70].

1.4.1 Cognitive Load

Structuring effective multimedia resources must be done in accordance with the current understanding of cognitive science and learning. One of the most important aspects of cognitive science to consider is the Cognitive Load Theory (CLT). CLT is based on a set of empirically verified assumptions which can be summed up in four statements: 1) Humans have a limited working memory, approximately seven bits of information at a time, 2) These limitations are mitigated by interaction with a practically infinite long-term memory, 3) Schemas stored in long-term memory are structured into chunks of information, which can increase the amount of information in working memory, and 4) Repeated processes become automated over time, reducing the load in working memory [71]. According to CLT, a reduction in the amount of information being presented can lead to increased learning in students [72]. It also implies that instructional messages which contain redundant or repeated information inhibit learning, called the redundancy effect [73].

Development of an effective resource must also be kept brief, less than 10 minutes per video, to maintain the attention of students. Content should focus on one or two new topics to limit the amount of new information that students need to focus on. And the time should be spent efficiently, focusing on the main points, reasonings, and justifications for applying certain steps.

1.4.2 Best Practices

In a recent paper, Lincoln 2017, a series of best practices were identified and defined in the making of good physics videos [74]. In this paper Lincoln reminds his readers that any successful videos must be planned with their audience in mind. In particular, he recommends the following practices: 1) Use of a live personality- including a host, animal, cartoon or other figure. This personality is recommended to be well dressed, have a pleasant voice, present a positive attitude, and be devoid of distracting features such as jewelry. 2) Demonstrations- using video to show something ordinary doing something extraordinary, or use of close ups for a common demonstration. The goal is to show students something beyond what could be seen in a lecture hall. 3) Words or symbols- having key phrases, new vocabulary, equations, or proportions appearing on screen at the relevant times during a video. These mark out what is particularly important for the audience to notice and to remember. 4) Voice-over/Narration- verbal explanation from off camera, when the live personality is not in the shot. Off camera dialog should be acted as if the speaker is on screen, preferably in the same room with the same microphone for consistency in sound quality. Lastly, 5) Music/Sound effects- control of what the audience is hearing tells them what to focus on.

The practices listed above encapsulate many of the recommendations for video production found online, from other studies, and what the researcher has gained through experience in this study. During the pre-production, or development, phase of videos, it is best to select the combination of practices to be employed in the final product. Not all practices need be used. It would be quite awkward to use both a live personality and narration, but an effective combination is required. As will be discussed in Chapter 4, four out of five of these best practices were employed during the creation of a new video resources which forms part of this body of work.

1.5 Purpose of Study

Engineering degrees are academically rigorous endeavors, which often end with a student migrating to another subject, or away from collegiate enrollment entirely. As part of the foundation of knowledge, it is essential to better understand the role that physics plays in the success (or failure) of engineering majors. Therefore, the goal of this study is to examine the impact of IP on the education of engineering majors. This is done in three parts, with each part addressing one of the following research questions: 1) What is the correlation of performance in IP with institutionally relevant metrics?, 2) How well is IP course content aligned with subsequent engineering coursework?, and 3) Does a new online supplemental resource improve students learning in the IP sequence?

For many students, IP can act as a barrier to continuation, with students either dropping the course and having to enroll in a later term, or earning a grade too low for them to continue to the next set of courses. In Chapter 2, this relation between IP performance and institutionally relevant metrics of subsequent academic performance in engineering courses, matriculation rate (how long it takes a student to graduate), and retention are studied using relevant educational data mining (EDM) techniques. Statistically significant connections between IP and these metrics will yield an indication of the effect that low performance in IP can have on the overall progression of an engineering major.

As IP Mechanics acts as a pre-requisite course for subsequent engineering courses, it is important that the material be well aligned to facilitate student success. Particularly because of the existing perception of misalignment between IP Mechanics and Statics & Dynamics, it is vital to study, in detail, the content of these courses for the frequency with which various physical concepts and mathematical skills are used. This work is further motivated and presented in Chapter 3.

Since IP courses act as barriers to completion for many engineering majors, it is important not just to understand the effect of the course, but also to try and improve the learning outcomes for students enrolled. To this end, a new online supplemental video resource was developed, deployed and assessed during the Spring 2017 term. The development and impact of this new resource is detailed in Chapter 4.

Together the three parts of this work seek to understand the broad impact of IP on engineering majors as a whole, the longitudinal effect of IP material between the freshman year with the sophomore and junior years, and the specific improvements which can be made to the learning outcomes within the IP courses. Significant results and conclusions of the three components of this thesis are summarized in Chapter 5.

2. DATA MINING ENGINEERING STUDENT RECORDS

This chapter explores the relation between success in IP Mechanics and success in two subsequent engineering courses which rely heavily on the concepts and skills taught in IP Mechanics. These courses, titled Statics & Dynamics and Dynamics & Vibrations, will be detailed later, along with course descriptions for the three versions of IP Mechanics in which TAMU engineering students may enroll.

The connections between academic performance in IP Mechanics and the engineering courses this chapter begins with a description of the data acquired from TAMU in Section 2.1. The statistical analysis methods employed are then described in Section 2.2. Details about the course compositions for IP Mechanics flavors and the subsequent engineering courses are given in Section 2.3. Section 2.4 presents detailed results for a single cohort of students, from the year 2010, and Section 2.5 presents aggregated results for years 1990-2010.

2.1 The Dataset

To examine the impact of introductory physics on engineering majors subsequent academic performance, retention and matriculation rate a dataset was obtained from TAMU. This data, obtained by a request filed with the appropriate TAMU office, contains a broad set of information on all undergraduate students registered as an engineering major for a minimum of one term starting at TAMU between 1990-2010. The data were separated into three distinct files encompassing demographic information, TAMU coursework, and transfer coursework. The transfer coursework file includes any credit transferred in from high school (*e.g* AP credit, or dual credit courses).

Details of the demographic information obtained for students is listed in Table 2.1. While records for more than 73,000 students were included in the data, many of these students were enrolled at satellite campuses of the Texas A&M System, including Galveston, Corpus Christi, Commerce, etc. Accounting only for students at the main campus in College Station, Texas, there are just over 50,000 records for engineering majors for students starting at TAMU between Fall 1990, and Spring 2011 (the end of the 2010-2011 academic year). Selection of 2010 as the final year of the data set ensured only the inclusion of students who had a full six academic years to complete their degrees. The final status entry of students was indicated by a degree and department for major(s) (*e.g.* BS-MEEN), a WITHDRAWN for officially left the university, or remained blank for no official terminal status. Students with a blank terminal status are assumed to have left the university, or to have taken more than six years to complete their degree.

Table 2.1: Detailed list of the demographic data for students obtained from TAMU.

Demographic	Details
Identifier	Random numerical ID unique to each student
First Term	Student's first term of enrollment at TAMU
Last Term	Student's last recorded term of enrollment at TAMU
Final Status	Terminal status with the university
Birth Year	Student's year of birth
Gender	Student's reported gender at time of enrollment
Ethnicity	Student's reported ethnicity at time of enrollment
1^{st} Generation	First college student within family

The majority of the data was contained in the information of coursework taken at TAMU, shown in Table 2.2. Within this file, each course in which a student enrolled is recorded in its own row. Therefore, every student ID corresponds to multiple rows (typically 35-40) comprising all of the courses attempted by that student at TAMU. Due to the structure of the TAMU records, instructor names for courses are available only for classes taken during or after 2009. Majors were listed based on data from the beginning of each term and are assumed only to change between terms. It is not possible to include the exact timing of a major change within this study.

Table 2.2: Detailed list of the TAMU coursework data for students obtained from TAMU.

TAMU Coursework	Details
Identifier	Random numerical ID unique to each student
Term	Term a particular course was taken
Subject	Department code for the course
Course	Course number within the department
CRN	Registration code unique to each course for a term
Professor	Name of instructor if available
Grade	Final course grade/status
Major	Listed student major for term

Details of coursework attempted at institutions other than TAMU is listed in Table 2.3. This includes credits transferred from high school or AP credit, in addition to courses taken at other institutions while concurrently enrolled as a student at TAMU. Credit received for courses taken in high school, or awarded through AP exam scores are marked as *CR* for a grade. This makes them easily distinguishable from coursework attempted concurrently with TAMU enrollment.

Table 2.3: Detailed list of the transfer coursework data for students obtained from TAMU.

Transfer Coursework	Details
Identifier	Random numerical ID unique to each student
Term	Term a particular course was taken
Original Institution	Institution at which the course was completed
TAMU Subject	Code for equivalent TAMU academic department
TAMU Course	Number for equivalent TAMU course within department
Grade	Final course grade/status

Combining the data listed above provides a robust set of information about the academic success and progression of engineering students across two decades. In the following section this data is further explored to gain a more complete understanding of the composition, retention, and matriculation rates of the engineering students during this period.

2.1.1 Demographics

Starting from the raw data set obtained from the university, student records were separated out by year to optimize analysis. Within each year basic demographics were examined in order to understand the composition of the engineering student body between 1990-2010. First, Figure 2.1 shows the number of engineering majors enrolled at TAMU during these years. On average each year has approximately 2,500 students. Though this number fluctuated from 1995-2005, the final years of this data set are relatively constant.

Between 1990-2010 there is a relatively constant fraction of male and female students, see Figure 2.2. Each cohort of engineering students is predominantly male, at around 80% of students. While this may be surprising due to the prevalence of recent programs designed to attract and retain female engineering majors, it is consistent with previous studies that identified ineffective recruitment as the major issue for women in undergraduate engineering majors [75]

Fractions of the reported ethnicities of students is shown in Figure 2.3. Ethnically students are predominantly Caucasian, with Hispanic students being the second most common followed by Asian and then African American students. The fraction of Caucasian students remains relatively constant until around 2003, when there is a slight decline from 78% to roughly 70%. This corresponds to an increase in Hispanic students over the same period. Native American and Hawaiian students are the smallest categories for domestic undergraduates, typically having less than 15 students for each per year.

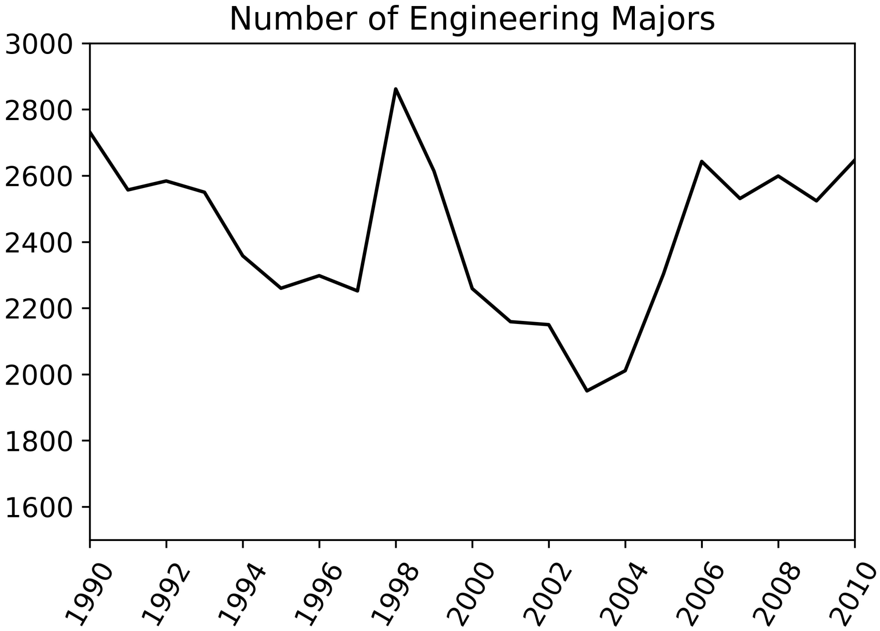


Figure 2.1: Number of students enrolled as an engineering majors for cohorts entering 1990-2010.

Figure 2.4 shows that students take the majority of their coursework at TAMU, as would be expected. There is a consistent trend, however, of students taking approximately 20% of their coursework at other institutions. Though this is the average behavior, the number of courses an individual student takes at TAMU or at another institution varies greatly as evidenced by the standard deviation. It is interesting to note a trend in decreasing deviation for the number of courses taken at TAMU simultaneously with an increase in deviation for coursework transferred from another institution. The standard deviation for TAMU coursework decreased approximately 33% while the standard deviation for transferred coursework grew 60% from 1990-2010.

A final feature of enrollment composition is the fraction of 1^{st} generation college students within each year, shown in Figure 2.5. From the figure it is clear that there is a significant fraction of 1^{st} generation college students in the 2009-2010 years. The low

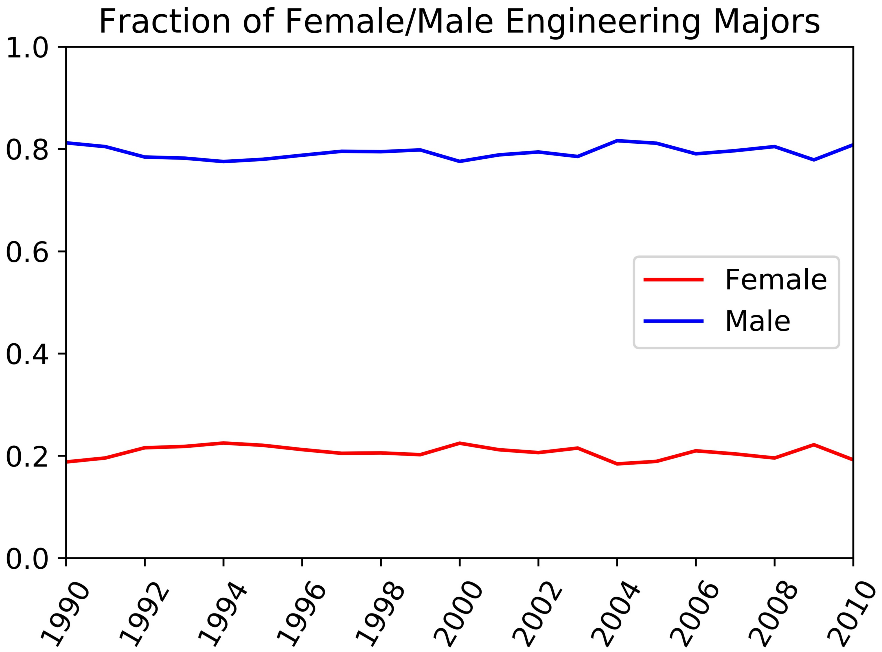


Figure 2.2: Fractions of students enrolled as engineering majors identifying as female or male for cohorts entering in the fall semesters 1990-2010.

fractions evident prior to those years is assumed to be an artifact of poor reporting mechanisms. As such, the values prior to 2009 are ignored for 1^{st} generation college students.

2.1.2 Retention

Demanding academic programs, which includes engineering, often struggle with a high attrition rate for their majors. This high attrition rates leads to the inverse statistic of low retention, and therefore low graduation rates. To meet the growing demand for engineering professionals in the upcoming years it is vital to understand why students leave engineering programs [cite, cite cite]. Part of such an investigation may begin identifying *when* engineering majors tend to migrate away from their departments, and further to build a profile of the common themes in their academic performance if any exist. In this section, retention behavior for all engineering majors is shown. In a subsequent section

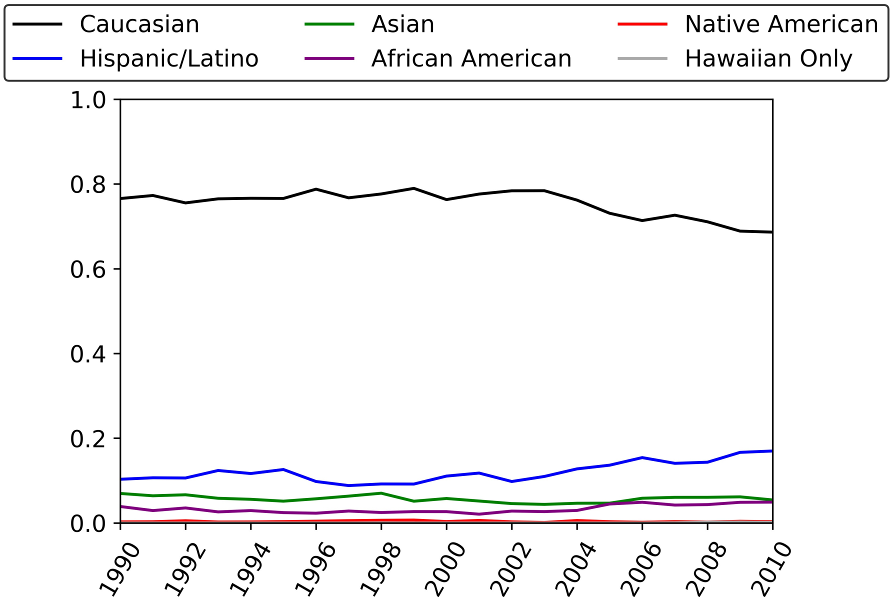


Figure 2.3: Distribution of ethnicities for engineering majors belonging to cohorts entering in the fall semesters 1990-2010.

the connection between academic performance and retention will be examined.

As a first examination, engineering student retention at the end of the 1^{st}, 2^{nd}, 4^{th}, and 6^{th} years of undergraduate enrollment for students entering 1990-2010 are shown in Figure 2.6. Students are categorized by their status as remaining in an engineering department, changing to a department outside of engineering but still at TAMU, or having no status (*e.g.* transferring or withdrawing). Only modest improvement has been made in retention rates for engineering majors during this period. It is striking that over 20% and 40% of engineering students leave the field in the 1^{st} and 2^{nd} year respectively. Better gains in retention have been made beyond the 4^{th} year for engineering students, primarily at the cost of reducing the fraction of students with no status. The relative number of students transferring out of engineering to another academic area at TAMU is relatively constant for all years.

Taking a more granular look at specific years, Figure 2.7 shows the term by term break

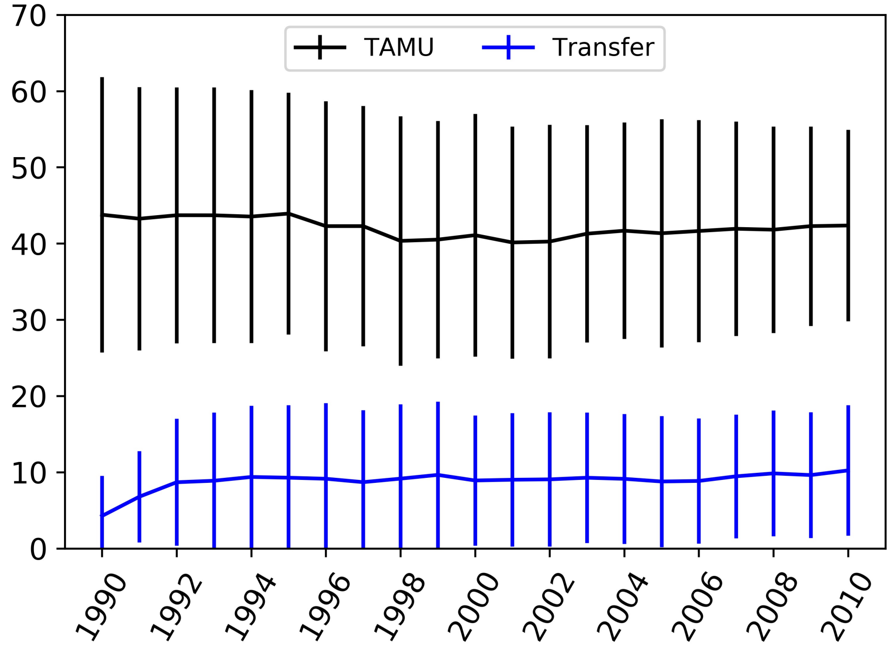


Figure 2.4: Average and standard deviation of the number of courses engineering majors took either at TAMU or transferred from another institution for cohorts entering in the fall semesters of 1990-2010.

down for retention, and graduation, for students who begin their undergraduate degrees as engineering majors. The years shown were selected for being evenly spaced in time through the available data. As noted above, gains were made in the retention after the second year; but it is clear from Figure 2.7 that it is specifically the first three terms that have the largest effect on retention in engineering. At the end of each of the first three terms, enrollment within engineering drops around 10%-13%. Beyond the first three terms the percentage of students migrating from engineering decreases to much smaller values.

While these figures act as confirmation of anecdotal knowledge for when students leave their engineering majors, they also act as motivation for some specific research questions: Is there a commonality in academic performance for students leaving engineering? If so, which courses are most, or least, responsible for this trend? From Chapter 1, it is known

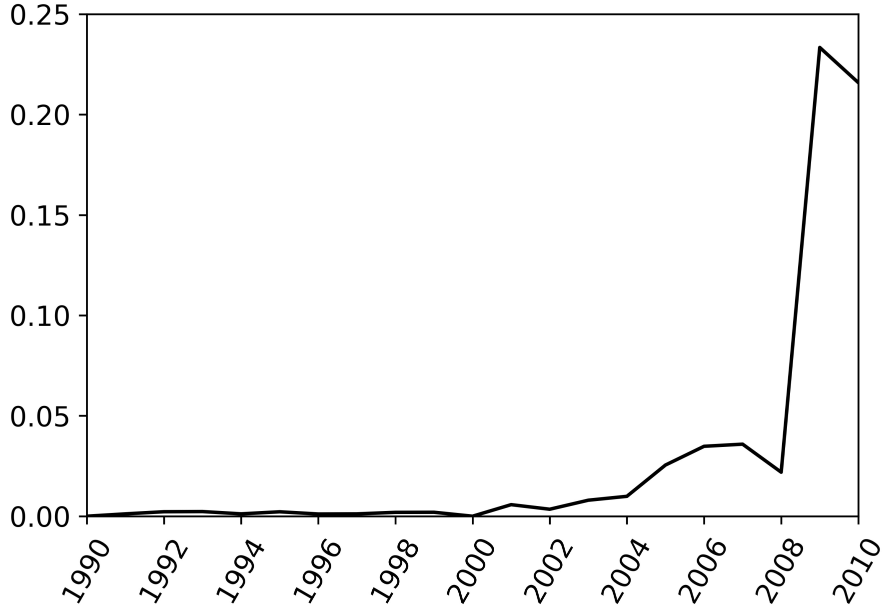


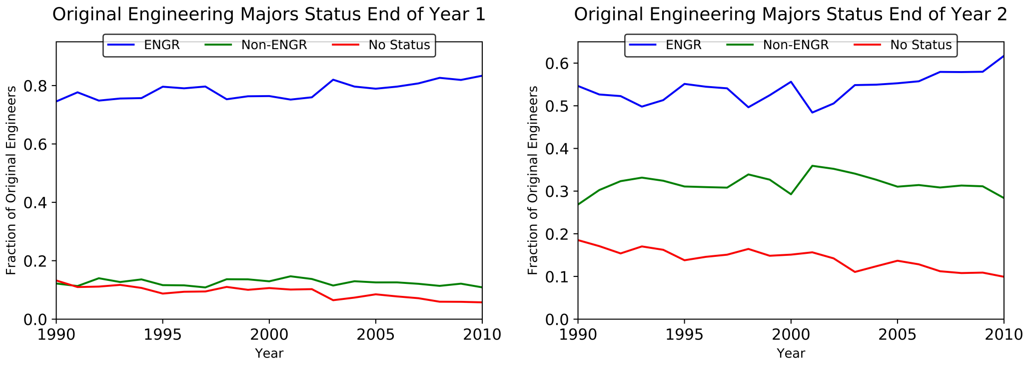
Figure 2.5: Fraction of students identified as 1^{st} generation college students at time of enrollment for cohorts 1990-2010.

that physics makes up 2 out of 7 required courses for freshman engineerings, and that students have a varied background in preparation, and typically negative feelings towards the subject. The impact of introductory physics on retention will be specifically examined later in this chapter.

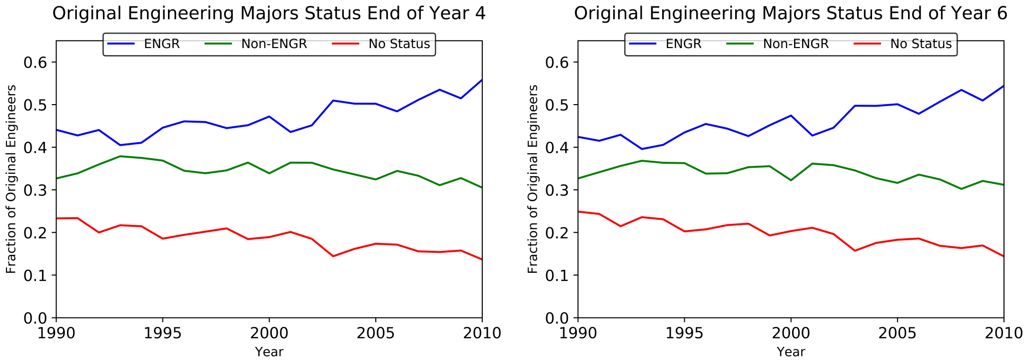
2.1.3 Graduation

The fraction of students graduating, and the time it takes those students to graduate, are important follow up metrics to retention for any department. Students retained, discussed in the previous section, will eventually reach a terminal status, whether that status is a degree, withdraw from the university, or no official status (cessation of enrollment).

Graduation rates for those who began as an engineering undergraduate and matriculated with a degree in an engineering discipline, or a non-engineering discipline are shown in Figure 2.8. Graduation rates of engineering majors have clearly increased from 1990-



(a) 1^{st} Year (b) 2^{nd} Year

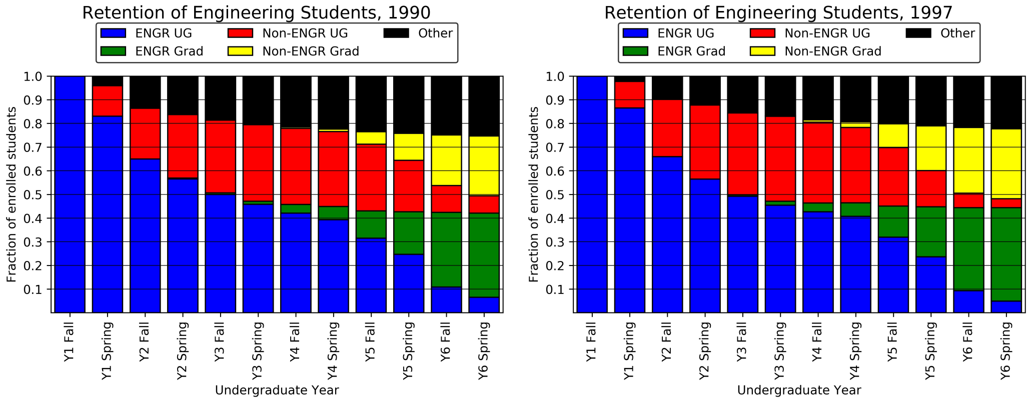


(c) 4^{th} Year (d) 6^{th} Year

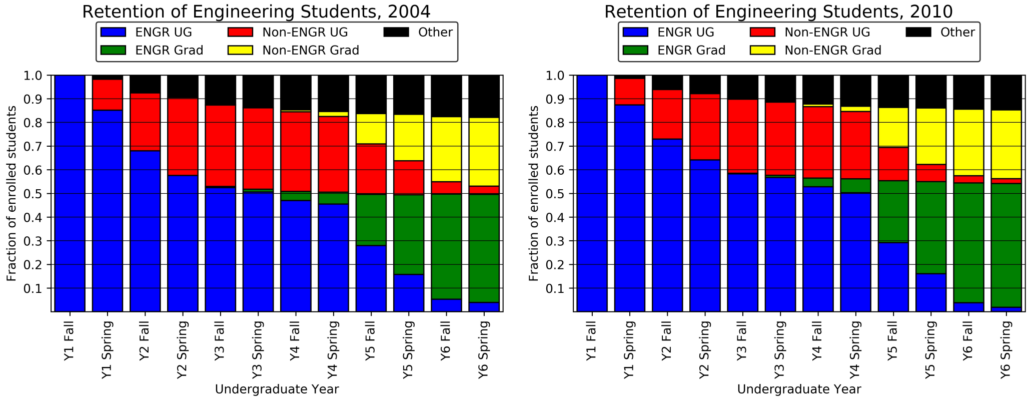
Figure 2.6: Retention rates for engineering majors at the end of their 1^{st}, 2^{nd}, 4^{th} and 6^{th} years for cohorts entering 1990-2010.

2010 by almost 5% of enrollment. This shift is concurrent with a depletion from the *Other* category, which is students having no further enrollment or terminal status. Graduation rates of students leaving engineering for another department on campus appears relatively constant across this period. From the bar graph portion of Figure 2.8 it is interesting to note that more engineering majors are graduating around the end of their 4^{th} year by 2010 than were in 1990.

Examination of the distribution of gender and ethnic composition of students graduating with degrees in engineering shows similar trends to enrollment. Figure 2.9 shows



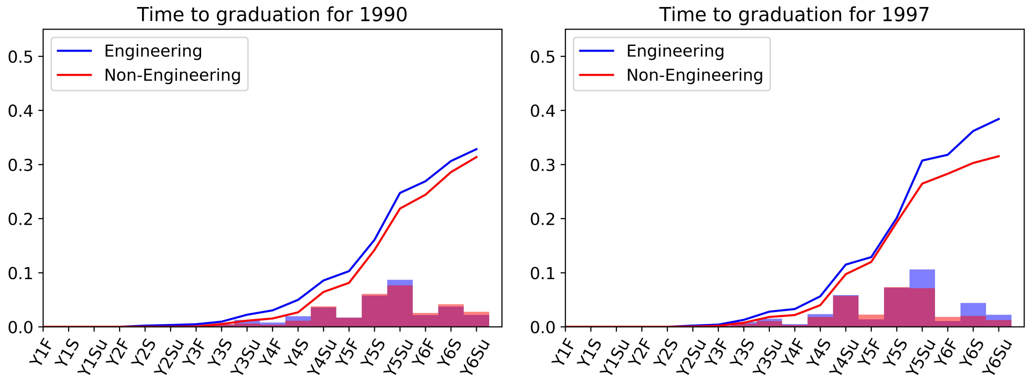
(a) 1990 (b) 1997



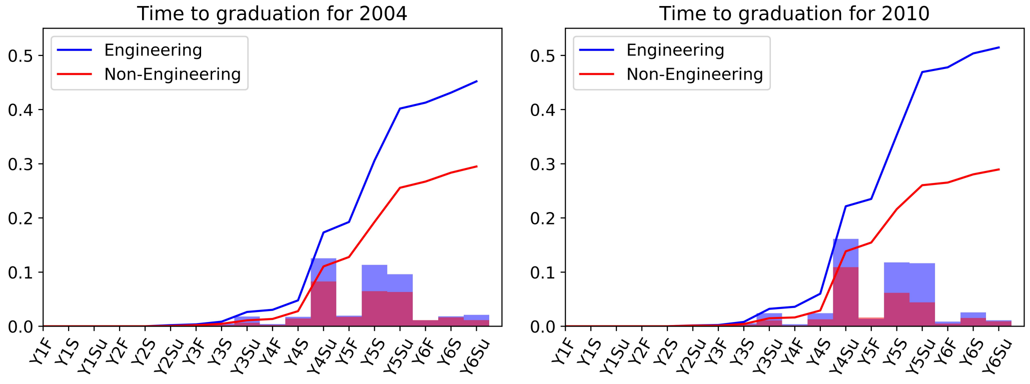
(c) 2004 (d) 2010

Figure 2.7: Retention of engineering students term by term for cohorts entering in the fall semester of 1990, 1997, 2004, and 2010.

a slightly higher fraction of male students graduating from engineering relative to original enrollment for approximately half of the years between 1990-2010 (see Figure 2.2). This indicates a higher fraction of female students leaving engineering majors.In Figure 2.10 there is no distinguishable difference in the rate of graduation of engineering students based on reported ethnicity (compare with Figure 2.3). The similarity between these pairs of figures indicates that no demographic group is being under served by their education at TAMU.



(a) 1990 (b) 1997



(c) 2004 (d) 2010

Figure 2.8: matriculation rate rates for engineering majors from cohorts entering in the fall semesters of 1990, 1997, 2004, and 2010. Solid lines indicate total fraction of graduated students from engineering, and non-engineering majors. The bar graph below shows the fraction of students graduated by the indicated term.

2.2 Analysis

2.2.1 Spearman Coefficient

To assess the interrelationship between two variables, the descriptive statistic of correlation is commonly applied [76]. For interval or ratio data, which may be continuous, it is appropriate to select the Pearson coefficient. When using ordinal data sets the alternative correlation statistic of the Spearman Rho (ρ) is appropriate [76, 77]. The Spearman

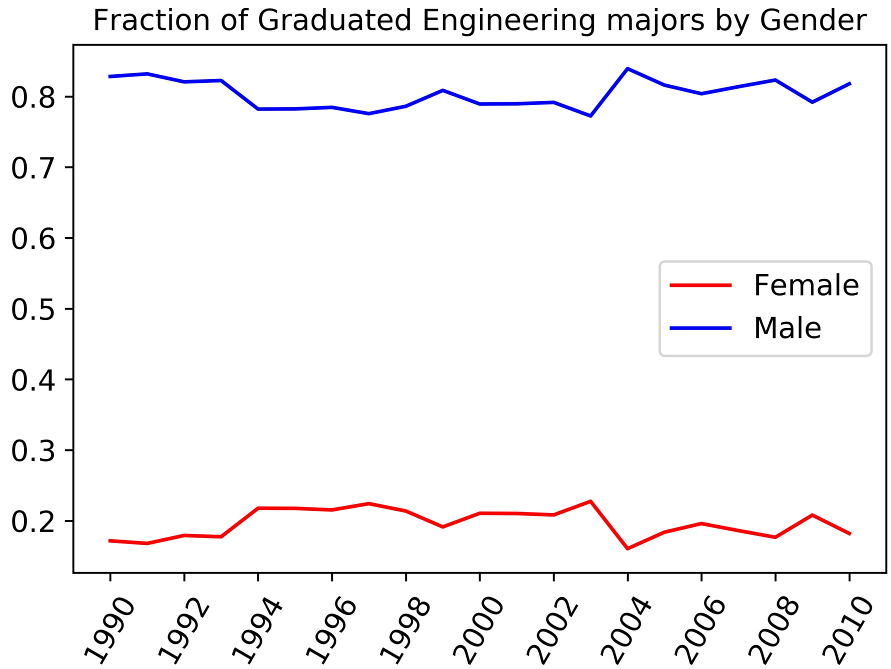


Figure 2.9: Fractions of students receiving degrees from an engineering department having identified as female or male at the time of enrollment for years 1990-2010.

ρ is frequently employed in PER research to assess the correlation between two different assessment techniques of the same quantity [78]. The Spearman ρ is a non-parametric measure of the monotonicity of the relationship between two variables.

Using the SciPy package available in Python, Spearman ρ coefficients may be calculated between two sets of ordinal data, such as grades from two different courses. Correlations range from +1 for perfect correlation between the variables to -1 for perfect anti-correlation. For a correlation to be significant it must have a significance level, p, below a certain threshold. Significance is a measure of the effect calculated (the correlation in this instance) being random chance. For this study results are considered significant below the $p = 0.05$ threshold. Example correlations and significance levels were generated using dummy data and may be seen in Figure 2.11 to further understand correlation [4].

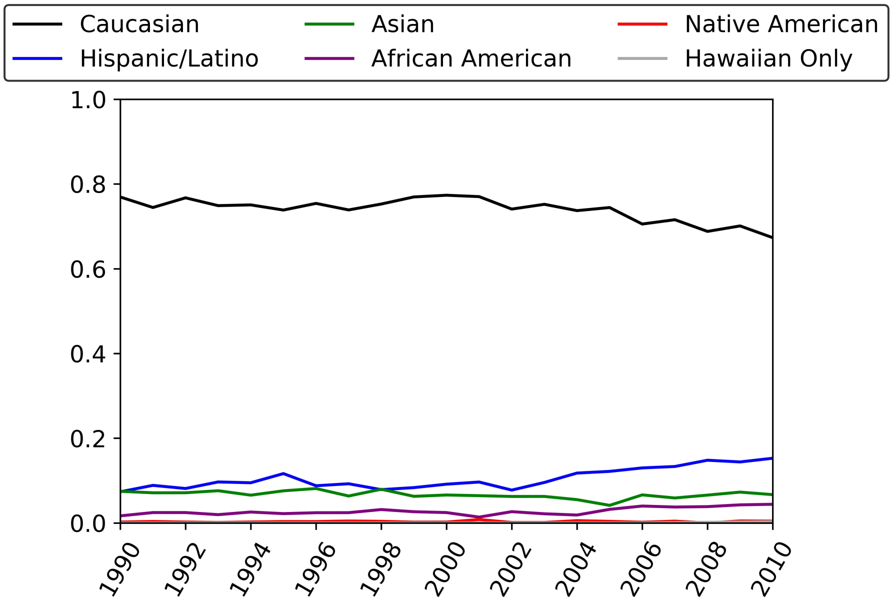


Figure 2.10: Distribution of ethnicities for students receiving degrees from an engineering department for cohorts entering 1990-2010.

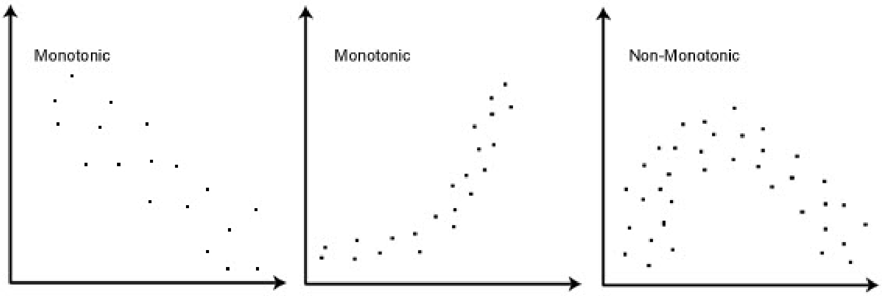


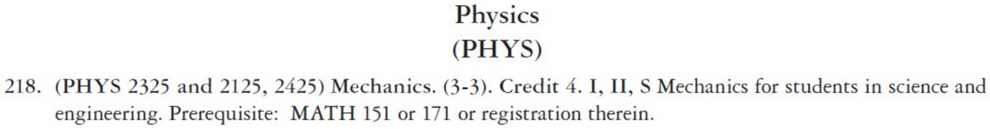
Figure 2.11: Example of data representing two monotonic trends and one non-monotonic trend, reproduced here from Laerd Statistics [4].

2.3 Physics & Engineering Courses

Within this section the courses which were examined in detail are described. For IP Mechanics a basic description of the course, and its relation to the expectations of the state coordinating board is detailed. Additionally, the three types of physics courses TAMU engineering students may enroll in are presented. Descriptions are also provided for the two follow-on engineering courses which rely heavily on the topics from IP mechanics.

2.3.1 Introductory Physics- Mechanics

The first course in the calculus-based introductory physics sequence is PHYS-218, a Newtonian mechanics course. This course is equivalent to the Texas Higher Education Coordinating Board's (THECB) PHYS 2425 (2325+2125). The TAMU undergraduate catalog entry for this course is shown in Figure 2.12. The Mechanics IP course is a large enrollment course, typically serving over 2,000 students per academic year, primarily from engineering majors. Each lecture has 75-150 students (depending on year and available space), with small group recitations containing 20-28 students.



Physics
(PHYS)

218. (PHYS 2325 and 2125, 2425) Mechanics. (3-3). Credit 4. I, II, S Mechanics for students in science and engineering. Prerequisite: MATH 151 or 171 or registration therein.

Figure 2.12: Course description for PHYS-218, a calculus-based introductory physics course, reproduced from the 2010-2011 TAMU Undergraduate Catalog [5].

Based on the requirements of the THECB and the necessary topics for Mechanics (also referred to as Newtonian Mechanics), the course covers subjects including: kinematics, Newton's laws of forces, work, energy, circular motion, rotational motion/dynamics, torque, linear and angular momentum, gravity, and simple harmonic motion.

Engineering students enrolled at TAMU have the freedom to take multiple versions of the Mechanics IP course. Two of these different "flavors" of IP are available at TAMU through the department of Physics & Astronomy. They are referred to as *University*

Physics (UP) and *Don't Panic* (DP) respectively. A third option is to transfer a physics credit from another institution. In this chapter all transfer credits of physics are considered for students only after they are enrolled at TAMU. Therefore, any transfer physics credit was taken during a summer term or concurrently with a fall or spring term. This excludes students who were enrolled full time at another institution. Each of these flavors of physics is described here.

2.3.1.1 University Physics

The UP flavor of introductory physics uses the lecture/recitation format described above. For the years examined in this study the primary textbook was Young & Freeman's University Physics textbook, published by Pearson [79]. In recent years this textbook has been paired with online systems for homework and pre-lecture material. Specifically using MasteringPhysics from Pearson Education for online, automatically graded homework, and SmartPhysics/FlipItPhysics for pre-lecture videos.

Mid-term and final exams are accompanied by a robust equation sheet. This lets the test focus on selection and manipulation of a particular set of equations for each problem. The UP equation sheet may be found in Appendix C, while an example mid-term exam is available in Appendix B.

2.3.1.2 Don't Panic

Similar to UP, the DP version of introductory physics uses the large lecture and small group recitation course format. The flavor of IP is named for its textbook, written by Dr. William H. Bassichis, a member of the Physics & Astronomy faculty at TAMU long interested in the education of physics, particularly to engineering majors [80]. In contrast to UP, no additional online systems are used with this course. No homework is assigned, collected, or graded; students are simply informed of the availability of problems in the book to check their understanding.

Mid-term and final exams are accompanied only by a small set of equations relevant to the material. Students are expected to recall a set of fundamental physical laws and apply them to problems. The equations available from mechanics for DP are shown in Appendix C, while an example mid-term exam is available in Appendix B.

2.3.1.3 Physics from Other Institutions

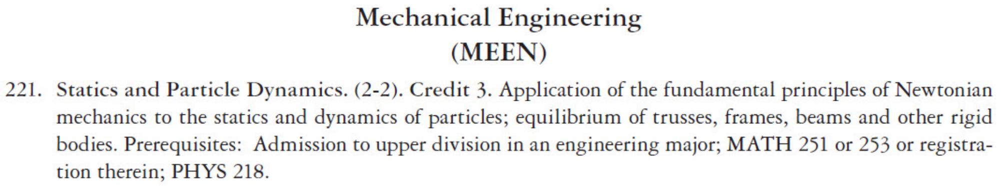
Engineering students at TAMU come from every part of the state of Texas, and from many places beyond. This is mirrored in the breadth of institutions from which students transfer credits, which makes an exhaustive description of their potential physics courses untenable. However, the single most common institution TAMU students attend outside of the main campus is the local community college: Blinn. Physics courses are Blinn are taught by a mixture of full time and adjunct faculty with a class size of ≤ 30, with a mixed lecture and lab section. Physics instructors at Blinn tend to use the same textbook as the UP physics course at TAMU.

Mid-term and final exams also used a robust equation sheet, again similar to UP. Examples of a mid-term examine available to students and the equation sheet from a single Blinn instructor may be found in Appendices B & C respectively.

2.3.2 Statics & Dynamics

Typically taken in the second year of an undergraduate engineering program, Statics & Dynamics is cross-listed in multiple departments at TAMU. The departments of Mechanical, Civil, and Aerospace engineering each have their own version of Statics & Dynamics, which may also serve other majors (especially Mechanical engineering). A description of the Mechanical engineering version of this course, currently listed as MEEN-221, is shown in Figure 2.13. Enrollment for this course exceeds 1,000 students over the fall and spring semesters each year.

A brief look through the topics of Statics & Dynamics supports the anecdotal title



Mechanical Engineering
(MEEN)

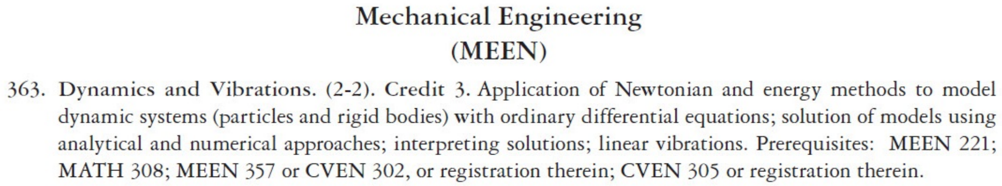
221. Statics and Particle Dynamics. (2-2). Credit 3. Application of the fundamental principles of Newtonian mechanics to the statics and dynamics of particles; equilibrium of trusses, frames, beams and other rigid bodies. Prerequisites: Admission to upper division in an engineering major; MATH 251 or 253 or registration therein; PHYS 218.

Figure 2.13: Course description for MEEN-221, a sophomore level Statics & Dynamics course, reproduced from the 2010-2011 TAMU Undergraduate Catalog [5].

given by a former engineering student of this course being “PHYS-218 2.0”. Many topics covered in this course (including forces, torques, and static equilibrium) are first covered in the IP Mechanics course.

2.3.3 Dynamics & Vibrations

Scheduled for the junior year of some engineering majors, Dynamics & Vibrations is also cross-listed in multiple departments at TAMU. This cross-listing is limited to the Mechanical and Civil engineering departments. A description of the Mechanical engineering version of this course, listed as MEEN-363, is shown in Figure 2.14. Enrollment in Dynamics & Vibrations is the smallest of the courses examined in this work, with an average year seeing 500-600 students.



Mechanical Engineering
(MEEN)

363. Dynamics and Vibrations. (2-2). Credit 3. Application of Newtonian and energy methods to model dynamic systems (particles and rigid bodies) with ordinary differential equations; solution of models using analytical and numerical approaches; interpreting solutions; linear vibrations. Prerequisites: MEEN 221; MATH 308; MEEN 357 or CVEN 302, or registration therein; CVEN 305 or registration therein.

Figure 2.14: Course description for MEEN-363, a junior level Dynamics & Vibrations course, reproduced from the 2010-2011 TAMU Undergraduate Catalog [5].

Similarity of Dynamics & Vibrations to the Mechanics IP course is found in the overlap of Newtonian mechanics (again free-body diagram) and energy analysis. Many of the solution methods for this course rely on solving differential equations, something that is not expected from a freshman level course. These differences will be discussed further in a subsequent section.

2.4 Single Cohort- 2010

In this section a detailed breakdown of a single cohort of students is presented in depth. This includes a discussion of grade distributions for IP Mechanics courses, comparative performance in two engineering courses described previously, matriculation rate, and retention. These results are expanded for all years 1990-2010 in Section 2.5.

The composition of the 2010 cohort may be interpreted from Figures 2.1, 2.2, 2.3, and 2.5, however the information will be reiterated here as reference for the following results. The entering cohort of 2010 had just over 2,600 students enrolled as engineering majors for a minimum of one semester. The gender split was 80.8% male, and 19.2% female. Ethnically the 2010 cohort was 68.6% Caucasian, 17.0% Hispanic, 5.4% Asian, 3.0% International, 2.3% African American, 0.3% Native American, and 0.1% Hawaiian, with the remainder falling into other categories. Approximately 22% of the cohort identified as being first generation college students.

Grade distributions vary based on the flavor of IP Mechanics in which students enrolled. Distributions of grades for the three flavors of IP Mechanics for the 2010 cohort is shown in Figure 2.15. Grade point averages (GPA) across the flavors of physics are calculated as 2.43 for UP, 2.17 for DP, and 2.93 for Transfers. The overall DFQ rate, that is students receiving a grade of D, F, or dropping the course (Q), is 22.0% for UP, 29.4% for DP, and 5.7% for Transfer students.

More students appear to fail or drop the IP Mechanics course at TAMU relative to those enrolled at other institutions. Further, students tend to receive a higher fraction

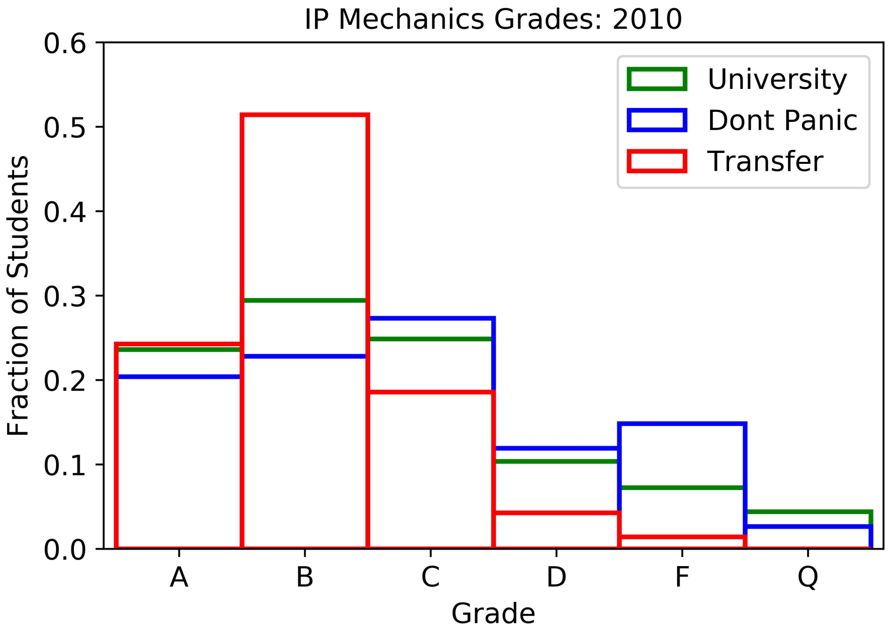


Figure 2.15: Grade distributions for the three potential flavors of the Mechanics IP course.

of lower grades in TAMU courses relative to IP Mechanics taken elsewhere. This leads to a question of consistency for content, teaching, and grading standards across courses, instructors, and institutions. This question is beyond the scope of this work, however, it remained an excellent question for future study.

Recall that students taking the IP Mechanics course have three options for enrollment: 1) University Physics (UP) at TAMU, 2) Don't Panic (DP) at TAMU, and 3) Transfer credit from another institution.

2.4.1 Performance in Engineering Courses

Due to the similarity of topics between the Mechanics IP course and the follow on courses of Statics & Dynamics as well as Dynamics & Vibrations, it is expected that successful performance in the former should produce a successful performance by students in the latter. This expectation is for the average behavior of all students, not for any particular individual.

Grade distributions for the Statics & Dynamics course are shown in Figure 2.16. Distributions are separated by the passing grade students achieved in the Mechanics IP course, and each flavor of physics is shown. The UP and DP distributions shows small differences or no differences at all levels. This suggests that students leave their Mechanics IP course equally prepared for Statics & Dynamics, while students with a transferred credit may be less prepared.

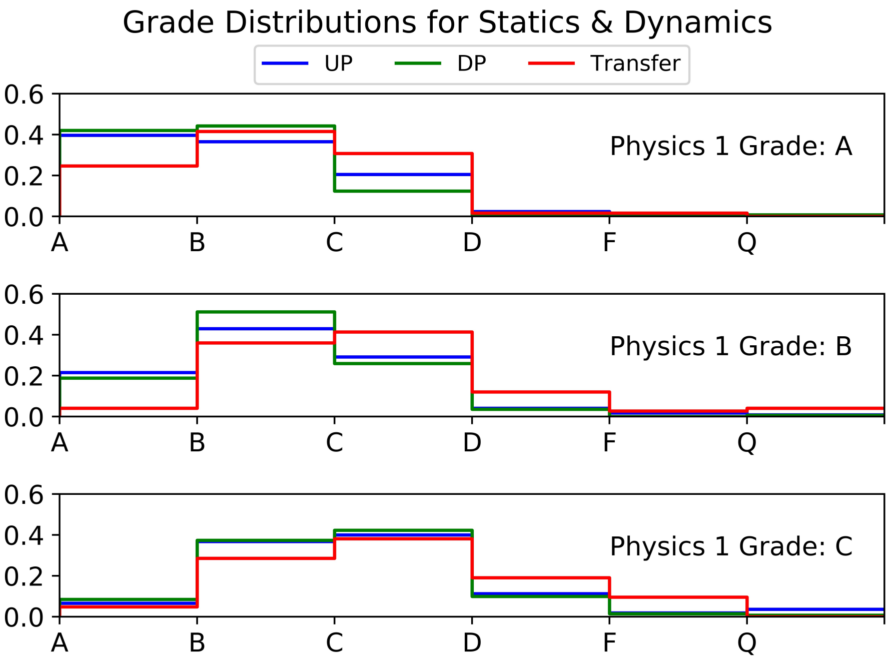


Figure 2.16: Grade distributions for all Statics & Dynamics courses for the 2010 cohort at TAMU. Each panel corresponds to a passing grade from a Mechanics IP course.

For each physics grade, students who transferred their credit under perform in the Statics & Dynamics course compared to both UP and DP students. This is evidenced by the transfer category having the smallest fraction at the equivalent grade or higher, and the highest fractions at lower grades. For example, students who transferred in physics with an *A* from another institution were half as likely to achieve an *A* in Statics & Dynamics compared to UP and DP students. Transfer students were also the most likely to achieve a result of DFQ from Statics & Dynamics. This is especially clear for *B* and *C* IP Mechanics grades.

An equivalent comparison of IP Mechanics grades with Dynamics & Vibrations was also conducted. Grade distributions for Dynamics & Vibrations based on a Mechanics IP grade are shown in Figure 2.17. As in Figure 2.16, grade distributions are separated by the passing grade students achieved in their Mechanics course, and each flavor of physics is shown.

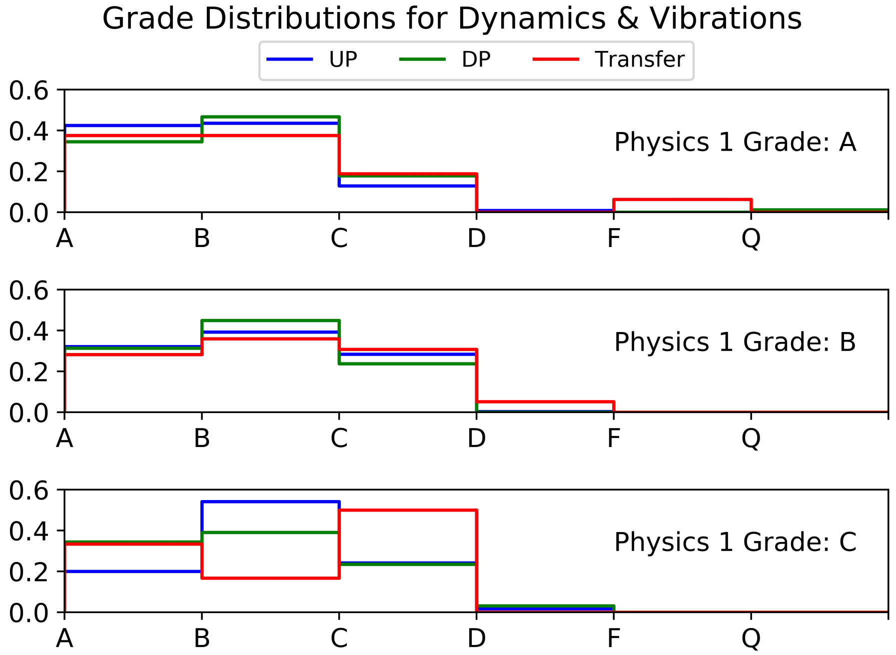


Figure 2.17: Grade distributions for all Dynamics & Vibrations courses for the 2010 cohort at TAMU. Each panel corresponds to a passing grade from a IP Mechanics course.

For Dynamics & Vibrations there is not a clear and consistent trend for any flavor of physics. For students achieving an *A* in Mechanics, later performance is very similar at all passing grades, though DP exhibits a lower fraction in the *A* range. Students achieving a *B* in Mechanics are roughly equally likely to get either an *A* or a *C* in Dynamics & Vibrations. Transferred physics appear to be less likely to achieve a *B* and slightly more likely to fail the course with a *D* or *F* compared to UP and DP. At the *C* level DP show the highest probability to increase their grade to an *A*, and are equally likely to achieve another grade of C as UP. Transferred physics achieves a grade of *C* at a 50% rate here and is roughly equally likely to achieve either an *A* or *B* otherwise, under performing UP and DP at the B level, and similar to UP at the *A* level.

Further comparison of performance between IP Mechanics and the engineering courses may be done using the Spearman correlation as defined in Section 2.2. Correlation coefficients and their associated significance levels are displayed in Table 2.4 for Statics & Dynamics and in Table 2.5 for Dynamics & Vibrations.

Table 2.4: Spearman correlation coefficients and their significance levels for the 2010 cohort between IP Mechanics and the sophomore level Statics & Dynamics course at TAMU.

Flavor	Correlation	Significance
University	0.308	<0.0001
Don’t Panic	0.401	< 0.0001
Transfer	-0.024	0.892

Correlations between IP Mechanics and the Statics & Dynamics course shows a definite difference depending on the flavor of IP a student enrolled in. The DP flavor exhibits the strongest correlation, at $0.401, p < 0.0001$, indicating a small causal link between the two courses. Next the UP flavor exhibits a weaker positive correlation, at

Table 2.5: Spearman correlation coefficients and their significance levels for the 2010 cohort between IP Mechanics and the junior level Dynamics & Vibrations course at TAMU.

Flavor	Correlation	Significance
University	0.158	0.016
Don't Panic	0.139	0.232
Transfer	-0.066	0.801

$0.308, p < 0.0001$. This correlation is too small to be taken as causal (being < 0.35), however it is a modest positive correlation. Transfer IP Mechanics has the weakest correlation, at $-0.024, p = 0.892$. This is effectively no correlation between the two grades, though the significance level is so high that no real conclusion may be drawn from the data. Where positive correlations exist between these two courses, it may be inferred that positive performance in IP Mechanics promotes positive performance in Statics & Dynamics, which is exhibited in Figure 2.16.

2.4.2 Matriculation Rate- 2010

Matriculation rates for engineering majors, separated by physics flavor, are shown in Figure 2.18. For each year, the terms of enrollment considered are the fall (F), spring (S), and summer (Su) terms with one of each comprising a single academic year. Students transferring in their physics credit graduate at a higher rate for 2010 compared to physics taken on campus. They also tend to start graduating sooner, due to their completion of more credits earlier in their collegiate enrollment compared to other students. For students taking IP Mechanics on campus, those enrolled in DP tend to graduate at a slightly higher rate in the fourth year compared to UP, though UP tends to graduate a high fraction at the end of the sixth year. This flip is occurs during the 5^{th} year. The total graduation rates for each flavor fall in the 45%-55% range.

Examining the relation of IP Mechanics grade relative to matriculation rate yields ad-

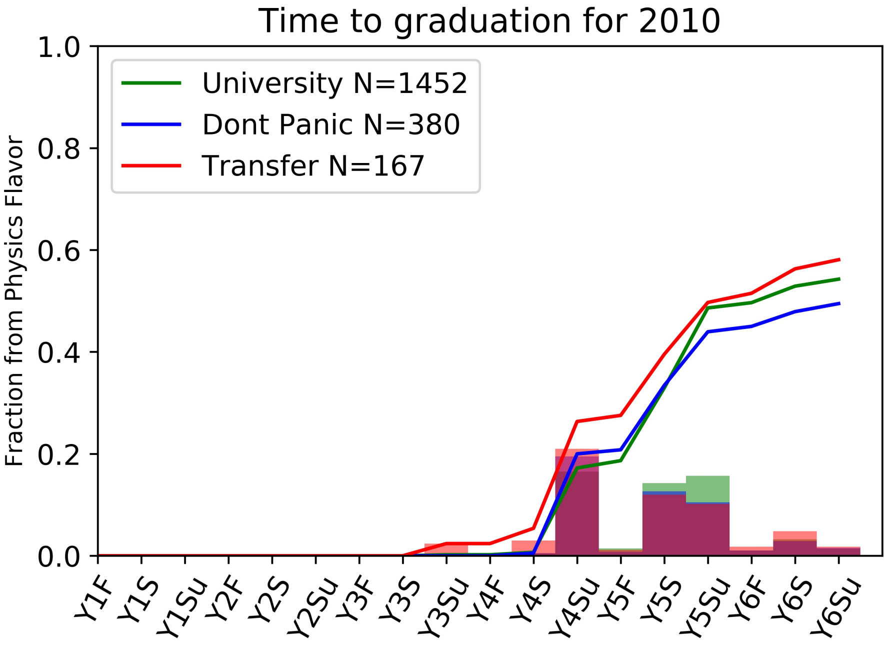
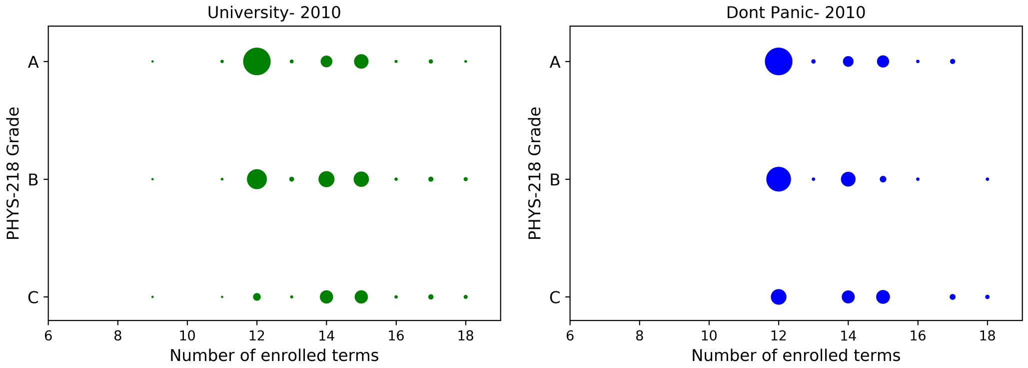


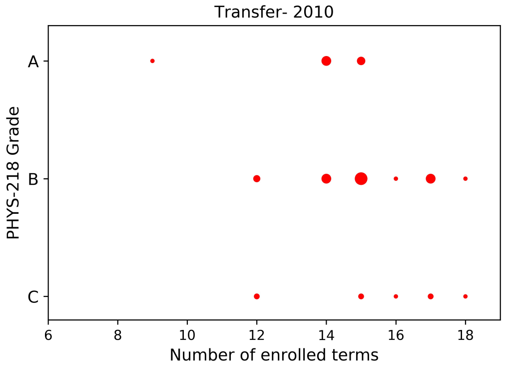
Figure 2.18: Time taken for undergraduate engineering students to graduate for each flavor of IP Mechanics.

ditional differences between the flavors of IP Mechanics, shown in Figure 2.19. The size of the circles corresponds to the number of students at each point. The UP flavor has the largest concentration of students as those earning an *A* in IP Mechanics and graduating at the end of four years, with a slightly smaller fraction of students earning a *B* graduating at the same time. However, there are significant fractions of students graduating in the fifth year earning any passing grade in UP. The DP flavor has nearly equal numbers of students graduating at four years with either an *A* or a *B* in IP Mechanics, with a slightly smaller number of *C* students doing so as well. Similar number of students across all passing grades also graduate at the fifth year mark. Students transferring physics in are well distributed between the fourth to sixth years across all passing grades.

While the information of Figure 2.19 provides visual clues about the relation of IP grades to graduation, the correlation is more instructive about the relation between IP



(a) University (b) Don't Panic



(c) Transfer

Figure 2.19: Grade from IP Mechanics versus year of graduation separated by flavor. The size of the circles indicates relative fraction from the number of students enrolled in that flavor of IP Mechanics.

Mechanics and matriculation rate. Aggregate correlations for the UP flavor between IP Mechanics grade and Statics & Dynamics is $-0.278, p < 0.0001$, for DP $-0.220, p < 0.0001$, and for transfers $0.486, p < 0.0001$. Correlations for the UP and DP flavors indicate that higher grades in IP Mechanics produce lower graduation times. Though the correlation is not strong, comparison with the transfer correlation suggests a preferred outcome for IP Mechanics taken at TAMU. Results from the Spearman correlation are consistent with the data seen in Figure 2.19.

2.4.3 Retention

The final institutionally relevant metric is the retention of students within a degree. This work does not study any change of majors within the College of Engineering. For all grades received the average retention percentages are 68.5% for UP, 68.4% for DP, and 65.7% for transfers. More detailed retention percentages based on total enrollment within a flavor of physics is shown in Table 2.6.

Table 2.6: Retention percentages for each flavor of IP Mechanics based on total enrollment within that flavor of the course for all passing grades.

Flavor	A	B	C
University	18.4%	19.5%	12.8%
Don't Panic	15.5%	13.4%	14.2%
Transfer	14.3%	31.4%	11.4%

From this retention information and the data available in Table 2.6 it appears as if there is no advantage to students taking IP Mechanics on the TAMU campus. This view is somewhat skewed because of the higher number of *B*'s transferred in from other institutions. More instructive is the percentage of students retained per letter grade received, as shown in Table 2.7. From this table it is clear that there is a difference to retention across the flavors. Students achieving an *A* in IP Mechanics stay in their engineering major at a higher percentage taking IP at TAMU versus transferring credit in from another institution. At the *B* level retention is consistent no matter the flavor of IP. For students receiving a *C* in IP Mechanics there is a higher rate of retention for transfer students compared to either UP or DP.

Table 2.7: Retention percentages for each flavor of IP Mechanics scaled by the number of students within that flavor receiving each grade.

Flavor	A	B	C
University	74.6%	63.1%	49.2%
Don't Panic	74.0%	57.0%	50.5%
Transfer	58.8%	61.1%	61.5%

2.4.4 Summary- 2010

As whole the data from students within the 2010 cohort offer some instructive, though contradictory details, about the impact of IP Mechanics on graduation, academic performance, and retention. Though many more students transfer in grades of *A* or *B* from other institutions, they tend to under perform in the Statics & Dynamics course relative to UP and DP. No similar behavior is seen in comparison to the Dynamics & Vibrations courses. All three flavors of IP Mechanics have similar terminal graduation rates, though a higher fraction of transfer students graduate at or around the fourth academic year compared to UP and DP students. Finally, similar fractions of students are retained within the engineering majors independent of the flavor of IP Mechanics taken. This does, however, depend on the grade received in IP Mechanics, with *A* students from the transfer category migrating out at a higher rate that those receiving an equivalent grade in UP or DP. This trend is flipped at the *C* level with a higher fraction of transfer students being retained. Taken together there is a slight causal link between taking IP Mechanics at TAMU with better performance in subsequent engineering courses and a weak link in taking IP Mechanics at another institution with a faster matriculation rate.

2.5 All Cohorts 1990-2010

Following the same pattern on analysis as the preceding section, this section presents the result for the metrics of academic performance, graduation, and retention for years

1990-2010.

2.5.1 Performance in Engineering Courses

The Spearman correlation coefficient calculation is applied for grades from IP Mechanics and Statics & Dynamics for all years, with results shown in Figure 2.20. As seen in earlier sections there is a lack of data around 1998-2001 between the two courses due to changes in the curriculum at those times. During the majority of the 1990's, and since 2002 there is a consistent trend for UP with correlations between 0.30 and 0.40. Correlations for transfer credits are less definitive due to the high p value (and therefore no statistical significance) across many years. For years where the significance value is low enough to be considered meaningful, transfer students have a correlation typically just below that of UP. For years in which DP may be identified, this flavor exhibits higher correlations compared to UP.

Aggregate values for the Spearman correlations are shown in Table 2.8, including the median, average, and standard deviation. The UP flavor has a moderately strong median correlation, giving a small indication of causal linking between IP Mechanics and Statics & Dynamics. For DP the correlation is slightly stronger, though only two years of unique records are available for this flavor. Transfers rank as the weakest correlation, and at 0.22, the value is too low to draw any conclusions about causal linking between the two courses.

Table 2.8: The median, mean, and standard deviation of all Spearman correlation coefficients between IP Mechanics and Statics & Dynamics.

Flavor	Median	Mean	σ
University	0.353	0.339	0.210
Don't Panic	0.413	0.413	0.012
Transfer	0.224	0.171	0.289

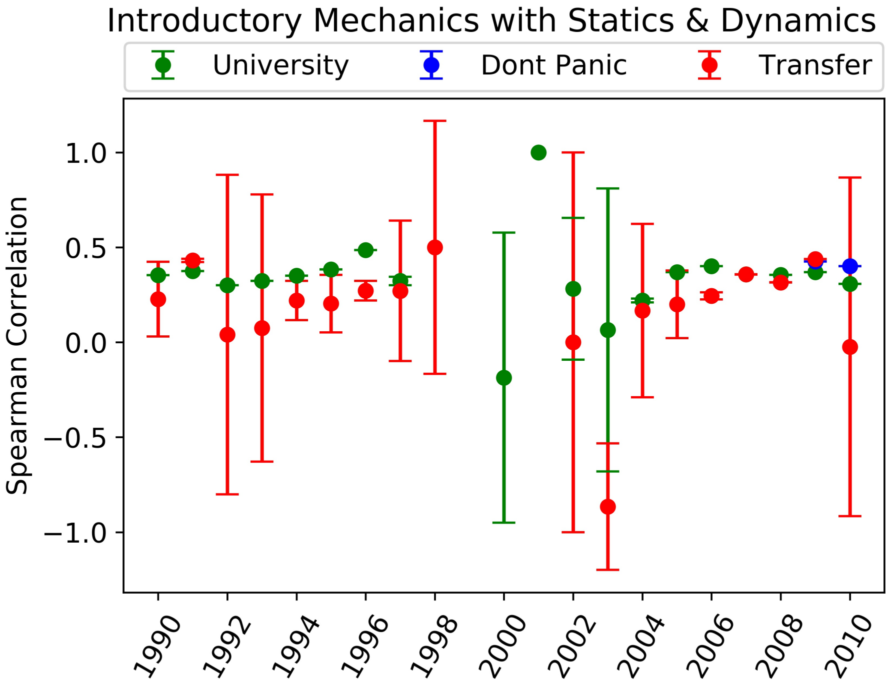


Figure 2.20: Spearman correlation coefficients between IP Mechanics and the Statics & Dynamics course. Error bars correspond to significance level p.

Application of the Spearman correlation coefficient between IP Mechanics and Dynamics & Vibrations for all years is shown in Figure 2.21. The UP flavor is the only flavor which tends to have a statistically significant correlation across the years analyzed, though the value tends to remain below 0.30 (see Table 2.9 for mean value). The DP flavor has no statistically significant values. Transfers once again exhibit a highly varying behavior in the correlation coefficients, with many years having no statistical significance. Years that are significant tend to exceed UP to a small causal level.

2.5.2 Matriculation Rate

As with the correlation between IP Mechanics grades and subsequent engineering courses, the Spearman correlation coefficient between IP Mechanics grade and the matriculation rate has been calculated for all years, and is shown in Figure 2.22. Median, mean,

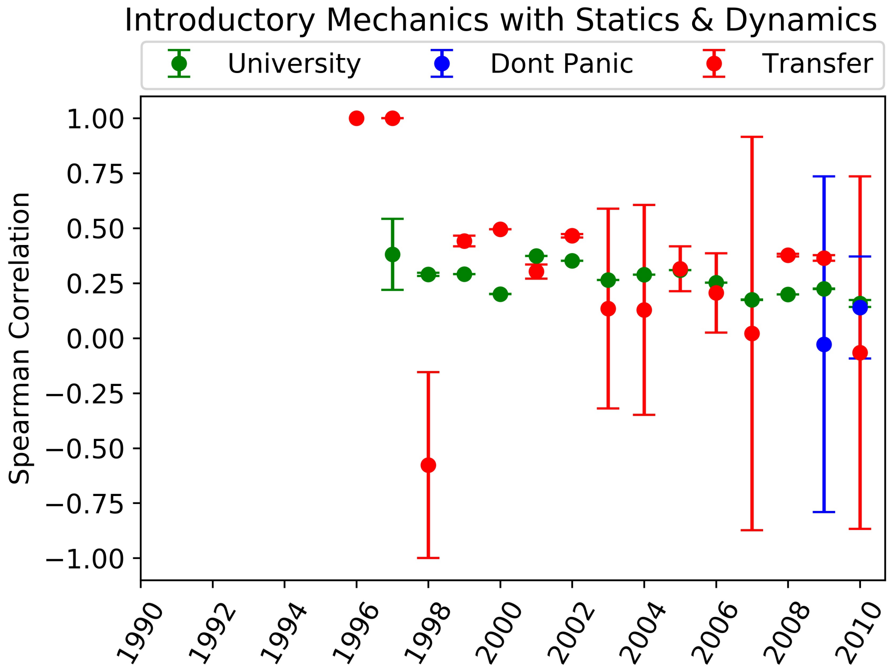


Figure 2.21: Spearman correlation coefficients between IP Mechanics and the Dynamics & Vibrations course. Error bars correspond to significance level p.

Table 2.9: The median, mean, and standard deviation of all Spearman correlation coefficients between IP Mechanics and Dynamics & Vibrations.

Flavor	Median	Mean	σ
University	0.276	0.268	0.069
Don't Panic	0.055	0.055	0.083
Transfer	0.315	0.307	0.376

and standard deviations for correlation coefficients are also given in Table 2.10. With these metrics, negative correlation is preferred, implying a higher IP Mechanics grade leads to a shorter matriculation rate. For UP there is a consistent trend at approximately -0.20 across all years, and all years have statistical signifiance. DP shows correlations comparable to UP for 2009-2010. Transfers show a number of years in the early 1990's, 1998, 2005-2006 where the correlations have no statistical significance. For years where transfers do have significance there is a little more variability. The most recent years show comparable values to UP and DP with the exception of 2010 which has a positive correlation.

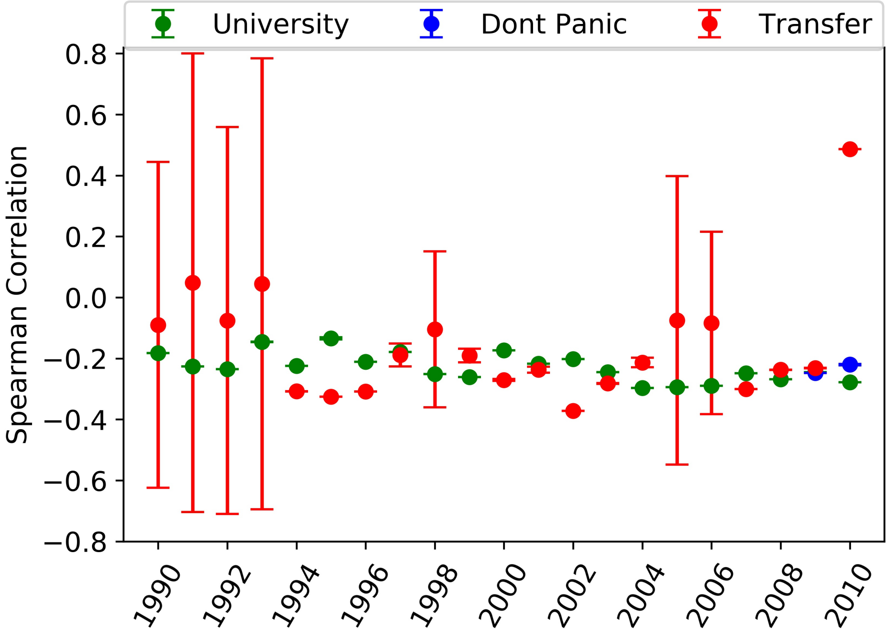


Figure 2.22: Spearman correlation coefficients between IP Mechanics and matriculation rate. Error bars correspond to significance level p.

Table 2.10: The median, mean, and standard deviation of all Spearman correlation coefficients between IP Mechanics and the matriculation rate for engineering students.

Flavor	Median	Mean	σ
University	-0.236	-0.229	0.046
Don't Panic	-0.234	-0.234	0.014
Transfer	-0.213	-0.158	0.184

2.5.3 Retention

As with the single cohort from the previous section, the final metric considered here is the rate of retention for students. Total retention by flavor of IP is shown in Figure 2.23. For most years, students transferring in an IP credit tend to be retained within engineering degrees at a higher fraction compared to those taking UP or DP. One notable exception is the 2010 year, which had no statistically significant correlation between IP Mechanics and either follow on engineering course. This year also had a strong positive correlation between IP Mechanics and matriculation rate (an undesired correlation).

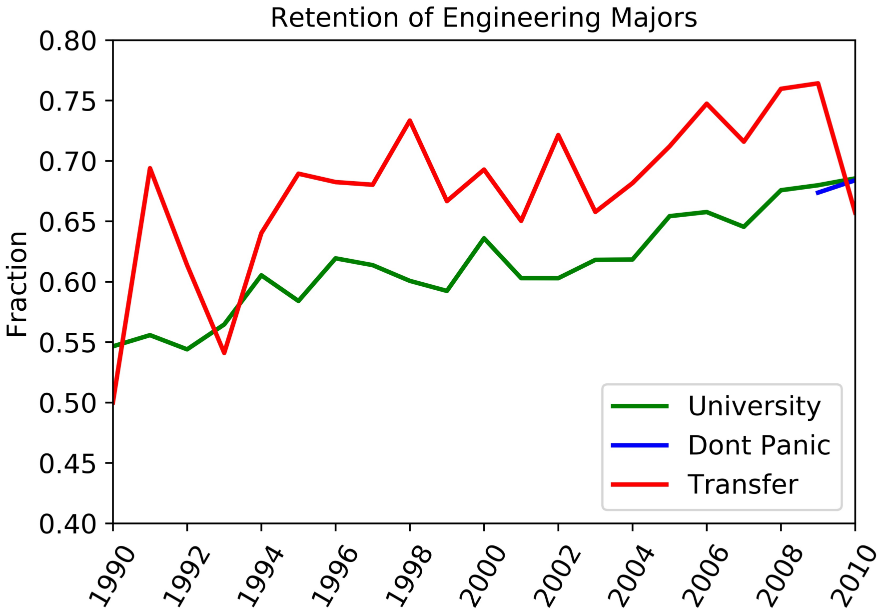


Figure 2.23: Retention fraction for engineering students based on the flavor of IP Mechanics taken.

A more granular picture of retention behavior is given in Figure 2.24, which is separated by the IP Mechanics grade a student received. Students achieving an *A* in IP Mechanics are retained at an equal or higher rate in UP and DP compared to transfers. At the *B* level the retention levels are similar across all flavors. For students receiving a *C* transfers tend to be retained at a slightly higher rate, particularly through the 2000-2010 years.

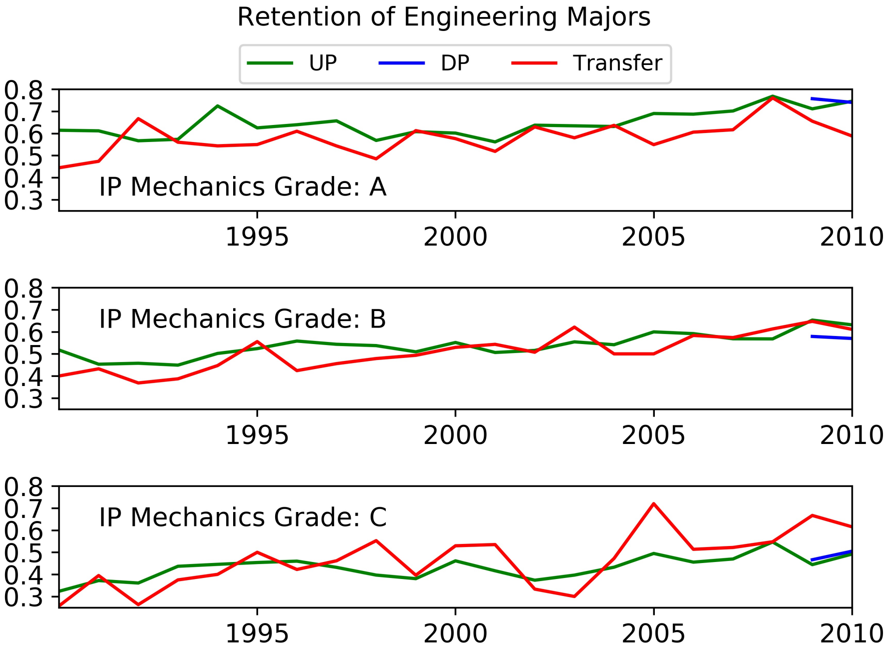


Figure 2.24: Retention of students for all years 1990-2010 separated by their IP Mechanics grade.

2.5.4 Summary

Expanding the analysis used in Section 2.4 to the years 1990-2010 yields some interesting connections between IP Mechanics and the examined metrics. Considering linked academic performance between IP Mechanics and subsequent engineering courses there is a significant difference in student performance with those taking IP Mechanics at TAMU having a small causal link to better performance in Statics & Dynamics. This link is not evident when comparing IP Mechanics to Dynamics & Vibrations for any flavor. Examining the relation of IP Mechanics to matriculation rate, there is a weak negative correlation (a positive result in this case) with similar values for all flavors. However, the TAMU flavors of IP Mechanics exhibit a much smaller standard deviation for correlation coefficients, implying a more consistent relation. While those transferring their IP Mechanics credit do appear to be retained at a higher rate than UP or DP, this primarily seems to be for students at the *C* level, similar to the 2010 cohort.

3. VERTICAL ALIGNMENT

This chapter studies the alignment of course content between three flavors of IP Mechanics available to engineering students at TAMU and two follow on engineering courses, Statics & Dynamics and Dynamics & Vibrations. Alignment of course content is particularly important between these sets of courses, as IP Mechanics acts as one of the primary prerequisites for the engineering courses, and there is significant conceptual overlap between the courses. This overlap stems from the presence of mechans concepts, including motion, forces, energy, oscillations and more within both the introductory course, and the subsequent courses. Strong alignment between courses would indicate good preparation of students for the new material to come, while poor alignment is an indication that something is missing within the curriculum. This could be within one of the courses examined, or in another course taken concurrently or between the courses examined in this chapter.

The contents of this chapter begin with a brief description of previous work done in examining the alignment of IP Mechanics with an engineering course, Section 3.1. Next, in Section 3.2, the q-matrix is defined. Section simstud introduces a model used to simulate student performance (course grades) between two courses using their q-matrices. Results for both alignment between courses and predicted course grades from the model are shown in Section 3.4. A brief summary of these results are given in Section 3.5.

3.1 Previous Work

A part of a previous study, Shryock 2011, researchers compared the alignment of a small set of physics concepts between IP Mechanics and Statics & Dynamics [6]. Within this study a q-matrix, described later, was developed for the Statics & Dynamics course to develop an understanding of the frequency with which physical and mathematical concepts appeared in problems. In order to compare with the frequency of these topics in IP

Mechanics, course syllabi were evaluated with the relative frequency being inferred from the weekly schedule of topics covered in lecture. From this comparison the researcher reached the following conclusion: *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*. Reproduced below, Figure 3.1 is from this dissertation showing the comparison of frequency for physical concepts between IP Mechanics and Statics & Dynamics found by Shryock.

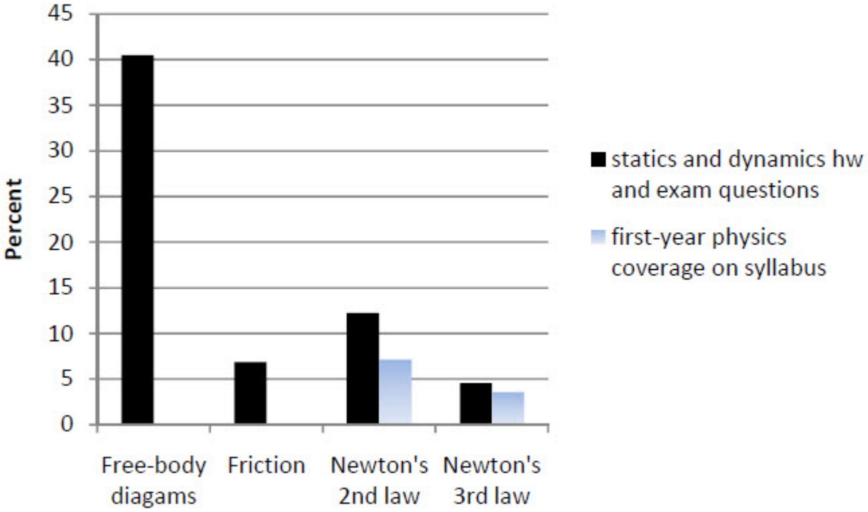


Figure 3.1: This figure is reproduced from Shryock 2011 dissertation (Figure 47/75) on the alignment of first-year physics mechanics topics comparing percentages of homework and exam problems in Statics & Dynamics and the topic list from a syllabus in a first-year physics mechanics course [6].

Examination of Figure 3.1 leads to a troubling conclusion if the reader is unfamiliar with the content of a typical IP Mechanics course. The absence of *Free-body diagrams* and *friction* is an indication that the data leading to the figure is incomplete. For an introductory mechanics course, all topics related to forces are extremely important. Therefore, this figure is not an accurate representation of the alignment of physical concepts between IP Mechanics and Statics & Dynamics.

It is this inaccuracy that has provided partial motivation for the work contained within this chapter. Examination of all homework and exam items of the Statics & Dynamics course led Shryock to develop a deeper understanding of the topics which are vital to student success. This method has been applied to three versions of an IP Mechanics courses and two engineering courses to form a more complete dataset to determine quality of alignment.

3.2 Q-Matrix

To determine the alignment between IP Mechanics and subsequent engineering courses, the course content is used to create an expert developed q-matrix. Here the term expert implies that the research is an expert in the content to which the q-matrix is being applied. Created by Tatsuoka in the 1980's, a q-matrix is a representation of the relationship between observed variables and observations in a matrix format [81, 82]. For course alignment, observed variables are considered to be the skills required to solve problems. Observations are the homework and exam problems students are expected to complete during a particular course.

An example of a small q-matrix is shown in Table 3.1. Skills are comprised of physical concepts and mathematical methods necessary to solve problems. This list was created by a former graduate student in the department of Physics & Astronomy at TAMU, Landon Chambers, in collaboration with multiple engineering faculty. A full listing and description of each of these is available in Appendix D. Homework and exam problems were gathered from faculty who had recently taught IP Mechanics, Statics & Dynamics and Dynamics & Vibrations. Where solutions were available, they were checked and verified by the researcher. Where solutions were not available the researcher created new solutions using the methods from the associated text and course notes.

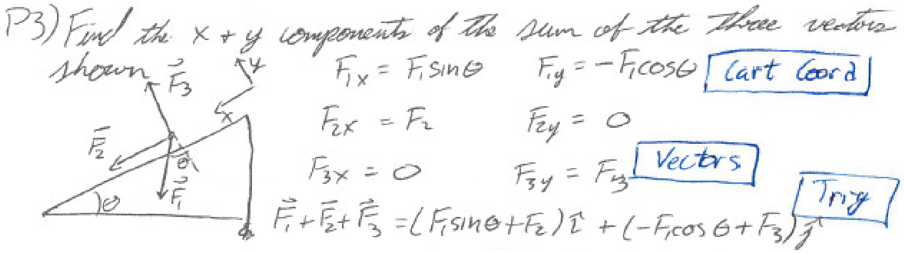
Table 3.1: An example q-matrix showing the relation between observations (homework and exam problems) and the observed variables (physical concepts and mathematical skills).

	Problem #1	Problem #2	Problem #3	Problem #4
Skill 1	1	1	0	0
Skill 2	0	1	0	0
Skill 3	1	0	1	1
Skill 4	0	0	0	1

Previous studies have employed q-matrices in a variety of situations. Barnes *et al.* used them to determine the correlation between student knowledge of a concept and their ability to correctly apply that concept on test questions [83]. Other studies have used q-matrices to explore different methods of grading exams and to represent the performance of test takers [84, 85].

This work employs the q-matrix as a representation of the skills used to correctly solve problems on homework and exams. In subsequent sections this q-matrix will be used as a metric for alignment of course content, and as part of a simulation of student performance between two closely linked courses. Some problems may be correctly solved using more than one set of skills. The number of items where this occurred is relatively small ($< 2\%$), and the set of skills recorded is a best reflection of the associated material covered on that assignment.

An example problem, solution, and concept identification is shown in Figure 3.2. Here a student is asked to determine the sum $x-$component and $y-$component of three forces for coordinates parallel and perpendicular to the inclined plane. The magnitudes of the forces shown in the free-body diagram are knowns. Because of this only the concepts and skill of *Cartesian Coordinates*, *Vectors*, and *Geometry/Trig* are included in this problem. As the students are not asked to find the acceleration of the block, just to find the sum of the forces, other concepts like *Newton's 2nd Law* are not included in the q-matrix for this item.



P3) Find the x + y components of the sum of the three vectors shown

$F_{1x} = F_1 \sin\theta$ $F_{1y} = -F_1 \cos\theta$ Cart Coord

$F_{2x} = F_2$ $F_{2y} = 0$

$F_{3x} = 0$ $F_{3y} = F_3$ Vectors

Trig

$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = (F_1 \sin\theta + F_2)\hat{i} + (-F_1 \cos\theta + F_3)\hat{j}$

Figure 3.2: An example from the IP Mechanics DP flavor, asking students to find a vector sum for three forces of known magnitude acting on a block which is on an inclined plane.

3.3 Simulated Students

As a further test of the alignment of course content between IP Mechanics and subsequent engineering courses, a model was created to simulate student outcomes for the engineering courses. This model uses student simulated student knowledge from IP Mechanics as the sole determining factor for the grade achieved in the subsequent engineering course using a probabilistic model based on prior performance. The goal of this model is to test whether high academic performance in IP Mechanics should be truly predictive of high performance in a subsequent course. If the material within an engineering course is strongly dependent on topics from IP Mechanics, this model should produce grade distributions consistent with those seen in academic records. Such results will be compared with distributions from Chapter 2.

This process could be conducted using real student data. However, a model is chosen here due to the significant demand for time and resources the use of students would require. Such a study would require a minimum of two years, and the collection of all homeworks, and exams for all students across both courses. Gathering these materials would have to be done via contact with faculty and graduate assistants to make copies of solutions in order to conduct the q-matrix analysis. While such a study would be worth doing, it is beyond the scope of this dissertation, and therefore the model is chosen for simplicity.

3.3.1 The Model

Modeling a simulated student follows a direct process, starting from a seeded grade in IP Mechanics to an output grade from the subsequent engineering course. The flow of this model is shown in Figure 3.3. The initial IP Mechanics grade is probabilistically determined based on the flavor of the course and the historical grade distribution for IP Mechanics. The historical grade distribution is based on the same set of academic records used in Chapter 2. Only grades of *A*, *B*, or *C* are kept for the model, meaning only students who achieved a passing grade in IP Mechanics, continued on to the engineering courses (mirroring university policy). Each flavor of IP Mechanics is modeled separately using the individual q-matrix developed for each.

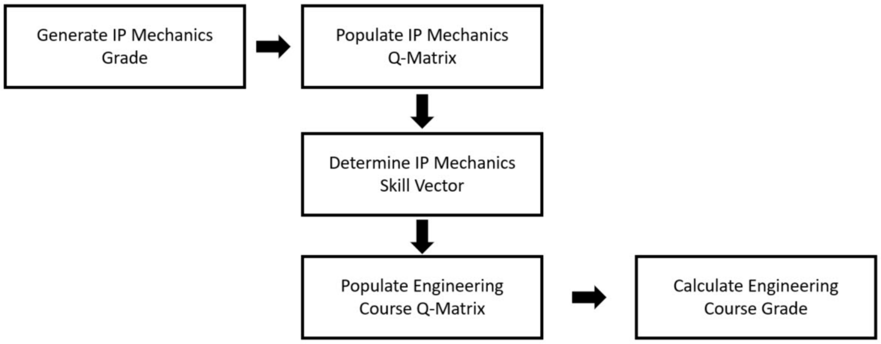


Figure 3.3: Flowchart describing the process of modeling simulated student performance between IP Mechanics and subsequent engineering courses.

A simulated students IP Mechanics grade is then used as the probabilistic seed to populate the q-matrix for that course. Only skills which were present in the expert version of the q-matrix are determined in this step. The student's grade is equivalent to the likelihood of a present concept remaining a 1, otherwise it is turned to a 0. After the entire q-matrix has been determined in this manner, the simulated students' skill vector is calculated. This vector is the fraction of times a simulated student got each concept or skill correct. For instance *Newton's 2*nd *Law* could have a fraction of 0.89 (correctly used 89% of the time), where Differentiation could have a fraction of 0.65 (correctly used 65% of the time).

The skill vector determined from the IP Mechanics course is then used as a set of probabilistic seeds to determined the simulated students' q-matrix for the engineering course. Instead of a single probability, each concept or skill has their own probability for remaining correct or flipping to incorrect. Once the engineering q-matrix is determined, the simulated students' final course grade is calculated based on the number of correct concepts and skills used, divided by the total number of concepts and skills present in the expert q-matrix. This model is iterated for a large number of students for each flavor of physics to build a reasonable distribution of course grades for both subsequent engineering courses.

Some of the limitations of this model include: equal weighting of all concepts and skills, equal weighting of all items, and the assumption of no additional learning or less of concepts and skills between courses. Within this model, the final point was addressed in the use of *guess* and *slip* parameters [86]. A *guess* parameter is a probability that an item gotten incorrect in the model will be changed to correct, as if the student increased their knowledge of a concept or skill between courses. A *slip* parameter is a probability that an item gotten correct will be changed to incorrect, as if a student lost knowledge between the courses. For each simulated student, an additional series of models was run incorporating these two parameters. These parameters were included for integer probability values ranging from 0-0.25.

3.4 Results

3.4.1 Course Statistics

Five courses were assessed using the list of physical concepts and mathematical skills described in Appendix D. These courses were three different flavors of IP Mechanics (listed as PHYS-218 at TAMU), Statics & Dynamics, and Dynamics & Vibrations. Based on these skills, q-matrices were developed for each course using all homework and exam questions assigned during the course. Each q-matrix was based on a single instance of the course. While some variation is natural term to term, the general trend of material is assumed to remain fairly constant. A report on the number of items and the number of skills per problem is given in Table 3.2.

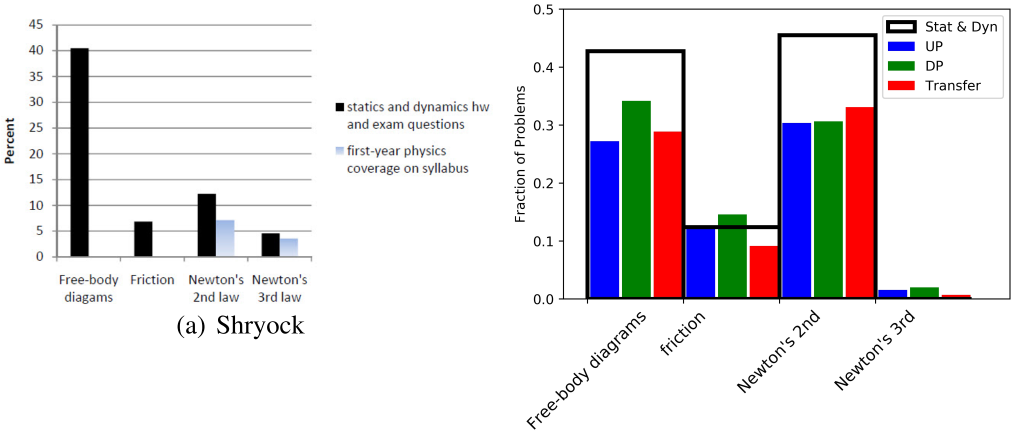
Table 3.2: Number of items as well as the median, mean, and standard deviation of average number of concepts and skills present in each item for the IP Mechanics and subsequent engineering courses evaluated using q-matrices.

Course	Number of Items	Concepts/Skills		
		Median	Mean	σ
Statics & Dynamics	145	6	5.9	2.6
Dynamics & Vibrations	129	9	9.3	3.7
IP Mechanics UP	191	4	4.8	2.8
IP Mechanics DP	199	5	5.6	2.7
IP Mechanics Transfer	142	3	4.2	2.5

The IP Mechanics courses taught at TAMU have similar number of items, with a small variation in the number of concepts found, on average in each problem. The transfer flavor had fewer items, with a lower median number of concepts. The high mean for the transfer flavor is due to a small number of items which had a very high number of concepts present. Compared to the IP Mechanics courses, the engineering courses have a higher number of concepts, particularly the junior level Dynamics & Vibrations course.

3.4.2 Alignment of Concepts & Skills

Drawing on the expert developed q-matrices created as described in Section 3.2, the alignment of physical concepts and mathematical skills may be examined by looking at the relative frequency of their appearance within a course. As a first measure of comparison, Figure 3.4 reproduces the figure from Shryock 2011 on the relative abundance of four physical concepts in Statics & Dynamics along with the three flavors of IP Mechanics.



(a) Shryock

(b) Perry

Figure 3.4: A parallel comparison of physics concepts in IP Mechanics and Statics & Dynamics based on the data collected for this study. The left panel (a) has been reproduced from a previous study which examined IP Mechanics syllabi for course content [6].

There are some clear differences between the two evaluations. First, *Free-body diagrams* and *friction* are indeed covered in the IP Mechanics curriculum, and at rates fairly similar to Statics & Dynamics. For *Newton's 2nd Law*, there is disagreement relative to Shryock's results. This study found *Newton's 2nd Law* to be far more common; as it should be since it is inherently linked to the vector sum of forces found within the *Free-body dia-*

gram. Between the three flavors of IP Mechanics there is some variation in the frequency of each concept appearing. These differences will be explored in more depth.

Total alignment between IP Mechanics and the two engineering courses may be seen in Figures 3.5 (Statics & Dynamics) and 3.6 (Dynamics & Vibrations). Here the concepts have been ranked from most common to least common appearance within the engineering courses, and their overlap is displayed with the residual sum of squares (RSS). Lower RSS values indicate a greater alignment between the courses due to the smaller differences in relative appearance of a concept.

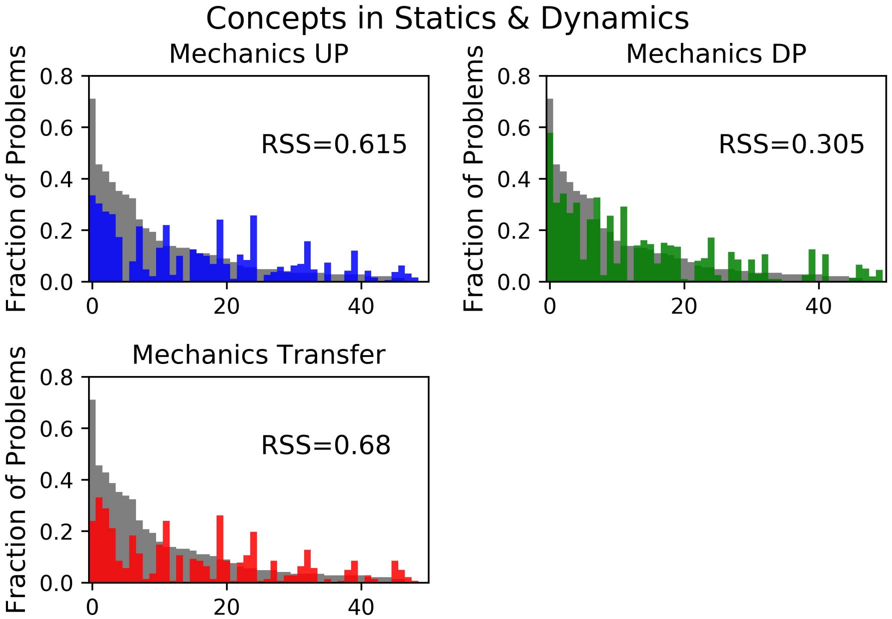


Figure 3.5: Fraction of times a concept/skill appears in assigned problems within a course between IP Mechanics and Statics & Dynamics.

From Figure 3.5 there is a clear difference in the relative coverage of concepts and skills between the different flavors of IP Mechanics. The DP flavor has the best coverage of topics present in Statics & Dynamics , thought certain concepts do exhibit some poor alignment. The UP and Transfer flavors exhibit similar coverages, with a slightly higher coverage evident in UP. This is likely due the flavors using the same textbook, though the individual problem sets and exam problems were quite different. As a singular measure of the goodness of the fit between each flavor of IP Mechanics and Statics & Dynamics, the least squares is shown one the relevant panels in Figure 3.5. The DP flavor shows a much smaller value than UP and Transfer flavors, indicating a much closer overall alignment. The Transfer flavor exhibits the most poor alignment with Statics & Dynamics.

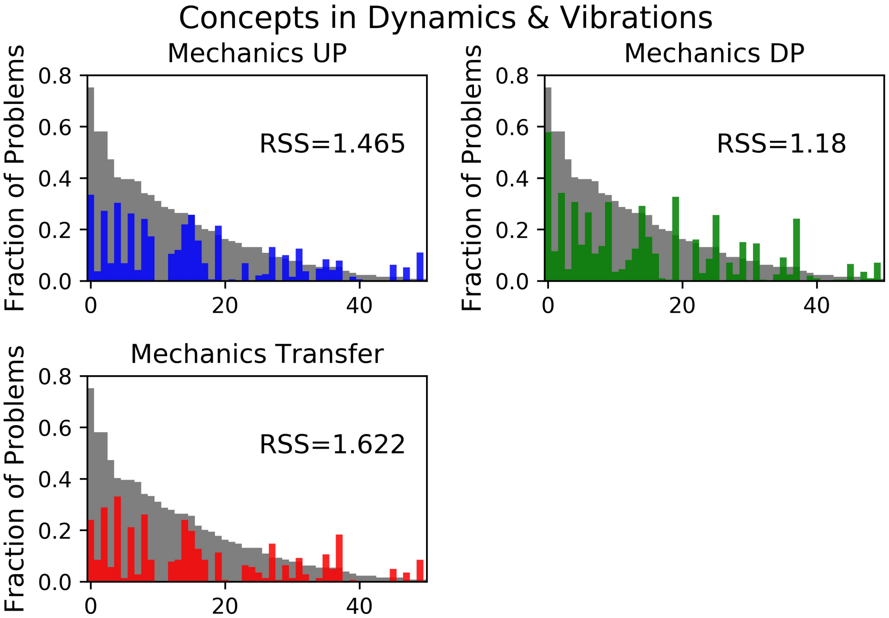


Figure 3.6: Fraction of times a concept/skill appears in assigned problems within a course between IP Mechanics and Dynamics & Vibrations.

Conceptual alignment between IP Mechanics and Dynamics & Vibrations is shown in Figure 3.6. There is no single flavor that exhibits significantly better coverage over the other flavors. It is clear, however, that there is significant misalignment of many concepts and skills between IP Mechanics and Dynamics & Vibrations. The least squares value between the courses is shown on the relevant panels in Figure 3.6. These values show poor matching between the frequency of concepts in IP Mechanics and Dynamics & Vibrations. Though the matching is poor, once again the DP flavor has the best matching, followed by UP, with the selected Transfer course being the least aligned.

3.4.2.1 Statics & Dynamics

To explore the differences of specific concepts between IP Mechanics and Statics & Dynamics, each concepts was compared on a relative scale. This scale was defined as

$$RelativeFraction = \frac{Statics\&Dynamics - IPMechanics}{Statics\&Dynamics} \tag{3.1}$$

The fraction of appearance for a concept within items was used for each course. Values range from $+1$ to less than -1, where positive values indicate the concept appearing *more often* in Statics & Dynamics and negative values appearing *more often* in IP Mechanics. Concepts which yield a relative fraction less than -1 are covered minimally in Statics & Dynamics, if they are covered at all. Relative fractions for a subset of important physical concepts and mathematical skills are shown in Figures 3.7- 3.11. The percentages shown to the right of each figure indicate the percentage of items in Statics & Dynamics in which that concept appears.

When considering topics related to *Forces* and *Torques*, there is good alignment for the *Force* topics and apparent poor alignment for *Torques*. For *Newton's 2nd Law* and *Free-Body Diagrams*, all three flavors of IP Mechanics exhibit similar alignment with Statics & Dynamics, with both topics covered slightly less often in IP Mechanics. For *Friction* there is a small difference between the three flavors of IP Mechanics, but these differences are small, and all closer to zero than other topics in Figure 3.7. Poor alignment is seen for *Torques* for all three flavors. This is due to the high fraction of problems in which *Torques* appear in Statics & Dynamics. Within IP Mechanics the concept of torques is found within two chapters in each of the texts, covering just 10%-15% of the course. Therefore, it is not feasible for torques to be present within 1/3 of the IP Mechanics courses. Problems involving *Moments of Inertia* are covered more often in IP Mechanics, but this concept is covered only minimally in Statics & Dynamics.

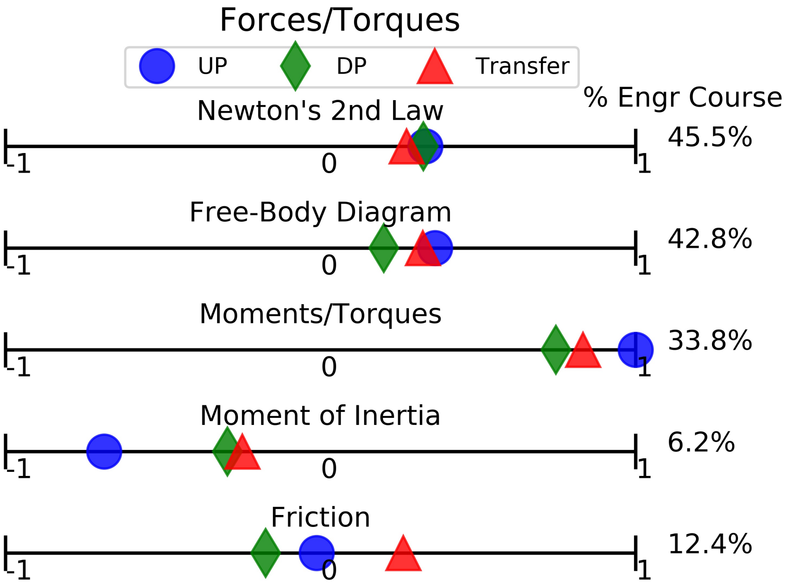


Figure 3.7: Relative alignment between IP Mechanics and Statics & Dynamics for Force and Torque concepts.

For concepts involving *Energy* and *Momentum*, shown in Figure 3.8, there is poor alignment for almost all concepts. The main reason for this is that energy is not a major topic in Statics & Dynamics, while it is a major topic within IP Mechanics. This lack of alignment should not be taken as a detriment to students, however, as an understanding of energy is important for other courses such as thermodynamics. The Transfer flavor of IP Mechanics does show close alignment for *Conservation of Linear Momentum* due to a very low number of problems on this topic for the course evaluated.

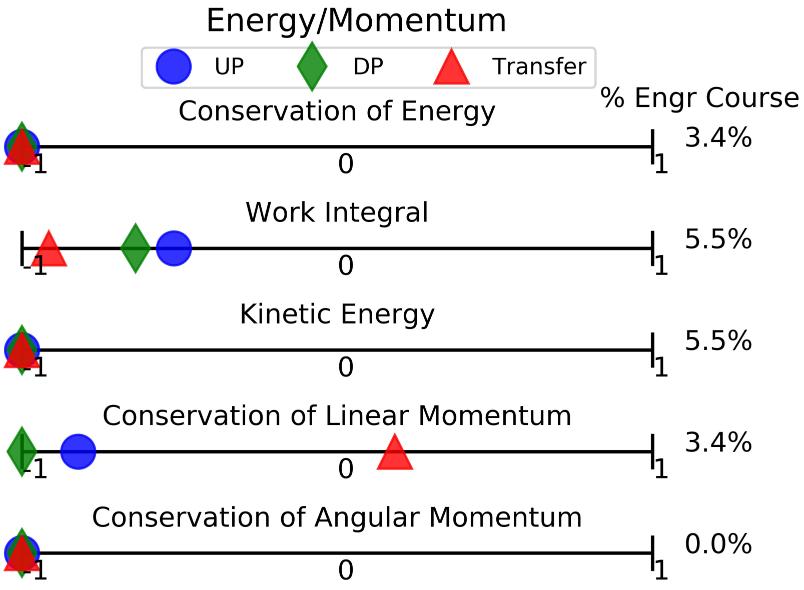


Figure 3.8: Relative alignment between IP Mechanics and Statics & Dynamics for Energy and Momentum concepts.

Concepts related to *Motion*, including one-dimensional, two-dimensional, and rotational motions, are shown in Figure 3.9. All flavors of IP Mechanics show close alignment for *1-D Motion*, with scattered alignment on other topics. Overall the DP flavor has the best alignment for the most prevalent topics of motion (as well as *Rotational Motion*). The UP and Transfer flavors exhibit better alignment for the topic of *Rolling without Slipping* compared to DP. This topic is omitted in DP in favor of problems with *Polar Coordinates*.

Vectors are a major topic within Statics & Dynamics, including definitions of two different coordinate systems and being able to write and work with vectors in those coordinate systems. Alignment of vector concepts is shown in Figure 3.10. The DP flavor of IP Mechanics exhibits the best total alignment for *Vector* concepts, though this flavor skews towards over doing it for *Define Coordinates* and *Polar Coordinates*. The next best flavor is UP across all vector concepts. The Transfer flavor exhibits very poor alignment

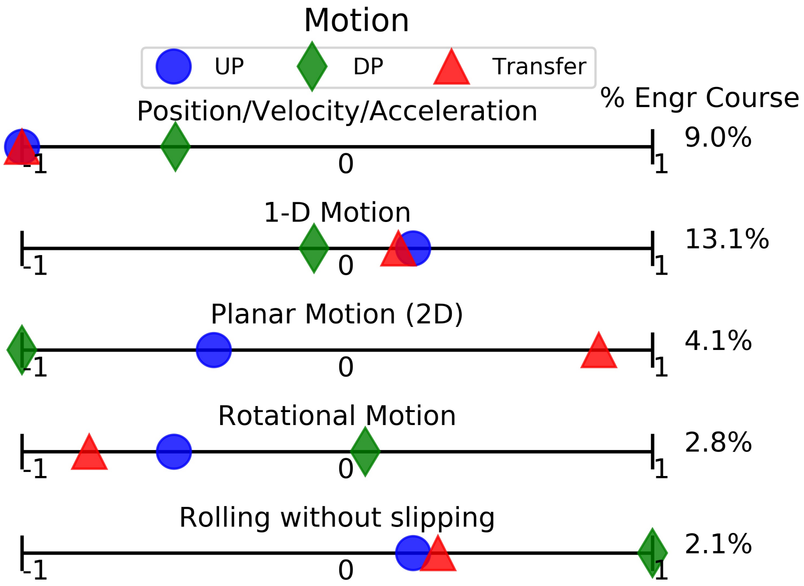


Figure 3.9: Relative alignment between IP Mechanics and Statics & Dynamics for Motion concepts.

in the use of vectors and coordinate systems. *Polar Coordinates* were almost unused in the instance of this course evaluated for this study.

The final group of concepts compared involved mathematical skills needed by students to successfully solve problems, shown in Figure 3.11. The most common mathematical skill, other than vectors, used is *Simultaneous Eqs.*, solving a system of equations. For this topic the DP flavor exhibits the best alignment, followed by Transfer and then UP. The UP flavor exhibits better alignment in the use of differentiation for Statics & Dynamics. Both the UP and Transfer flavors exhibit close alignment in the use of graphs for problems, which is covered negligibly in DP.

Much of the apparent strength of the alignment for the DP flavor of IP Mechanics compared to UP and Transfer is the use of concepts related to *Vectors* (Figure 3.10), *Motion* (Figure 3.9), and *Simultaneous Eqs.* (Figure 3.11). As *Vectors* are involved in such high

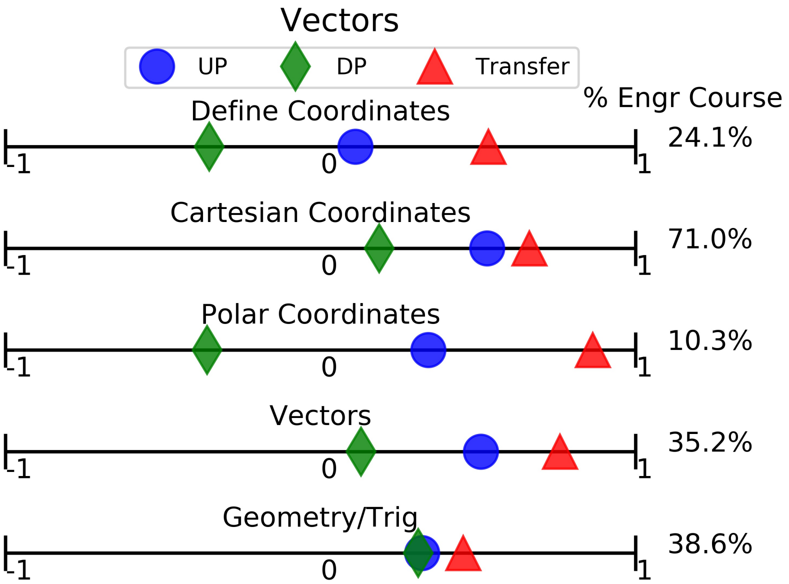


Figure 3.10: Relative alignment between IP Mechanics and Statics & Dynamics for Coordinate system and Vector concepts.

fractions of problems in Statics & Dynamics, the UP and Transfer flavors could potentially significantly increase their alignment by selection of different problems from the Young & Freedman text in which vectors occur more often. Though some concepts do exhibit significant misalignment with Statics & Dynamics, these tend to occur in topics which only appear in $< 10\%$ of problems in the engineering course (*e.g.* *Energy, Rotational Motion* and *Differentiation*.

3.4.2.2 Dynamics & Vibrations

As in the previous section, relative fractions were calculated according to Equation 3.1. Results for a selection of the most important are shown in Figures 3.12-

Concepts related to *Forces* and *Torques*, Figure 3.12, show reasonably good alignment, particularly for *Newton's* 2^{nd} *Law*, which are present in a high fraction of problems in Dynamics & Vibrations. For concepts related to *Position, Velocity*, and *Acceleration* the

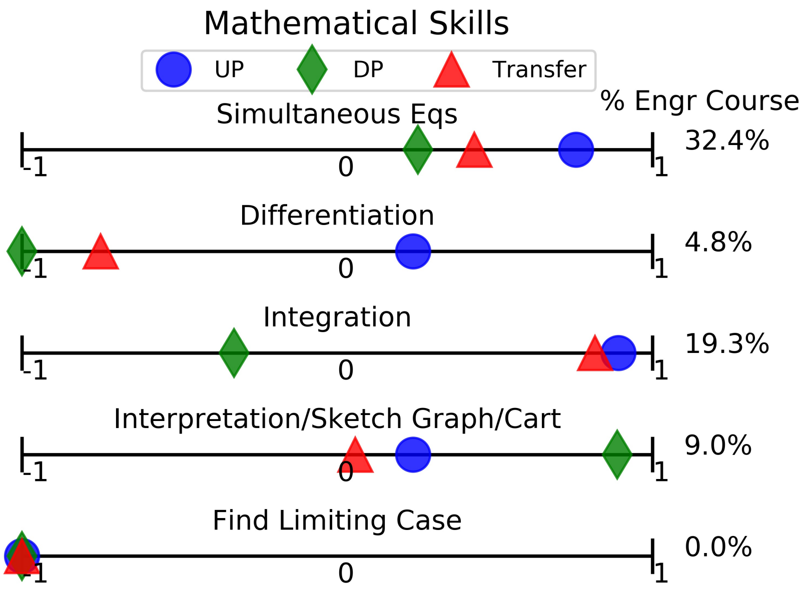


Figure 3.11: Relative alignment between IP Mechanics and Statics & Dynamics for other mathematical skills.

Transfer and UP flavors are better aligned than DP. For topics related to *Moments of Inertia* and *Torques* all three flavors are similar in their poor alignment. This is, once again, likely due to the smaller fraction of the IP Mechanics course in which these topics appear (roughly 10%-15% at maximum).

Some of the most prevalent and important topics in Dynamics & Vibrations are related to oscillatory motion of objects and systems, related to *Harmonic Motion*. Alignment to concepts related to *Harmonic Motion* are shown in Figure 3.13. All three flavors of IP Mechanics show very poor alignment to all concepts in this area. This is due to the small amount of attention that harmonic motion gets within IP Mechanics textbooks and courses, typically covered quickly immediately before the final exam of the semester. A limited number of items will cover topics like *Natural Frequency* and *Simple Harmonic Motion*. However, effectively zero items will cover the topics of *Damped Oscillations* or

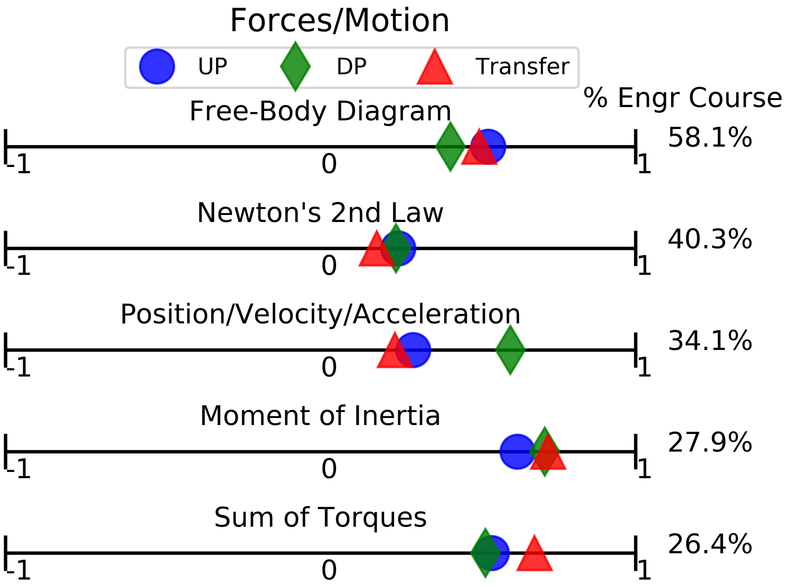


Figure 3.12: Relative alignment between IP Mechanics and Dynamics & Vibrations for Forces and Motion.

Forced Oscillations, as the required math to obtain a solution is beyond the level required and expected for students enrolled in IP Mechanics.

Alignment of IP Mechanics with Dynamics & Vibrations for topics relating to *Vectors* and *Coordinate Systems* are shown in Figure 3.14. The DP flavor exhibits the overall best alignment, as it did with Statics & Dynamics, though it overdoes the concept of Define Coordinates, in which a student must define their own system to solve a problem. The next best alignment is seen for the UP flavor, with the Transfer flavor showing the most poor alignment of the three. All three flavors show particularly weak alignment for the concept of *Polar Coordinates*.

The final set of topics comparing alignment of IP Mechanics with Dynamics & Vibrations concerns several mathematical skills and the *Conservation of Energy*, shown in Figure 3.15. For *Differentiation* and both *1^{st} & 2^{nd} Order ODE* all three flavors show

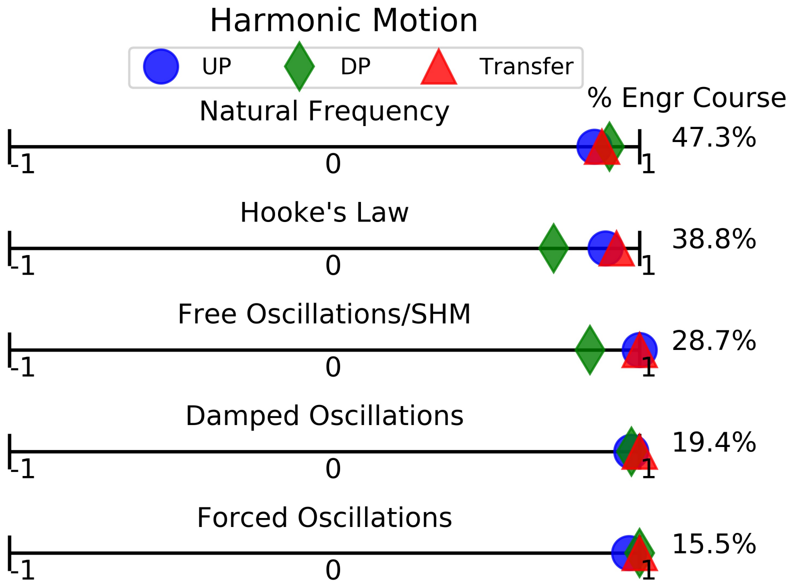


Figure 3.13: Relative alignment between IP Mechanics and Dynamics & Vibrations for Harmonic Motion.

very poor alignment. Even the DP flavor which exhibited an excess of *Differentiation* compared to Statics & Dynamics, Figure 3.11, covers the topic far too little for its use in Dynamics & Vibrations. This can be viewed as an acceptable deviation from alignment, as teaching this level of math is not the purpose of IP Mechanics, but rather a student's math courses, particularly Differential Equations. The alignment of *Conversation of Energy* is reasonably close across all three flavors, with UP being the best, followed by Transfer and then DP. This is an important alignment for a physical concept as it appears in more than a fifth of all items during Dynamics & Vibrations.

The poor alignment between IP Mechanics and Dynamics & Vibrations stems from the significance of topics related to oscillations (including *Simple Harmonic Motion*, *Damped Oscillations*, and *Forced Oscillations*), as well as *Differentiation* and *Differential Equations*. The mathematical topics involving *Differential Equations* are appropriately mis-

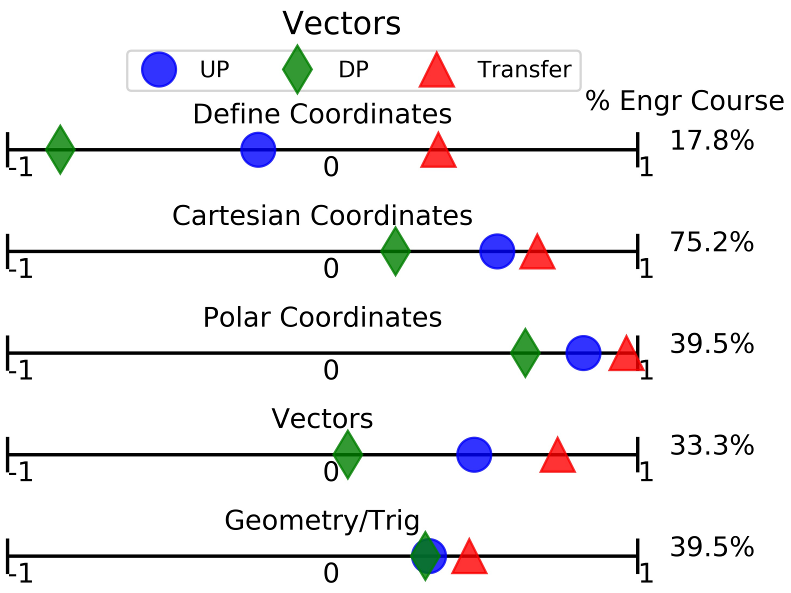


Figure 3.14: Relative alignment between IP Mechanics and Dynamics & Vibrations for Vectors.

aligned because this math course in which these are taught occurs 2-3 semesters after the IP Mechanics course in a typical undergraduate's curriculum. Oscillations, typically covered just before the final exam, are a brief topic that tends to lack significant depth within IP Mechanics. For physics majors, this topic is covered in great depth in subsequent semesters. However, to better serve engineering majors it could potentially be increased within the IP Mechanics course.

3.4.3 Simulated Students

Following the procedure described in Section 3.3.1 a dataset for each flavor of IP Mechanics was created, containing 500 simulated students modeled for 676 combinations of *guess* and *slip* parameters. The large number of simulated students was used to ensure a reasonable number of simulated students in each bin for the grade distribution ($A - F$), to avoid unnecessary variance.

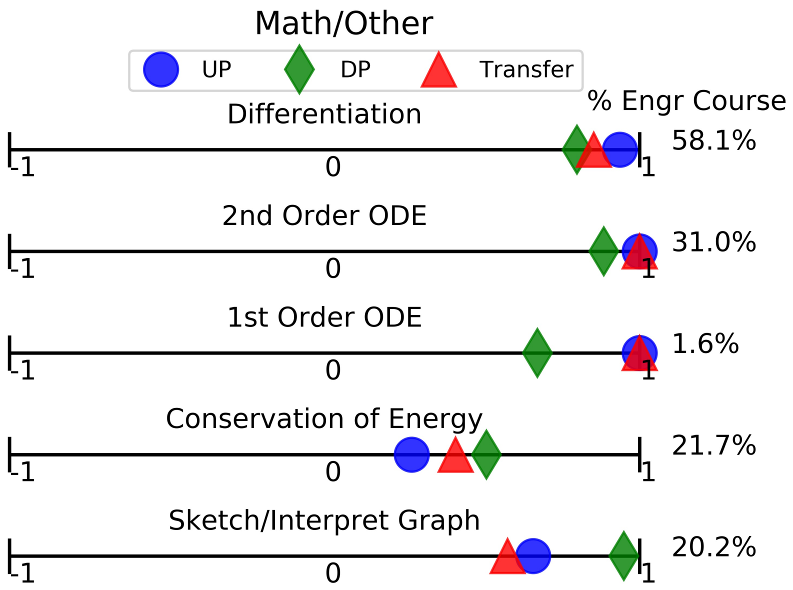


Figure 3.15: Relative alignment between IP Mechanics and Dynamics & Vibrations for Math and other concepts.

A comparison of the actual grade distribution for Statics & Dynamics for students taking each flavor of IP Mechanics, using the data set from Chapter 2, with the grade distributions of simulated students in shown in Figure 3.16. The UP flavor shows a very odd result, in that no students are modeled as achieving a grade of A , despite having a very similar alignment as the Transfer flavor (which shows a very well matched distribution between data and model). The DP flavor exhibits reasonably good matching, except for the B range of grades, which appear to have been lowered to the C range. No flavor of IP Mechanics has any simulated student achieving a grade of F for the basic model of zero guess and slip parameters.

For each flavor of IP Mechanics, a best first model (as measured by the mean squared error) was found between student grades, using academic records, and the simulated students incorporating the *guess* and *slip* parameters. The best fit for each passing grade from

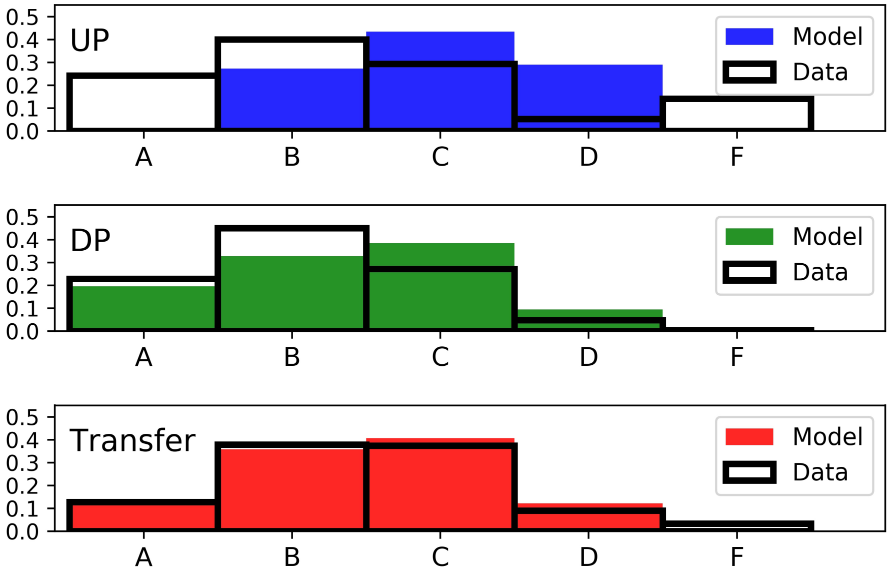
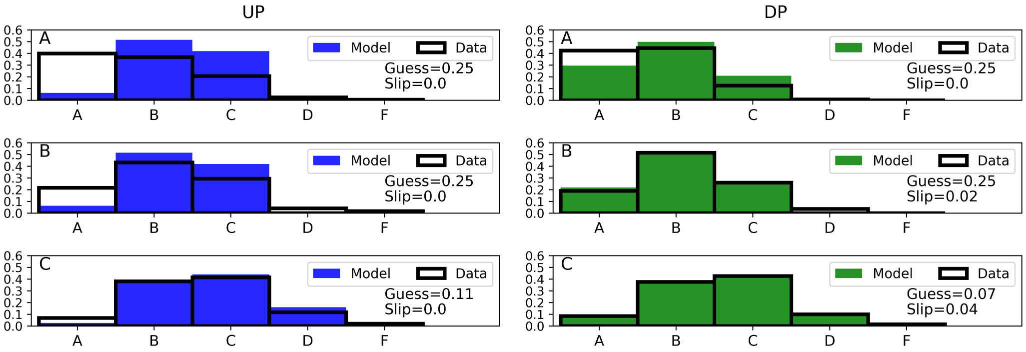


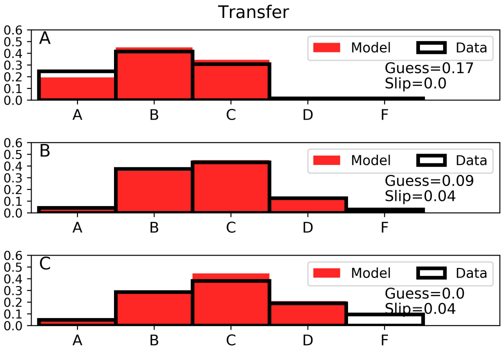
Figure 3.16: Comparison of simulated and actual grade distributions in Statics & Dynamics based on flavor of IP Mechanics. Simulations were conducted using the individual q-matrices for each flavor of IP Mechanics.

all flavors of IP Mechanics is shown in Figure 3.17. The UP flavor of IP Mechanics shows two poorly fit models, for IP Mechanics grades of A and B (particularly for students earning A's in Statics & Dynamics, though the IP Mechanics grade of C exhibits a good fit. Though these models are not a perfect fit, they are the best match of the 676 combinations of *guess* and *slip* which were simulated. Stronger fits are observed for the DP and Transfer flavors, though with the poorest matching at the IP Mechanics grade of A. As with the total grade distributions seen in Figure 3.16, there are very few grades of F, and this is consistent for all models. Students earning grades of F are likely doing so for reasons not strongly related to their grasp of previous material from IP Mechanics.

For clarity, the guess and slip values found for the best models shown in Figure 3.17 are shown in Table 3.4.3. Also included in this table is the total amount of material which was randomized, on average, for each simulated student within this category. For



(a) University Physics (b) Don't Panic



(c) Transfer

Figure 3.17: Comparisons of simulated and actual grade distributions in Statics & Dynamics broken down by IP Mechanics grade. The guess and slip parameters leading to these distributions are displayed in each panel.

all flavors, the A range of IP Mechanics grades exhibit the lowest overall match between the model and historical data, though these were the best of 676 models that were run. The UP flavor exhibits overall poor matching between simulated students being able to achieve an A in Statics & Dynamics, though the model very closely matches data for a grade of C in IP Mechanics. The DP flavor exhibits relatively strong agreement between the model and data, though again with some mismatch for an IP Mechanics grade of A. The DP model could potentially see increased agreement with a higher *guess* parameter, as the *slip* is equal to zero. The Transfer flavor exhibits good matching at the B and C levels of IP Mechanics grades, though there is a deficit of modeled A's in Statics & Dynamics, similar to the UP flavor. Taken as a while, the models had relatively low mean squared error (0.0155 for UP, 0.0021 for DP, and 0.0013 for Transfer), indicating relatively good fit.

Table 3.3: Best fit guess and slip parameters, along with the fraction of total concepts randomized, for each flavor of IP Mechanics.

	UP			DP			Transfer		
	A	B	C	A	B	C	A	B	C
Guess	0.25	0.25	0.11	0.25	0.25	0.07	0.17	0.09	0.00
Slip	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.04	0.04
Randomized	2.5%	5.0%	7.7%	2.5%	6.6%	4.9%	1.7%	5.0%	2.8%

The low values of randomized responses needed to achieve the best model fit with historical grades is reinforcement of the connection between the IP Mechanics material and the Statics & Dynamics course. If there was no connection, or a weak connection between the course material, the number of random responses would have to be much higher to match historical grades. This indicates that what a student does, or does not, learn in IP Mechanics has a strong relation to their performance in Statics & Dynamics.

3.5 Summary of Alignment

The work presented in this chapter defined a method to examine the alignment between courses using q-matrices, and applied this method to three flavors of IP Mechanics, compared with two subsequent engineering courses taken by a large number of engineering majors at TAMU. Examination of the frequency of physical concepts and mathematical skills used in homework and exam problems within the courses showed a stronger alignment between the DP flavor of IP Mechanics with Statics & Dynamics. The UP and Transfer flavors exhibited weaker alignment, particularly in topics concerning vectors. When the alignment between IP Mechanics and Dynamics & Vibrations was examined, very poor alignment was seen across all flavors, though DP showed the closest alignment of the three, with Transfer being the least aligned.

As a further test of course alignment, a model was created to predict a student's grade in Statics & Dynamics based on the IP Mechanics flavor taken and course grade achieved. Assuming no gain or loss of knowledge between IP Mechanics and Statics & Dynamics, the q-matrices predict maximum performance (highest grades) when taking the DP flavor, followed by Transfer, and UP predicting the lowest grades. Implementing *guess* and *slip* parameters into the model produced better alignment when compared to historical grades. With these parameters, a small fraction of material would need to be randomized (either in gain or in loss) to better match historical grades from Statics & Dynamics. The output of high *guess* parameters, particularly for simulated students to achieve an A in Statics & Dynamics, is likely a result of topics that are poorly aligned between the two courses. This is reinforced by the fact that even the best matched models for all flavors under produced A students in Statics & Dynamics who had earned an A in IP Mechanics. However, the similarity of the model with historical grades reinforces the strength of alignment in course material between IP Mechanics and Statics & Dynamics.

3.6 Future Work

Although this work began as a direct assessment course content between IP Mechanics and subsequent engineering courses for which it is a prerequisite, it has the potential for broader use. Expansion of this method could be used to evaluate program content on a more complete level, applied to multiple courses to evaluate both horizontal and vertical alignment. This could also be applied to other programs, using different sets of concepts and skills.

For example, pre-med students typically take a different sequence of introductory physics at many institutions, called *College Physics*. Recent efforts targeted at Introductory Physics Life Science (IPLS), have identified a number of specific concepts which are important to pre-med students [87, 88, 89]. Application of this type of q-matrix analysis for alignment could be a beneficial diagnostic to programs which serve a high proportion of pre-med or other students with a biological focus.

4. NEW ONLINE VIDEO RESOURCE FOR CALCULUS-BASED INTRODUCTORY PHYSICS [1]

4.1 Project Summary

There has been a rapid growth in the use of electronic materials as alternatives to traditional lectures which includes sources such as Khan Academy, FlipItPhysics, Veritaserum and others. A new online video resource was developed by a team at the Department of Physics & Astronomy at Texas A&M University (TAMU) intended to supplement calculus-based introductory physics courses. It has been termed Freshman Physics Classroom (FPC). Results from the first term of deployment, Spring 2017, are reported both for student performance on course examinations, and effects on the Brief Electricity & Magnetism Assessment (BEMA) score. The video modules received a high approval rating ($> 85\%$) from students according to anonymous clicker surveys administered twice over the course of the semester during lectures. Data from mid-term exams shows that students who engage with the resource tend to outperform students who did not make use of the FPC video modules. Distributions of exam scores indicate that students with partial understanding of a subject from the course (lecture, recitations, etc) benefit from engagement with the video modules. Students from the Spring 2015-2017 semesters are shown to have nearly identical levels of conceptual knowledge according to pre-testing conducted using BEMA. Normalized gains are found to be higher on average for those students who make use of the FPC video modules, compared to those who did not. Overall, the FPC video modules are found to have a positive gain on student conceptual understanding and problem solving ability.

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[1] Portions of this chapter are reproduced from *New Video Resource for Calculus based Introductory Physics, Design & Assessment I: Electricity & Magnetism*, accepted for publication in the *American Journal of Physics*, with the permission of AIP Publishing.

4.2 Background

The number and use of multimedia resources in physics instruction has increased greatly in recent years. Such multimedia resources have been shown to have a positive effect on student learning and performance, including but not limited to FlipItPhysics, or Interactive Video Vignettes [69, 90, 91]. Some resources, *e.g.* FlipItPhysics, use pre-lecture videos intended to replace traditional lectures, allowing contact time between instructor and students to be focused on problem solving strategies and demonstrations [69]. Other popular resources address multiple education levels, *i.e.* Khan Academy, but the content of these resources does not reach an appropriate level for introductory course work in STEM majors [92].

Successful multimedia resources are a boon to education, as they provide additional, multi-sensory engagement with the material [93]. Design of these resources must draw on the current state of cognitive science and empirical studies, with specific attention to the limitations and effective presentation methods of multimedia material. First identified by George Miller in 1956, it is known that learners have a limit to the amount of information which may be processed at one time [94]. Originally this limit was identified as 7 ± 2 items. Once this limit is exceeded the cognitive process bogs down. New items or information are assimilated in schema acquisition, which is recognized by Sweller as a primary component of skilled problem-solving performance [95]. In order to avoid heavy cognitive loads, which would interfere with learning, the FPC resource was designed as a technology-centered resource using short video modules [96]. This type of resource is intended to provide additional access to the concepts and methods relevant to the material in a manner that promotes transition of new information from working memory to long term memory [64].

In order to maximize student learning based on these cognitive limitations, the FPC modules selected some of the most effective video engagement methods. These effective methods have been detailed by Lincoln in a recent paper [74]. Specifically, the use of a live personality, demonstrations, effective words and symbols, and voice-over were employed. The use of a live personality and demonstrations were primarily used in the conceptual portion of the modules. Voice-over is paired with effective words and symbols in the example problems for each module. Additionally, content and wording was kept as simple as possible for viewers to focus on the material being presented. This avoids the distraction inherent in extra animations, video clips, or over-use of context-rich problems which can detract from moving information to long term memory mayer2005cambridge.

The current state of available multimedia resources online appears to have left a niche, which this work addresses. Specifically, there is a need for textbook independent material that addresses the challenging topics in calculus-based introductory physics courses. This need exists for any instructional style of introductory physics whether instruction is conducted via sage on the stage, or using more innovative techniques. Therefore, an open access, online, supplemental resource has been designed by researchers at Texas A&M University (TAMU) for an introductory Electricity & Magnetism (E&M) course. This resource was first implemented in the Spring 2017 semester. This paper reports on the development, analysis, and results from this initial deployment of such a multimedia resource consisting of a series of video modules entitled Freshman Physics Classroom (FPC).

4.3 Development

The FPC resource created a series of videos as self learning materials for students. The resource was organized into a series of modules addressing the major topics from the E&M curriculum. These topics are listed in Table 4.1. Each module consists of a conceptual video, covering the background of a particular topic, and multiple example problems (2-4) each contained in a separate video. Though this resource covers a large portion of the material found in a typical second semester introductory physics course, it is intended for supplemental use by students in addition to their course. It is not designed as a course replacement. To promote student interest in the videos, the content was kept short, with a conversational atmosphere, addressing relevant misconceptions and problem solving techniques. Detailed information about each module including a summary of the example problems used may be found in Appendix E.

Table 4.1: List of video modules for the introductory Electricity & Magnetism course.

Modules	
1) Coulomb's Law	7) Simple Circuits
2) Electric Fields	8) Magnetic Forces
3) Electric Potential	9) Biot-Savart Law
4) Flux/Gauss' Law	10) Ampere's Law
5) Capacitors	11) Faraday's Law
6) Ohm's Law	12) Time Dependent Circuits

Each module was designed to address a specific group of learning objectives using multimedia learning principles in order to maintain an acceptable cognitive load on students to promote understanding. Each video averaged 4:30 minutes, with an average length for a complete module at just under 15 minutes. For the Spring 2017 term, the videos were hosted on Vimeo and students' access was channeled through an online blackboard site. During the semester the date and frequency of access for students was logged for each video. After the Spring 2017 semester all video modules were ported over to a TAMU website https://classroom.physics.tamu.edu/. Any student enrolled at TAMU is able to access the video modules via their university log in credentials. Guest access is available by contacting FPC@physics.tamu.edu. Protocols for this study were approved by the TAMU Institutional Review Board (IRB), reference number IRB-2016-0173M. These study protocols were made available on e-campus during the Spring 2017 semester in the form of an information sheet approved for distribution by the IRB. The protocols remain available on the website mentioned above.

Conceptual videos give a basic overview of the use, application, and common errors in application for the major topics listed in Table 4.1. The presentation of material in these videos uses a combination of explanation, derivation, and demonstration to solidify a student's understanding. This presentation is done using a conversational presentation style, following the personalization principle, with an overlay of text, equations, and diagrams appearing in time with the speech content [**?**].

Example problem videos each contain the solution and explanation for a single problem, common to the topic being discussed. The question and solution are presented in a "Khan Academy" like manner, with no person appearing on the screen, which has been shown to be an effective practice [**?**]. Originally the problem videos made use of a screen split between the solution and the presenter. This was found to be too limiting for space and distracting to students who watched them. Each step in the solution is revealed to the students in time with the audio explaining the step. This structure is intended to model good problem solving practices using the equations and concepts introduced within that module.

Recordings were done using a tripod mounted Canon EOS 70D camera for video and a Zoom H6 Handy Recorder for audio. A plain black HiLite professional backdrop was used from Lastolite. Illumination was provided by a pair of FloLight microbeam 512 lights also mounted on tripods. Video and audio editing was done in Camtasia, with all written equations and diagrams being drawn in an open access piece of software called Gimp2. Equations and diagrams were written using a WaCom H13 tablet with a writing stylus. All videos were closed captioned to conform to the standards of the Americans with Disabilities Act (ADA). For this a captioning company from California, CIELO-24, was employed.

4.4 Currently Available Resources

It is recognized that there exists a number of available resources online for students to use as supplemental material for their introductory courses. In this section some of the common multimedia resources used by physics students are described.

4.4.1 FlipItPhysics

Designed by a research team at the University of Illinois, FlipItPhysics is now a commercially available product, available at https://www.flipitphysics.com/, consisting of a set of multimedia learning modules (MLMs) intended to be used by students prior to the lecture period of a course [97]. Each module contains two to three formative assessment questions, which students must answer to progress to subsequent material [98]. Previous studies of the effect of MLMs on student performance have found a positive correlation on exams and conceptual assessments such as the Conceptual Survey of Electricity and Magnetism (CSEM) [69, 99].

In a study conducted at California State Polytechnic University Ponoma MLMs were compared to a standard course where students were encouraged to read the textbook prior to lecture [98]. The study reported that only 20% of students read the majority of the textbook assignment prior to class, whereas 78% of students completed a majority of the MLMs. It was noted by the researcher, Sadaghiani, that students reading the textbook may have produced similar performance on exams as those engaged with the MLMs, but that students tend to bypass reading the assigned textbook regardless of the instructor.

4.4.2 Khan Academy

Created by Salman Khan in 2009, Khan Academy is an online, non-profit educational tool comprised of more than 2,700 videos, attracting millions of views per month [100].

Khan Academy's design creates an atmosphere of one-on-one instruction digitally using recorded videos that are typically 7-14 minutes long. The video instruction may also be paired with mastery-based learning through students answers a series of questions that must be completed prior to advancing to the next set of material [101].

According to two studies, conducted by the Albertson Family Foundation and SRI Education, there is evidence that Khan Academy has a positive effect on students performance as measured by a math assessment and standardized achievement tests [102, 103]. The limitation for applicability of Khan Academy to a collegiate setting is the content level found within the videos. Exploration of Khan Academy's website and videos makes it clear that the intended mastery level, for at least the physics content, is the high school level [92]. While this content may still be appropriate for many in college, such as liberal arts or the biological sciences in an algebra based course, it is insufficient for calculus based introductory physics courses.

4.4.3 Interactive Video Vignettes

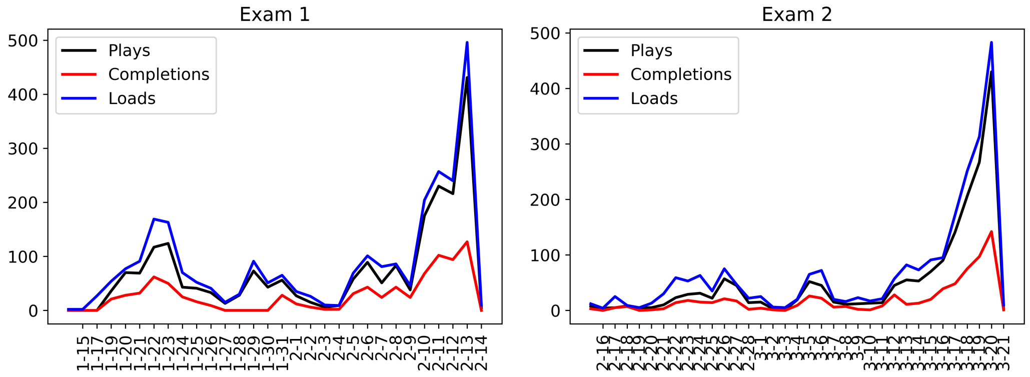
Researchers from the LivePhoto Physics group created a resource termed Interactive Video Vignettes (IVV) which attempts to combine active-learning strategies with video based content [91]. The IVVs are an ungraded, web-based assignment used in introductory physics courses employing a series of elicit-confront-resolve (ECR) techniques with formative assessment [104]. During their study, Laws *et al* found a statistically significant improvement on the FCI for students using the IVV resource. However, less than 40% of students were seen to complete the IVV modules without some form of course credit. It is unknown what effect selection bias had on their results.

4.5 Engagement

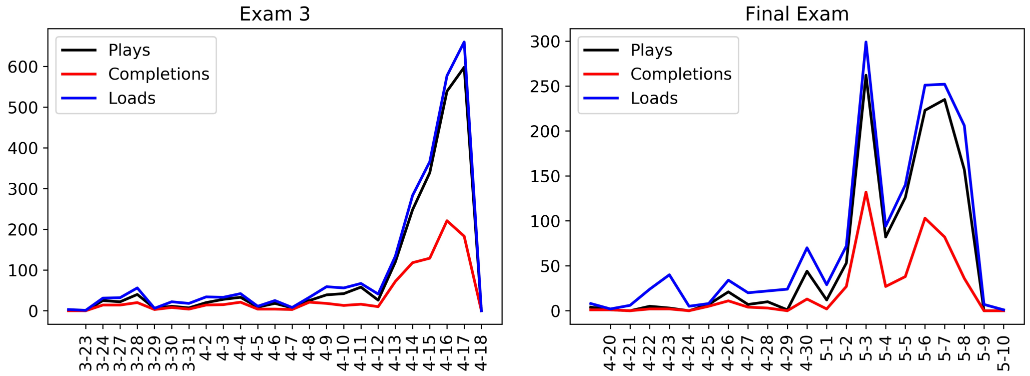
Student engagement with the FPC modules was encouraged via a limited set of in-class announcements made during lecture in the beginning of the semester, with a follow up email from their professor in the second week of the term. Reminders about the availability of the modules were given during the in-class surveys conducted after the 1^{st} and 3^{rd} mid-term exams. In addition to the access links to the FPC modules, very little course content was included on e-campus. For one instructor only course grades were kept on e-campus. The other two professors kept no additional course information or content on e-campus.

In contrast to some supplemental resources that have been studied, no course credit was given (nor penalty taken) for use (or non-use) of the resource [69, 99]. Such studies offered a token amount of course credit (approximately 5% of the course grade), or small amounts of cash, as an incentive for students. This is intended to encourage a higher level of participation on the part of students to achieve a reasonable sample size to effectively study the impact of the educational intervention.

Using the internal API from Vimeo, the engagement behavior of students may be determined. The API yields information about the number of times videos were loaded, played, and completed by students. Graphs of daily loads, plays, and completions for students are shown in Figure 4.1. It is not surprising to note that the majority of views takes place in the days immediately prior to an exam. For the final exam, there are two peaks corresponding to different lecture sections taking their final exam on different dates. There is, however, clear evidence of engagement earlier than immediately before an exam. This is most clearly seen in Figure 4.1.a where a series of three secondary peaks for views are seen in different weeks. This corresponds to students accessing a particular module related to the material being covered in lecture that week. This trend is present, though less pronounced in Figure 4.1.b for the 2^{nd} mid-term exam, and there is only slight evidence of it in Figure 4.1.c for the 3^{rd} mid-term exam. This is potentially due to a change of study habits as the semester progresses, with demands increasing from other course work. Another explanation is that more motivated students, who would study earlier typically, are not using the resource until closer to the exams, if at all.



(a) 1^{st} Mid-term Exam (b) 2^{nd} Mid-term Exam



(c) 3^{rd} Mid-term Exam (d) Final Exams

Figure 4.1: Daily number of times videos were loaded, played, and completed by students leading up to each exam in the Spring 2017 semester.

From the data in Figure 4.1 it is evident that only a low fraction (approximately 40%) of video plays are watched to completion. To gain a better understanding of how much of the material students are watching the mean percentage of video viewed is examined. As part of the API Vimeo outputs the percentage of total viewing time that plays encompassed. Using this daily record, the mean and median view percentages for students are given in Figure 4.2. The average percentage of videos viewed is seen to fluctuate across the different exams. This statistic is, however, sensitive to days with a low viewing percentage and low number of plays. The median completion percentage is consistent across all exams. Median completion percentage is also consistent across all video modules, as seen in Table 4.2. From this it may be concluded that students tend to watch at least 80% of the video content.

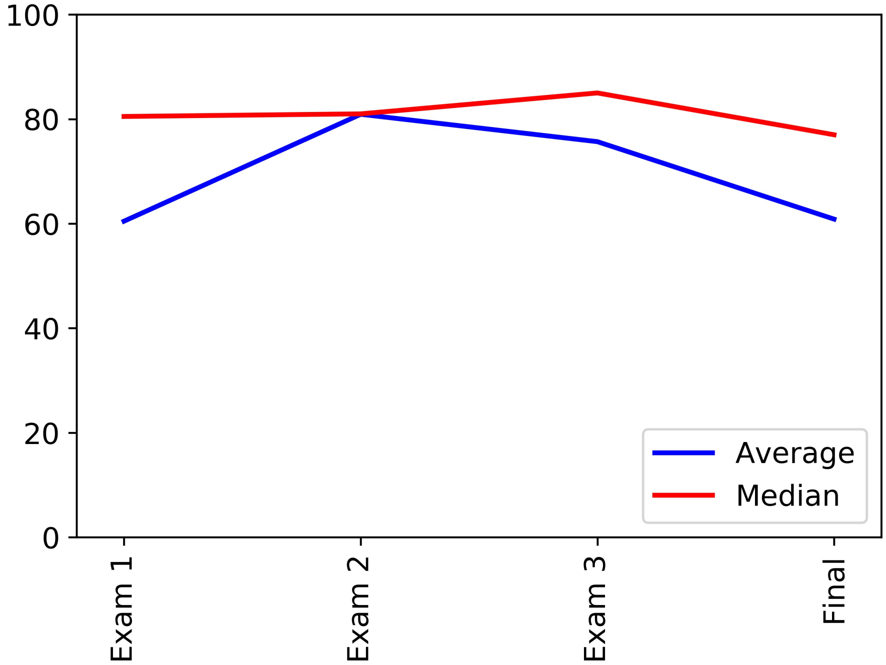


Figure 4.2: Average and Median completion percentages for all student views separated by exam period during the Spring 2017 semester.

4.6 Analysis

Impact of the FPC video modules was assessed based on results of student surveys, measurable effects of student performance on midterm exams and the Brief Electricity & Magnetism Assessment (BEMA) [29]. Students were grouped by those who chose to engage with the FPC resource and are referred to as *Viewers* hereafter, while those who did not make use of the resources are referred to as *Non-Viewers*.

Table 4.2: The median completion percentage for each E&M module of the FPC resource for Spring 2017. The error is calculated as the standard deviation from averaging the median completion percentage for all videos within a single module.

Module	Median
Coulomb's Law	80.0% ± 1.6%
Electric Fields	83.3% ± 1.2%
Electric Potential	83.3% ± 1.6%
Flux/Gauss' Law	81.6% ± 4.0%
Capacitors	83.0% ± 0.8%
Ohm's Law	81.0% ± 1.4%
Simple Circuits	83.3% ± 1.8%
Magnetic Forces	86.7% ± 0.5%
Biot-Savart Law	88.5% ± 2.5%
Ampere's Law	86.0% ± 2.9%
Faraday's Law	82.0% ± 3.6%
Time Dependent Circuits	80.8% ± 3.6%

Student response to the FPC video module content was acquired through the use of anonymous, in-class clicker questions. Surveys were administered after the 1^{st} and 3^{rd} mid-term exams. Students were polled separately on the content of the conceptual videos and example problem videos in order to maximize feedback to the researchers. Survey questions were multiple choice requiring respondents to select themselves into a bin of two overlapping categories for each question. For instance, one question polled students on the conceptual videos being helpful and enjoyable. The four answer choices were then all possible combinations of helpful/not helpful and enjoyable/not enjoyable. Another question focused on whether the solution methods demonstrated were instructive and easy to follow. For both questions a fifth response was available for students to identify as *Non-Viewers*.

To determine whether there exists any statistically significant difference between *Viewers* and *Non-Viewers* from their performances on the mid-term exams, the independent t-test was used. A t-test is used to determine whether a statistically significant difference exists between the mean values of two different groups of parametric data [76]. Separation of the data into two groups may be done via a categorical variable (stating that the two groups are unrelated), or by the continuous variable (same group attempting two different assessments). Here the independent t-test is used due to the easily separated, categorical nature of the *Viewers* and *Non-Viewers*. A dependent t-test would be appropriate if examining pre-test and post-test scores for the course as a whole. The t-test statistic is calculated based on the formula

$$t = \frac{\text{Sample one mean} - \text{ Sample two mean}}{\text{Standard error of the difference in means}} \tag{4.1}$$

In addition to the t statistic, an independent t-test also outputs a significance level p. Low values of p indicate a statistically significant difference between the two samples [78]. Obtaining a low enough value of p, discussed below, permits the rejection of the *null hypothesis* between the two samples. The *null hypothesis* asserts that there is no relationship between the two variables being tested. In other words, the two samples should have no statistically significant difference between them [105].

An independent t-test was applied to each of the 12 mid-term exam problems during the semester (4 problems each on 3 mid-term exams), and is reported along with the average and standard deviation in the following section. Each question on the mid-term exams draws primarily from one major concept, as listed in Table 4.1, though not all concepts were tested on the mid-terms during the Spring 2017 semester. Specifically, capacitors and magnetic forces were omitted from the mid-term exams in Spring 2017. Results from the independent t-tests are considered meaningful only for significance levels of $p < 0.05$.

During the spring semesters 2015-2017, students enrolled in the introductory E&M course were requested to take a pre and post course assessment. Ongoing education research efforts within the department led to cohorts of students taking different assessments depending on the term of enrollment. A cohort is defined here as all students enrolled in a course for a particular semester (*i.e.* students enolled in Spring 2015 are considered a single cohort). Common to all assessments for the cohorts for spring semesters 2015-2017 was a 21 item subset of the BEMA. Pre-test scores for this subset were examined to determine the consistency of conceptual knowledge for the Spring 2017 cohort relative to previous years. Post-test scores and normalized gains were examined to determine the difference in conceptual knowledge gain for *Viewers* relative to *Non-Viewers*, again using the Spring 2015 and Spring 2016 cohorts as baseline comparisons. The normalized gain is defined below [106].

$$g = \frac{posttest\% - pretest\%}{100 - pretest\%} \tag{4.2}$$

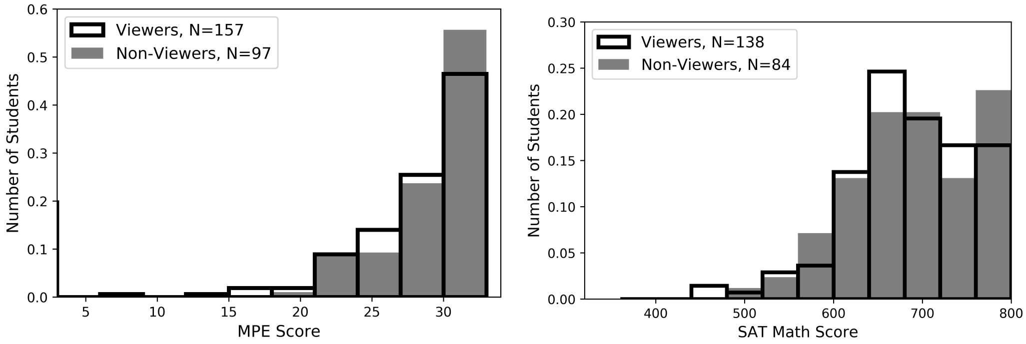
Pre-test, post-test, and normalized gains are examined only for students who took both assessments.

4.7 Results & Discussion

In this section, results from the initial deployment of the FPC resource to a calculus-based introductory physics E&M course, with an initial enrollment of $N = 315$ are presented. First, we report on the level of engagement and response from students during the course of the semester based on engagement and surveys. Comparative performance on mid-term exams is then presented. Lastly, distribution of student scores on the BEMA (pre-test, post-test, and normalized gains) are shown. For clarity, data from Spring 2015 and Spring 2016 terms are used as our control group, and Spring 2017 as our experimental group.

Due to the nature of this study, there is a natural selection bias within the data, where motivated students may seek out additional study resources more than less motivated students. As such, it would be difficult to extract meaningful results from the data without an understanding of the students pre-knowledge and skills. To develop this understanding we examined two pre-course metrics, other than BEMA, in order to compare the level of skill and knowledge between *Viewers* and *Non-Viewers*. This is done by comparing the distributions of scores on the TAMU Math Placement Exam (MPE) and the SAT Math. The MPE is a 33-item assessment used at TAMU during the registration process in order to determine a student's appropriate first math course.

Distributions for the MPE and SAT Math, normalized by the number of *Viewers* and *Non-Viewers* across the whole course, are shown in Figure 4.3. For the MPE, *Viewers* have an average score of 28.0 ± 4.2 while *Non-Viewers* have an average score of 28.8 ± 3.8. On the SAT Math, *Viewers* have an average score of 682 ± 70, while *Non-Viewers* have an average score of 688 ± 72. Though *Non-Viewers* score slightly higher on both of these assessments, and on the BEMA pre-test shown later, their distributions are nearly identical. From Figure 4.3 it is reasonable to assume that both groups of students have nearly identical mathematical knowledge and skills prior to their E&M course in Spring 2017.



(a) MPE

(b) SAT Math

Figure 4.3: Distributions on the MPE and SAT Math for *Viewers* and *Non-Viewers* for Spring 2017.

4.7.1 Student Engagement & Response

During the Spring 2017 E&M course student engagement was very high, as seen in Table 4.3. More than half of the enrolled students are categorized as *Viewers* for the three mid-term exams during the semester. This percentage slides to just under 40% leading up the final exam. Two possible explanations for this are: 1) the videos were not helpful to students, or 2) students felt they had already mastered the concept and problem solving procedure available in the FPC video modules.

Table 4.3: Percentage of enrolled students viewing at least one video in the time leading up to each exam. Midterm exams occurred approximately in the middle of February, March, and April.

Exam	*Viewers*
1^{st} Mid-term	70.3%
2^{nd} Mid-term	63.0%
3^{rd} Mid-term	52.2%
Final Exam	39.7%

Responses from clicker surveys administered after the 1^{st} and 3^{rd} mid-term exams during the Spring 2017 semester are shown in Tables 4.4- 4.7. Percentage responses are based only responses from *Viewers* for each survey question. The number of responses were $N = 255$ and $N = 200$ for the 1^{st} and 3^{rd} mid-term exams respectively. Each survey question was designed to probe the student responses to a particular part of the video module design, and of their feelings about the modules as a whole. The questions posed to students during lectures focused on: 1) the conceptual videos (Table 4.4), 2) the example problem videos (Table 4.5), 3) the solution methods (Table 4.6), and 4) on the complete video modules (Table 4.7).

Table 4.4 shows that conceptual videos were predominantly rated as being both helpful and enjoyable to students for both surveys. On the conceptual videos being helpful, students responded positively at an 87.0% and 89.8% rate for the 1^{st} and 3^{rd} mid-term exams. The similar positive response rate for enjoyable (85.2% and 85.9% respectively) is also an important result. Students are more likely to make use of an additional resource when it creates a positive experience.

Table 4.4: Survey responses from *Viewers* on the *conceptual videos* being helpful and/or enjoyable after the 1^{st} and 3^{rd} mid-term exams.

Response	1^{st} Mid-term	3^{rd} Mid-term
Helpful & Enjoyable	74.7%	77.3%
Helpful & Not Enjoyable	12.3%	12.5%
Not Helpful & Enjoyable	10.5%	8.6%
Not Helpful & Not Enjoyable	2.5%	1.6%

Survey responses on the second major component of the video modules, the example problems, are shown in Table 4.5. Example problems were highly rated by all *Viewers* after the 1^{st} and 3^{rd} mid-term exams, with only a minority of students finding the problems as being either not relevant, not helpful, or both. There is a bias in this question as one of the faculty members helping to select the example problems also creates the common mid-term exams. This bias is mitigated by the consistency of the exams for the E&M course over the past decade.

Building on the survey question on the example problems, students were specifically queried on the problem solving methods. Results for this question are shown in Table 4.6. Across both mid-term exams there is a high positive rating for the methods presented being instructive (93.4% and 93.7% for the 1^{st} and 3^{rd} mid-term exams respectively). While a majority of the positive responses reported the presented solution methods easy to follow, a significant minority reported the solution methods as being difficult to follow. This may

Table 4.5: Survey responses from *Viewers* on the *example problems* being relevant and/or helpful after the 1^{st} and 3^{rd} mid-term exams.

Response	1^{st} Mid-term	3^{rd} Mid-term
Relevant & Helpful	85.2%	80.8%
Relevant & Not Helpful	8.4%	4.8%
Not Relevant & Helpful	5.2%	9.6%
Not Relevant & Not Helpful	1.3%	4.8%

be due to the limitations of the screen presentation, or due to some of the simple steps being skipped in the interest of time.

Table 4.6: Survey responses from *Viewers* on the *problem solving methods* being instructive and/or easy to follow after the 1^{st} and 3^{rd} mid-term exams.

Response	1^{st} Mid-term	3^{rd} Mid-term
Instructive & Easy	66.2%	69.5%
Instructive & Difficult	27.2%	24.2%
Not Instructive & Easy	4.0%	6.2%
Not Instructive & Difficult	2.6%	0.0%

The final survey question administered was on the complete video modules, the responses for which are shown in Table 4.7. Just over 60% of students report the video modules as being beneficial to both their conceptual understanding and test preparation. A significant minority respond that the modules were beneficial only for conceptual understanding, not test preparation. This is an unexpected response as only one part of each module is dedicated to conceptual understanding. Such a response could be a result of the video modules being an effective channel of communication of conceptual knowledge in addition to the lecture period.

Table 4.7: Survey responses from *Viewers* on the *complete modules* being used for conceptual understanding and/or test preparation for the mid-term exams. Responses were taken by surveys administered after the 1^{st} and 3^{rd} mid-term exams respectively.

Response	1^{st} Mid-term	3^{rd} Mid-term
Conceptual Understanding & Test Preparation	61.3%	62.4%
Conceptual Understanding & Not Test Preparation	31.3%	31.2%
Not Conceptual Understanding & Test Preparation	4.4%	5.6%
Not Conceptual Understanding & Not Test Preparation	3.1%	0.8%

4.7.2 Performance on Exams

Midterm exams were comprised of 4 work out problems (12 problems total), each drawing from a single concept. The maximum score for each problem was 25 points. Problem scores were recorded and paired with an individual student's record of access to the FPC modules. Grading was conducted using a rubric provided by the course coordinator, with small teams of graders (consisting of a faculty and graduate teaching assistants) collaborating in order to provide consistent evaluation of each student's solution.

Averages, standard deviations, and t-test results between *Viewers* and *Non-Viewers* were calculated. Results from the three midterms are shown in Table 4.8. *Viewers* outperformed *Non-Viewers* for 9 out of the 12 problems by a noticeable margin. For two of the problems (Coulomb's Law and Simple Circuits #2) the difference between groups is very small, though in favor of the *Viewers* group. Gauss' Law is the only problem from the midterm exam, which shows a higher average for those who did not access the video resource. It is noteworthy that this is also the only module that did not have a separate conceptual video, an omission that will be rectified for future terms.

This difference in average scores is appreciable and encouraging. However, from results of the independent t-test, with equal variance, only three of the video modules had a statistically significant impact: Ampere's Law, Faraday's Law and Time-Dependent

Table 4.8: Averages, standard deviations, and independent t-test results for the exam questions on the three midterm exams for *Viewers* and *Non-Viewers*.

	Viewers		Non-Viewers		t-test	
Modules	Average	Std	Average	Std	t	p
Coulomb's Law	22.9	4.5	22.5	5.2	0.678	0.499
Electric Field	19.1	6.8	18.1	7.7	1.18	0.24
Electric Potential	16.7	8.5	14.9	9.4	1.79	0.0738
Flux	20.2	6.7	18.9	8.2	1.55	0.123
Simple Circuits #1	21.2	6.0	20.2	7.8	1.22	0.225
Simple Circuits #2	21.9	6.1	21.5	7.2	0.528	0.598
Gauss' Law	15.7	7.9	16.6	8.1	-1.02	0.307
Ohm's Law	16.2	8.9	14.8	9.9	1.33	0.186
Ampere's Law	18.9	7.7	16.0	10.0	2.35	0.0192
Biot-Savart	12.5	8.3	11.1	9.6	1.37	0.172
Faraday's Law	18.1	7.9	16.1	10.0	2.05	0.0412
Time-Dependent Circuits	18.9	7.3	15.2	9.9	3.79	0.0002

circuits. Together these three topics are among the most challenging physics concepts encountered in introductory E&M. The results for these modules are significant at the $p < 0.02$, $p < 0.05$, and $p < 0.001$ levels respectively. A larger statistical base from future terms is necessary to determine the potential significance of the other video modules.

Drawing on data taken from Spring 2016, direct comparisons of the distribution of student scores for concepts on the 3^{rd} midterm exam between 2016 and 2017 spring semesters are shown in Figures 4.4- 4.6. Students from the Spring 2017 semester have been subdivided into *Viewers* and *Non-Viewers* as in previous tables, where *Viewers* watched more than one video within the topics module. From Ampere's Law, Figure 4.4, a shift of scores from the 10-20 points range towards >20 points is evident, compared to the 2016 distribution. This would correspond to students with partial understanding of Ampere's Law achieving higher understanding, and problem solving ability through use of the resource. Similarly, a shift for Faraday's Law is noted, drawing from all bins below the highest.

The Time-Dependent Circuits problem does not show a shift towards higher scores

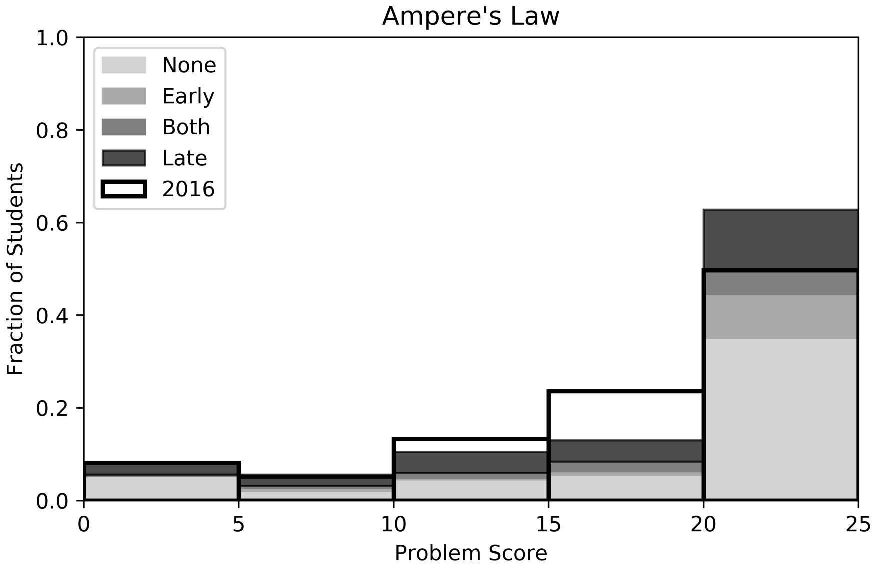


Figure 4.4: Distribution of student scores between Spring 2016/Spring 2017 for Ampere's Law. Spring 2017 students have been categorized by their *Viewer* and *Non-Viewer* status. Average problem scores were 17.6 and 18.9 for Spring 2016 and Spring 2017 respectively.

relative to Spring 2016. In fact, the average score for Spring 2017 is about 2 points lower on the 25 point scale. This is attributed to differences in construction of the exam problems between Spring 2016 and Spring 2017. In the Spring 2017 term, the Time-Dependent Circuit question was less straightforward compared to Spring 2016. However, the results from Table 4.8 show that *Viewers* performed comparable to Spring 2016, far in excess of the *Non-Viewers*.

4.7.3 BEMA

Comparisons of pre-test scores on the 21 item subset of BEMA are seen in Figure 4.7. The distribution of *Non-Viewers* has been added on top of the distribution for *Viewers* to comprise the total distribution for the Spring 2017 semester. It is clear from this distribution that the three cohorts had similar conceptual knowledge prior to the E&M course. Numerically, the average pre-test scores are 6.32 ± 2.45 for Spring 2017, 6.92 ± 2.75 for

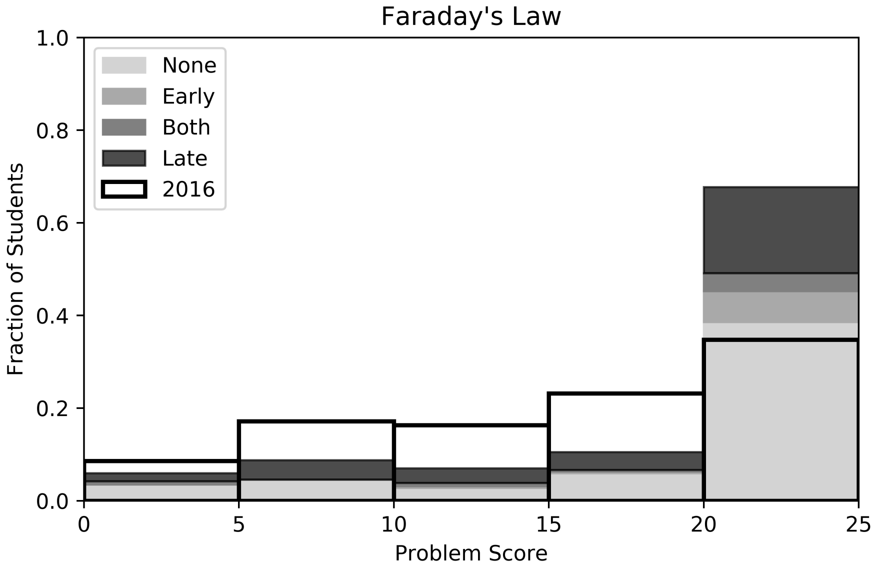


Figure 4.5: Distribution of student scores between Spring 2016/Spring 2017 for Faraday's Law. Spring 2017 students have been categorized by their *Viewer* and *Non-Viewer* status. Average problem scores were 15.3 and 18.8 for Spring 2016 and Spring 2017 respectively.

Spring 2016, and 6.58 ± 2.35 for Spring 2015. From this data, it is reasonable to conclude that all three cohorts had equal potential when entering the E&M course based on their prior conceptual understanding. Within the Spring 2017 distributions, *Non-Viewers* had an average pre-test scores of 6.62 ± 2.56, while *Viewers* had an average pre-test score of 6.00 ± 2.28. It is notable that like the TAMU MPE and SAT Math scores, *Viewers* scored slightly lower than *Non-Viewers*. However, both groups may reasonably be assumed to have very similar levels of conceptual knowledge when starting the E&M course, in addition to their similar mathematical skills seen in Figure 4.3.

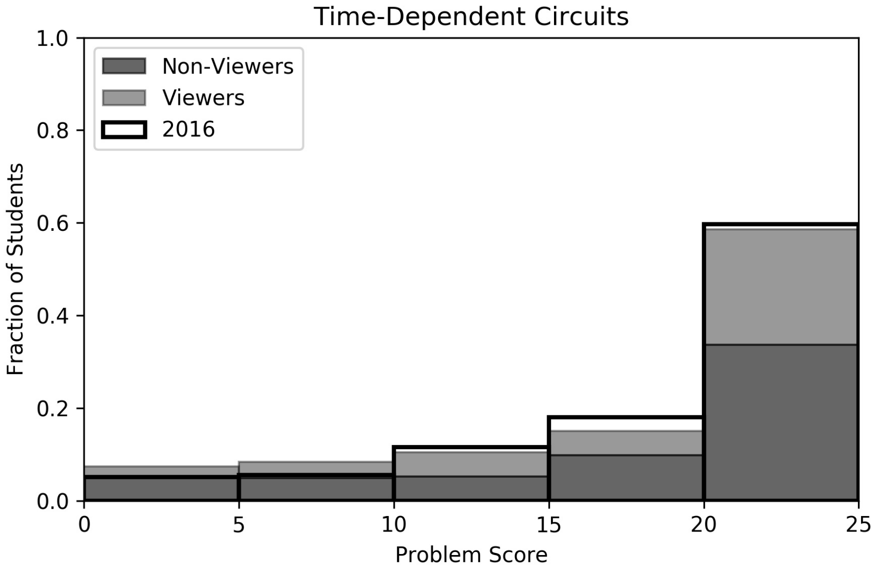


Figure 4.6: Distribution of student scores between Spring 2016/Spring 2017 for Time-Dependent Circuits. Spring 2017 students have been categorized by their *Viewer* and *Non-Viewer* status. Average problem scores were 18.7 and 16.6 for Spring 2016 and Spring 2017 respectively.

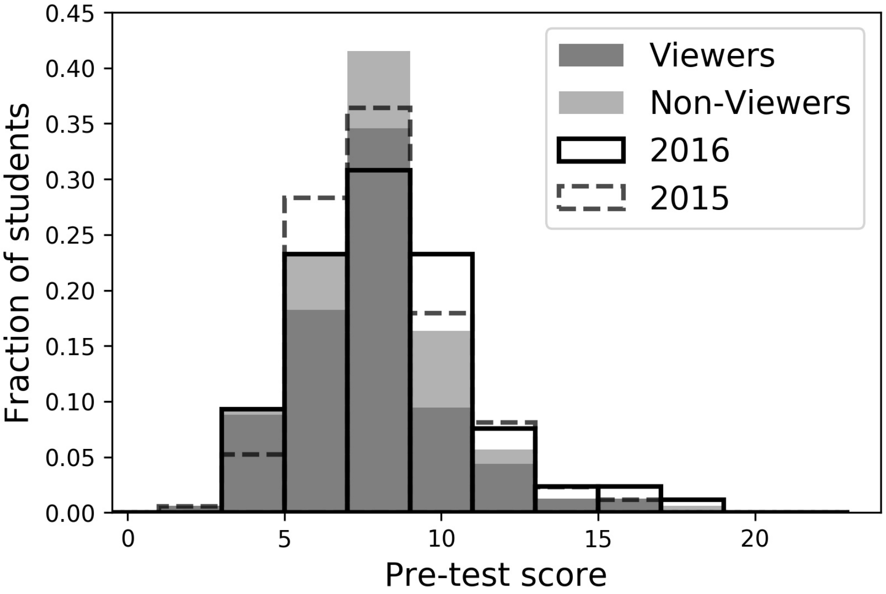


Figure 4.7: Histograms of BEMA pre-test scores for *Viewers* and *Non-Viewers* from Spring 2017, Spring 2016, and Spring 2015. Scores were binned every two points. The *Non-Viewer* distribution is added to the top of the *Viewer* distribution to show all scores for the Spring 2017 semester.

Figure 4.8 shows the comparisons of the post-test scores on the 21 item subset of BEMA. Similar to Figure 4.7, the distribution for Spring 2017 has been split into the *Viewer* and *Non-Viewer* categories. Numerically, the average post-test scores for the three cohorts are 9.03 ± 3.93 for Spring 2017, 9.40 ± 3.95 for Spring 2016, and 9.48 ± 4.13 for Spring 2015. *Non-Viewers* had a post-test average of $8.78 \pm .07$ where *Viewers* had a post-test average of 9.29 ± 3.75. Similar to the pre-test, the post-test results show that Spring 2017 was marginally less successful at the post-test assessment, though *Viewers* changed from being below average to above average relative to the rest of the Spring 2017 cohort.

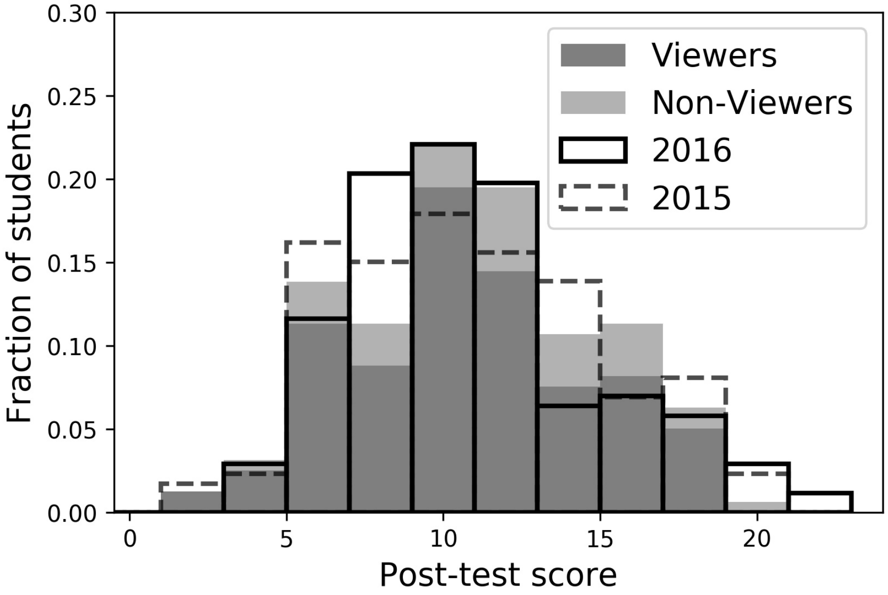


Figure 4.8: Histograms of BEMA post-test scores for *Viewers* and *Non-Viewers* from Spring 2017, along with the Spring 2016, and Spring 2015 cohorts. Scores were binned every two points. The *Non-Viewer* distribution is added to the top of the *Viewer* distribution to comprise all scores for the Spring 2017 semester.

Normalized gains, as calculated using paired student pre-test and post-test scores with

Eq. (4.2), yield average gains of 0.207 for Spring 2015, 0.183 for Spring 2016, and 0.185 for Spring 2017. Dividing Spring 2017 into viewership categories yields average gains of 0.221 for *Viewers* and 0.152 for *Non-Viewers*. Distributions for the normalized gains are shown in Figure 4.9. From the average values of the gain it is clear that *Viewers* tended to gain more conceptual understanding for BEMA topics relative to *Non-Viewers*. Examination of the gains shows a depletion in the lower bins (<0.3) for Spring 2017 relative to both Spring 2015 and Spring 2016. This missing fraction of students appears to have shifted to the mid gain bins (0.3<g<0.6).

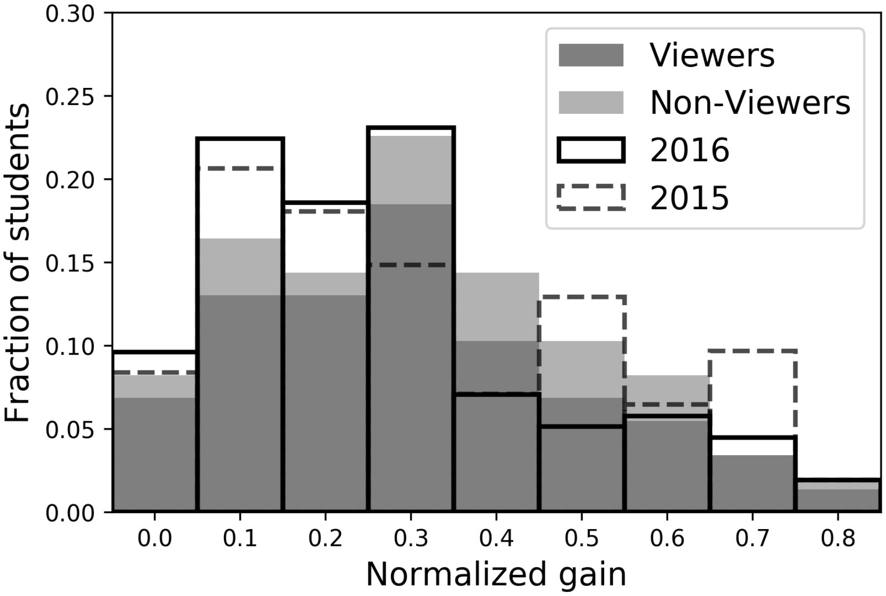


Figure 4.9: Histogram of normalized gains on the BEMA using linked pre-test and post-test scores for students from Spring 2017, 2016, and 2015 semesters. The *Non-Viewer* distribution is once again added to the top of the *Viewer* distribution to make up all scores for the Spring 2017 semester.

Overall, the three cohorts of students for spring semesters 2015-2017 for which BEMA data was used were similar in pre-test, post-test, and normalized gains. Those students who chose to use the FPC video modules, *Viewers*, exhibit a shift from lower average pre-test scores, to higher post-test scores (and therefore higher gains) relative to *Non-Viewers*. From the normalized gains in Figure 4.9 it appears that students were shifted out of the lower gains into moderate gains. As *Non-Viewers* exhibit lower overall gains, this shift for *Viewers* is potentially explained by increased conceptual understanding by engagement with the FPC modules. Deployment in future semesters would yield a larger statistical base to support or negate this conclusion.

4.8 Summary of Impact

Drawing on over 70 years of combined teaching experience, we set out to develop, deploy, and assess a new online video resource, Freshman Physics Classroom. This open access resource is intended for use as supplemental engagement for students enrolled in a calculus-based introductory Electricity & Magnetism course. For each concept addressed, a conceptual video was created with 1-3 videos of example problems related to the topic. The FPC was deployed to more than 300 students at Texas A&M University who took the Electricity & Magnetism course in Spring of 2017. No course credit was given nor penalty taken for use of the videos.

Surveys of students through anonymous, in class clicker questions reveal a strong positive response to the video content and format, with $>85\%$ approval from those using the resource. Further indications of the success of this resource is the high fraction of student engagement, as seen in Table 4.3, across all three midterm exams and the final exam. Recall that students were only reminded of the availability of the resource before the 1^{st} and after the 3^{rd} midterm exams. This high rate of student interaction with the FPC video modules is a confirmation of successful design, particularly given the no credit policy.

Analysis of midterm exam grades between *Viewers* and *Non-viewers* in Table 4.8 shows that those engaging with the resource tended to have higher scores on a relevant exam problem than those who did not. Standard t-test results indicate a statistically significant bias towards *Viewers* for the concepts of Ampere's Law, Faraday's Law, and Time-Dependent Circuits. Examination of the score distributions in Figures 4.4 and 4.5 indicate that students with a partial understanding of a topic benefit the most from use of the video resource. It is recognized that this correlation does not necessarily imply causation. However, because *Viewers* and *Non-Viewers* had such similar levels of mathematical ability, Figure 4.3, and conceptual pre-knowledge of E&M, Figure 4.7, it is reasonable to infer that the FPC resource produced a positive gain in student understanding and problem solving ability.

Results from adminstering a 21 item subset of the BEMA as a pre-test and post-test during the Spring 2015-2017 semesters indicate that each cohort entered the introductory E&M course with similar levels of conceptual knowledge. Students identified as *Viewers* tended to outperform *Non-Viewers* on the post-test assessment, and the normalized gain, indicating a greater gain in conceptual knowledge. These gains are specifically seen in Figure 4.9 as a shift from low gains to moderate gains. s

4.9 Future Work

Additional video modules were created throughout the Summer and Fall of 2017 addressing concepts encountered in a typical calculus-based introductory Mechanics course. Similar assessments will be conducted for a cohort of students enrolled at TAMU in the Fall 2017, utilizing the Force Concept Inventory (FCI) instead of BEMA, and will be presented in a future publication. Other efforts will include a more detailed analysis of student gains relative to video engagement in terms of addressing student misconceptions. Based on the indicators of success, it is intended that all modules will be made accessible online at https://classroom.physics.tamu.edu/.

4.10 Acknowledgment

This work was supported by the Texas A&M University Provost's office and the office of Instructional Technology Services. The researchers also wish to thank Dr. Emanuela Ene and Dr. Robert Webb for their help in acquiring and understanding the BEMA data.

5. CONCLUSIONS

The work presented in this dissertation studied the impact of the calculus-based IP courses on the education of engineering majors at TAMU. Drawing on the current state of PER based on literature the impact of IP on engineering education was studied in three ways: 1) correlation of IP performance with institutionally relevant metrics, 2) alignment of IP course content with material encountered in subsequent engineering courses, and 3) how student learning outcomes could be improved with the creation of a new, supplemental resource for the IP sequence. This study was motivated by the strong link between the concepts employed in engineering coursework with what is taught in the IP sequence as well as a perceived misalignment of that content with engineering courses.

This study employed a mixture of data mining techniques, q-matrices, simulation, and statistical analysis to extract significant results from the different facets listed above. In this chapter, the significant results and implications from each portion of this dissertation are summarized, with major figures reproduced where necessary. First, in Section 5.1, the major results of data mining the academic records of engineering majors enrolled 1990-2010 are summarized and discussed. Second, in Section 5.2, results from the analysis of vertical alignment between the three versions of IP with subsequent engineering courses is discussed, along with the methods potential as a diagnostic tool for curricular reforms. Last, in Section 5.3, results from the initial deployment of the FPC resource are recapped and discussed as a potential improvement to student learning in the IP sequence.

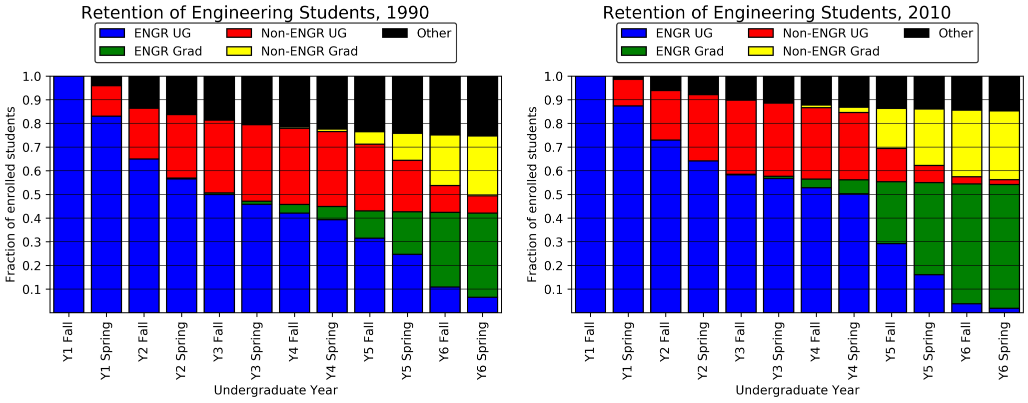
5.1 Data Mining

Academic records were collected for all students enrolled at TAMU as an engineering major for at least one academic term starting between Fall 1990 and Spring 2011 (the Spring 2010 cohort). Removing students enrolled primarily at satellite campuses in the

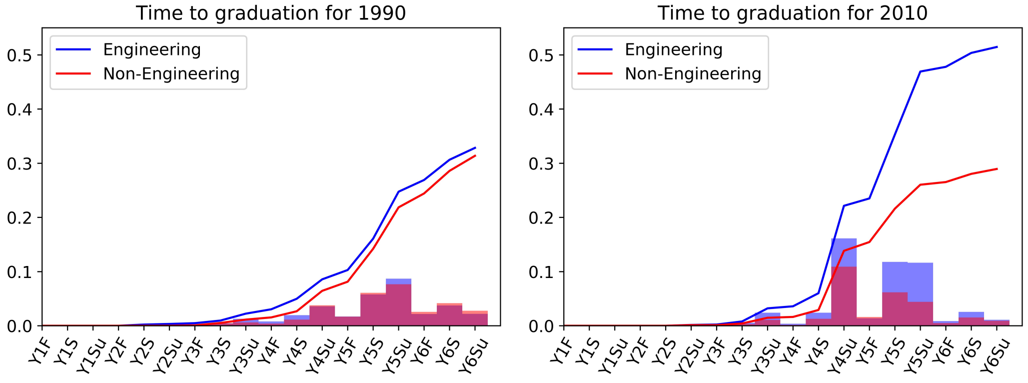
TAMU system, yielded approximately 50,000 student records. The demographics of this population, broken down by year of enrollment, is given in a series of tables and figures in the first part of Chapter 2. Some of the most striking panels related to retention and matriculation rates have been reproduced from Figures 2.7 and 2.8 here as Figure 5.1. From the retention panels, it is evident that significant improvement has been made in the middle years of the majors to reduce student migration out of engineering. By 2010, almost all of the students retained after the third term (middle of the sophomore year) will finish their degree. From the matriculation rate panels there is significant improvement in the fraction of students completing their engineering degree (almost a 20% increase). It is interesting to note that the fraction of students who began as an engineer but complete a degree outside of engineering remained almost constant during this twenty year period. This indicates that the improvements made to the engineering program have retained students who would have either transferred to another institution or left college altogether.

5.1.1 Subsequent Academic Performance

The relation between grade achieved in IP Mechanics, separated by flavor, and grade achieved in two subsequent engineering courses was examined. The results of this are reproduced from Chapter 2 here as Figures 5.2 and 5.3. Looking at the comparison with Statics & Dynamics, there is evidence of consistent under performance by students having taken the Transfer flavor of IP Mechanics. Under performance is defined as a lower fraction at an equal or higher level, and a higher fraction at lower levels. Across all three passing grades from IP Mechanics, students from the Transfer flavor under perform. Students that took either UP or DP perform similarly across all levels. This trend of under performance is indicated by the Spearman correlation coefficient, calculated for each year (Figure 2.20). This figure shows very low correlation values, often with large significance levels that prevent any conclusion about a causal link between IP Mechanics performance



(a) Retention 1990 (b) Retention 2010



(c) Graduation 1990 (d) Graduation 2010

Figure 5.1: Reproduced from Chapter 2. The top panels show the retention of engineering majors term by term for the (a) 1990 cohort and (b) 2010 cohort. The bottom panels show the matriculation rates for (c) 1990 cohort, and (d) 2010 cohort.

and performance in Statics & Dynamics. The DP flavor, distinguishable only for 2009-2010, shows higher correlation values, over 0.40, which do indicate a modest causal link between performance in IP Mechanics and Statics & Dynamics. This causal link is likely related to the strength of alignment of the course content, as summarized in Section 5.2. The UP flavor has correlation values around 0.35, at the bottom of the range at which a modest causal link could be inferred. Both of the on campus flavors exhibit stronger correlation values compared to the Transfer flavor.

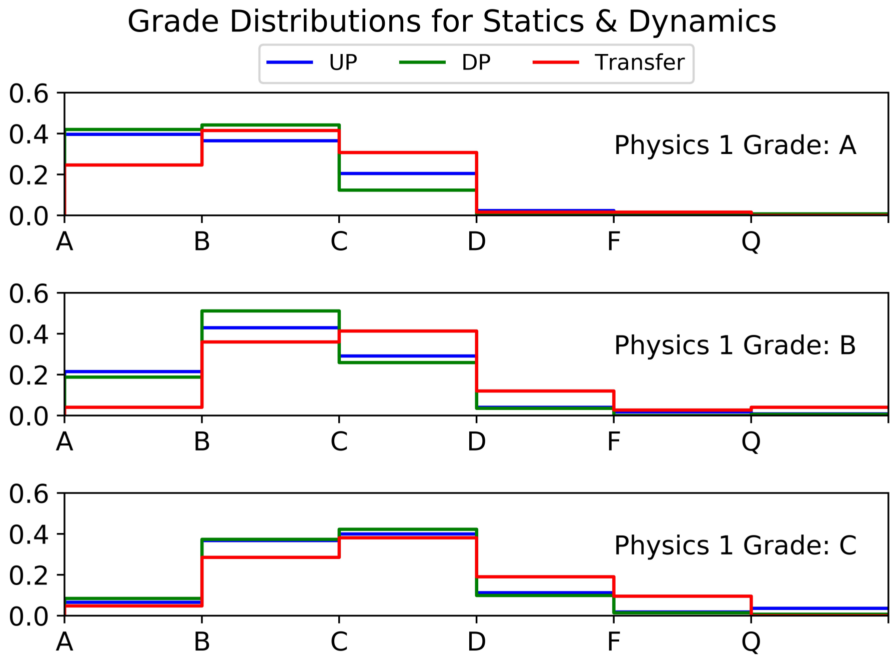


Figure 5.2: Reproduced from Chapter 2, the grade distributions for all Statics & Dynamics courses for the 2010 cohort at TAMU. Each panel corresponds to a passing grade from a Mechanics IP course.

Comparing performance based on flavor in IP Mechanics with Dynamics & Vibrations does not show a trend as seen with Statics & Dynamics. All three flavors of IP Mechanics exhibit similar behavior for students achieving either an A or a B in IP Mechanics. However, at the C level there are differences. Students from the UP and DP flavors outperform students achieving a B in Dynamics & Vibrations and Transfers outperforming for those achieving a C. This lack of trend is also seen in the longitudinal data for the correlation value, see Figure 2.9. For many years there is too high of a significance value to draw any meaningful conclusions. Additionally, the values of the correlation coefficients, when significant, are too low to infer any causal link. This lack of a link likely follows from the distance between the two courses, both in time and in material. Statics & Dynamics follows IP Mechanics by approximately one year, whereas Dynamics & Vibrations is two years removed from IP Mechanics. In addition, students should have completed their math progression (including differential equations) prior to or concurrent with Dynamics & Vibrations.

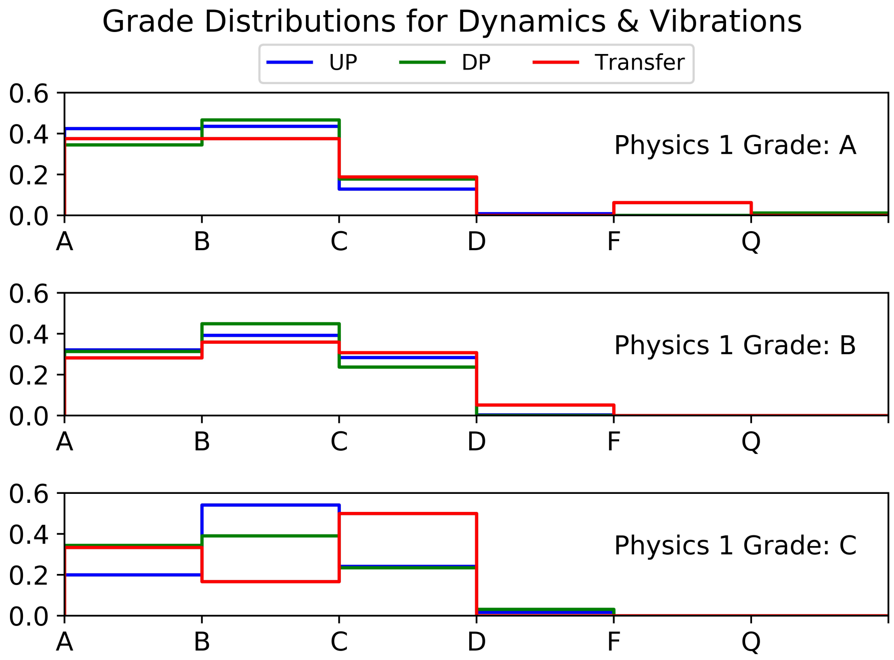


Figure 5.3: Reproduced from Chapter 2, the grade distributions for all Dynamics & Vibrations courses for the 2010 cohort at TAMU. Each panel corresponds to a passing grade from a IP Mechanics course.

5.1.2 Matriculation Rate

Examination of the matriculation rate based on flavor of IP Mechanics taken shows a different trend compared to academic performance. The term by term graduation rates (with cumulative graduation rate) has been reproduced from Chapter 2 here in Figure 5.4. Here it is seen that it is Transfer students who tend to graduate at the highest rate, beginning sooner compared to UP and DP. This is likely due to students taking IP Mechanics just prior to enrollment at TAMU, or during a summer term, getting ahead of other students. At the four year mark, DP students exhibit a slightly higher graduation rate compared to UP students, though this flips in the fifth year with UP students graduating at a slightly higher rate overall. In total, the DP flavor graduates the lowest fraction of students, while Transfer graduates the highest fraction. Looking at matriculation rate across all years for a correlation revealed no consistent trend based on flavor of IP Mechanics taken, Figure 2.22. Though Transfer students do seem to graduate at a higher rate, there is no statistically significant trend year to year between IP Mechanics performance and matriculation rate.

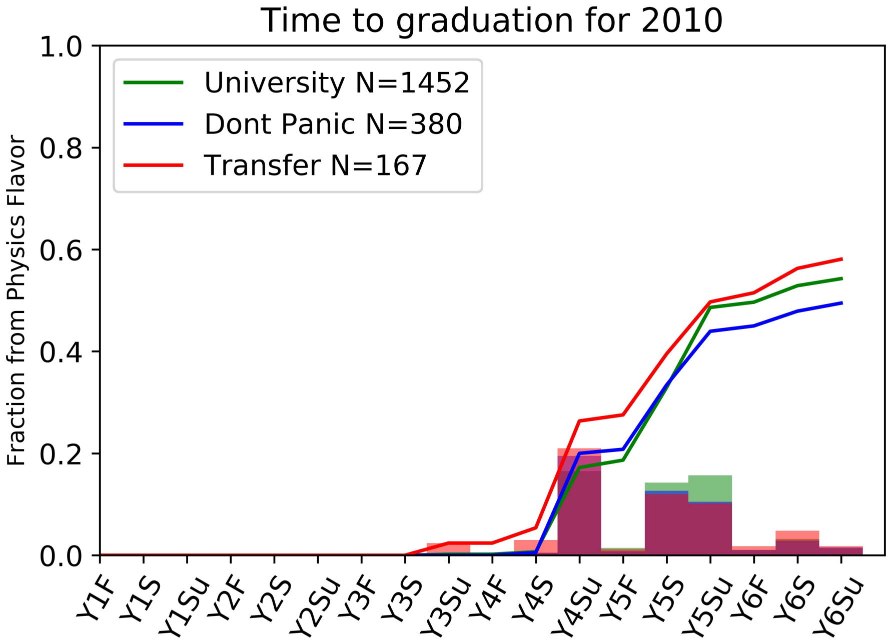


Figure 5.4: Reproduced from Chapter 2, the time taken for undergraduate engineering students to graduate for each flavor of IP Mechanics.

5.1.3 Retention

Concerning the metric of retention, the data suggests that general improvement has been made for engineering majors as a whole (Figure 2.6), with this trend being reflected in the total retention of each flavor of IP Mechanics (Figure 2.23). Deeper examination of retention based on IP Mechanics grade shows small variations depending on the flavor of IP Mechanics taken. Reproduced from Chapter 2, Figure 5.5, shows that for all years Transfer students were generally less likely to be retained when earning an A in IP Mechanics, more likely to be retained when earning a C, and roughly equally likely to be retained when earning a B. The DP flavor retention rates are roughly the same as UP for all three grade levels for the years the two are distinguishable. While this trend is consistent, the differences evident are small and vary significantly year to year, particularly for the Transfer flavor. Due to these small differences, and large variations, no relation is evident between flavor of IP Mechanics taken and the retention of students in engineering.

5.1.4 Discussion

Results from EDM on the academic records of engineering students 1990-2010 shows a steady improvement in retention and graduation rates. When examining the specific effect of IP Mechanics on the relevant metrics, a small causal link is seen only between the grade achieved in IP Mechanics and the grade achieved in the sophomore Statics & Dynamics course. No significant results are evident related the flavor of IP Mechanics instruction with retention or matriculation rate. This lack of statistically significant correlation between IP Mechanics performance with retention and matriculation rate is understandable as it is a single course among dozens within a student's undergraduate curriculum. This link between IP Mechanics and Statics & Dynamics was explored in Chapter 3, which analyzed the alignment of course content, and is summarized in the next section.

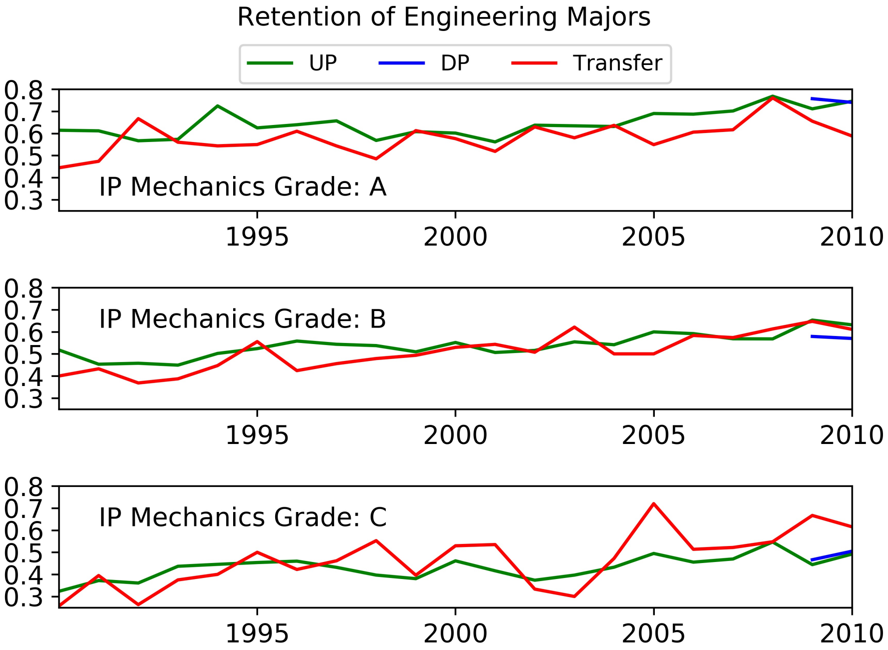


Figure 5.5: Reproduced from Chapter 2, the retention of students for all years 1990-2010 separated by their IP Mechanics grade.

5.2 Vertical Alignment

The calculus-based IP course sequence provides a major component of the foundation of knowledge for engineering majors. As such it is important that this material is not only learned well by students, but that it is aligned with subsequent coursework. To evaluate this alignment, the course content between three flavors of IP Mechanics available to TAMU engineering students was examined along with two subsequent engineering courses. Part of the motivation for this study is due to a perception of misalignment of IP Mechanics course content with engineering courses, detailed in Shryock 2011 [6]. Another motivation for this study is that poor alignment between courses, such as IP Mechanics with a sophomore level Statics & Dynamics course, would create a burden on students who would be forced to make up for missing knowledge themselves, or to miss out on fundamental components of the underlying knowledge in their chosen field. A summary of the results of this work are presented here.

5.2.1 Course Alignment

Examination of the alignment between IP Mechanics and two subsequent engineering courses was performed using q-matrices developed for three versions of IP Mechanics and two engineering courses (Statics & Dynamics and Dynamics & Vibrations). Compared to a previous study, see Figure 3.4, which only examined the course syllabi for IP Mechanics, this study developed detailed q-matrices for all courses showing a much different alignment. Alignment was examined for approximately 50 different physical concepts and mathematical skills, listed in Appendix D. Every item within a course (homework and exam problems) was examined for the concepts and skills present within the solution. A summary of the number of items and skills found for each course is reproduced from Table 3.2 as Table 5.1. The three flavors of IP Mechanics had similar number of concepts and skills per problem, while Statics & Dynamics had a slightly higher number of concepts and skills per item, and Dynamics & Vibrations had significantly more concepts and skills per item.

Table 5.1: Reproduced from Chapter 3, the number of items as well as the median, mean, and standard deviation of average number of concepts and skills present in each item for the IP Mechanics and subsequent engineering courses evaluated using q-matrices.

Course	Number of Items	Concepts/Skills		
		Median	Mean	σ
Statics & Dynamics	145	6	5.9	2.6
Dynamics & Vibrations	129	9	9.3	3.7
IP Mechanics UP	191	4	4.8	2.8
IP Mechanics DP	199	5	5.6	2.7
IP Mechanics Transfer	142	3	4.2	2.5

Total alignment between the three flavors of IP Mechanics and Statics & Dynamics is reproduced here from Figure 3.5 as Figure 5.6. Visual inspection of the alignment, along with the RSS value, shows a significant difference between the flavors of IP Mechanics. The DP flavor has the best overall alignment, followed by UP, with the Transfer flavor being the least aligned. Alignment of specific topics, Figures 3.7- 3.11 shows comparable alignment between all flavors of IP Mechanics for topics related to physics, particularly forces, torques, energy, and momentum. The major differences between flavors becomes apparent when examining the use of vectors and other mathematical skills as part of the solution. In particular, the three flavors of IP Mechanics differ in their use of *Simultaneous Equations*, *Integration*, and *Coordinate Systems*. Future iterations of the UP and Transfer flavors could achieve significantly increased alignment by selecting different homework problems from the Young & Freedman text book.

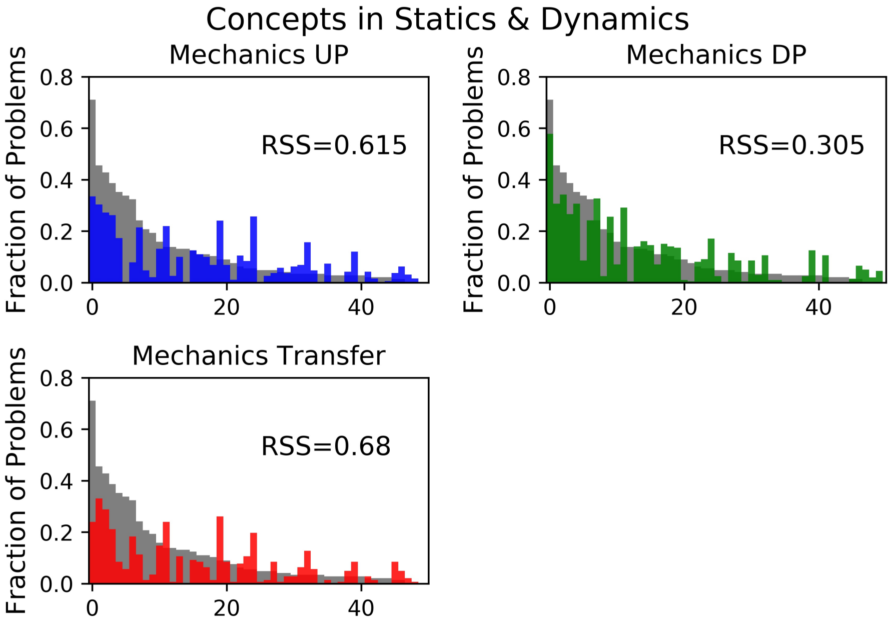


Figure 5.6: Reproduced from Chapter 3, the fraction of times a concept/skill appears in assigned problems within a course between IP Mechanics and Statics & Dynamics.

Alignment between the three flavors of IP Mechanics and Dynamics & Vibrations is very poor by comparison with the previous alignment (shown in Figure 5.7, reproduced from Figure 3.6). Here none of the three flavors of IP Mechanics has a strong alignment with Dynamics & Vibrations, though the relative ranking remains the same, with DP having the highest alignment, followed by UP, and then the Transfer flavor. Alignment of specific topics was summarized in Figures 3.12- 3.15. While reasonably good alignment exists between IP Mechanics and topics related to forces, motion, and torques in Dynamics & Vibrations, extremely weak alignment is evident for the topics related to oscillatory motion and Hooke's Law. These topics are integral to the content of the Dynamics & Vibrations course. Additional poor alignment is evident from the mathematical skills employed. In Dynamics & Vibrations there is significant use of differentiation and differential equations. The first is covered to a small degree in IP Mechanics, while the second is covered negligibly. The negligible coverage is due to the limited time that oscillatory motion is given in the IP Mechanics course, often just part of the final week of instruction, and the fact that differential equations are typically covered by a math course taken after IP Mechanics. All three flavors of IP Mechanics would need thoughtful reform and addition of material to enhance their alignment with Dynamics & Vibrations.

5.2.2 Simulated Student Performance

A further test of the alignment of the IP Mechanics courses with Statics & Dynamics was conducted using a group of simulated students to determine how predictive a course grade in IP Mechanics could be of the course grade in Statics & Dynamics based solely off of a students mastery of the physical concepts and mathematical skills in the q-matrix. The model, described in Figure 3.3, used randomly seeded IP Mechanics grades, probabilistically drawn from historical academic records, to develop a vector of student mastery of concepts and skills. This vector was then used as knowledge probability to get a con-

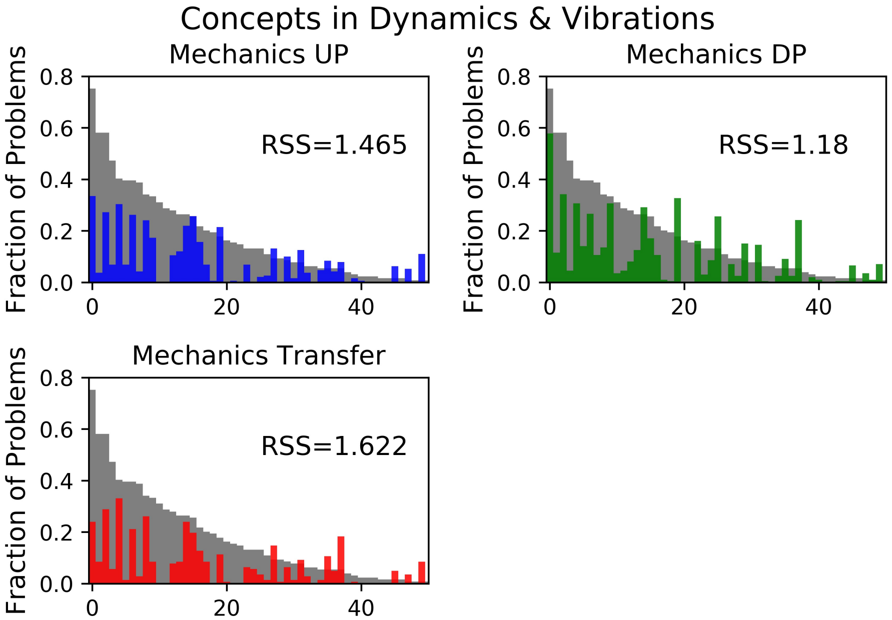


Figure 5.7: Reproduced from Chapter 3, the fraction of times a concept/skill appears in assigned problems within a course between IP Mechanics and Dynamics & Vibrations.

cept or skill correct in the Statics & Dynamics course. *Guess* and *slip* parameters between 0%-25% were employed to determine the best fit. These parameters account for random knowledge gain and loss between the two courses.

Results, detailed in Figures 3.16, 3.17 and Table 3.4.3, showed a high level of conceptual knowledge and mathematical skills would need to be randomized to match historical outcomes from Statics & Dynamics. The exceptions appear for the DP flavor, with students achieving grades of B or C in the IP Mechanics course. For these students, very little would need to be left to change (*guess* and *slip*) to match historical outcomes. Overall, the results indicate that IP Mechanics mastery is a strong, but not complete predictor of performance in Statics & Dynamics.

5.2.3 Broader Application

The process of examining course alignment through q-matrices has potential applications beyond the work presented within this dissertation. Any pairing, or sequence of courses could be evaluated based on a set of intelligently selected concepts and skills that are important to either the subsequent course, or a specific group of students (*e.g.* pre-medical students). Employing this method for additional comparisons of lower level/general introductory courses with upper level/major specific courses could, potentially, explain systematic gaps in student knowledge, or course bias for one portion of concepts or ideas over others. This would provide not just an answer to a common frustration of instructions (*"Why don't you know this? Didn't you learn it in your previous course?!"*), but also provide a valuable tool to initial curriculum reform. Such reform course be applied to specific courses, or to a broader sequence of courses within the progression of majors.

5.3 Freshman Physics Classroom

A new open access, online supplemental video resource termed Freshman Physics Classroom was developed, deployed, and assessed. FPC was designed as a set of self-learning materials for students to use in addition to the rest of their course, with the goal of increasing student conceptual understanding and problem solving ability on the mid-term exams. Data collected in this study focused on the use of the FPC resource, feedback gained through two instances of anonymous, in-class clicker surveys, mid-term exam scores, and performance on the BEMA.

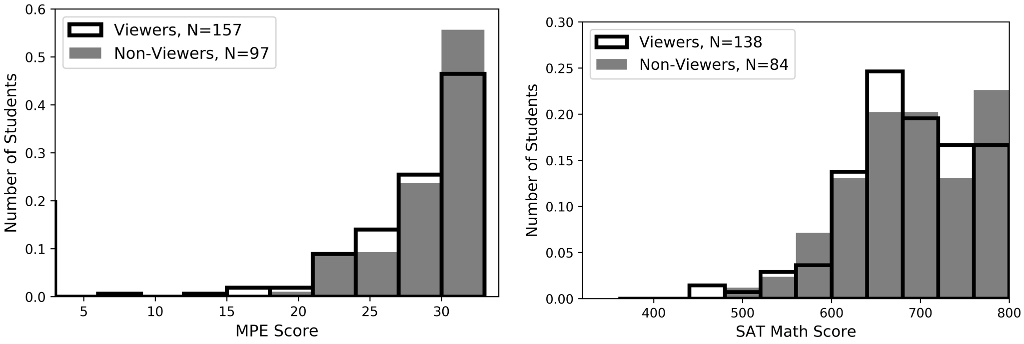
5.3.1 Summary of Results

Twice during the Spring 2017 semester, after the 1^{st} and 3^{rd} mid-term exams, students were given a brief survey during the lecture portion of their course. Based on responses from the anonymous, in-class clicker surveys, the FPC resource was beneficial to students, with highly positive responses observed across all categories surveyed. Concerning the helpfulness of the *conceptual videos* students responded positively at rates of 87.0% and 89.9% for the 1^{st} and 3^{rd} mid-term exams respectively (see Table 4.4). A majority of those responses indicate the *conceptual videos* as being enjoyable to watch in addition to being helpful. On the FPC resource's *problem solving methods* being instructive, students responded positively at rates of 93.4% and 93.7% for the 1^{st} and 3^{rd} mid-term exams respectively (see Table 4.6). Roughly 1/3 of responding students marked the *problem solving methods* as being difficult to follow, with the rest marking them easy to follow. A majority of the students responded using the FPC resource for both their *conceptual understanding* and *test preparation* (61.3% for 1^{st} mid-term and 62.4% for 3^{rd} mid-term), with a significant minority using the resource only for *conceptual understanding* (31.3% for 1^{st} mid-term and 31.2% for 3^{rd} mid-term), see Table 4.7. The composite responses show a strong positive response to the video content and design as a supplemental resource for students, though improvement could be made to the *problem solving methods* employed to increase applicability to *test preparation* in the future. However, the strong responses for *conceptual understanding* are a significant validation of the FPC resource.

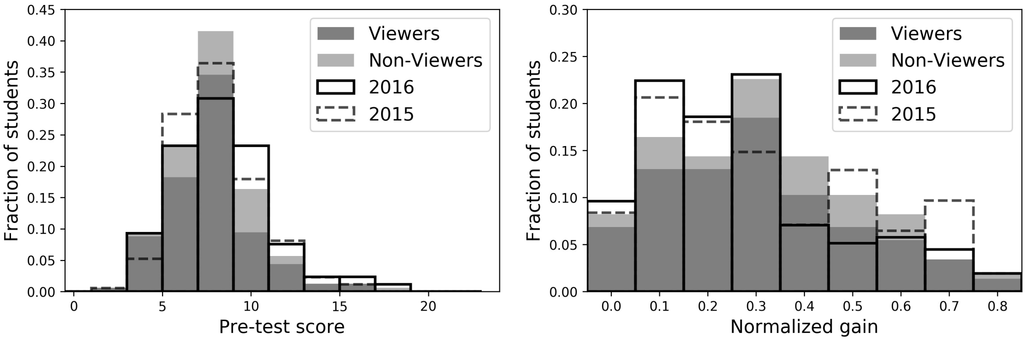
Comparing performance on mid-term exams between *Viewers* and *Non-Viewers* shows a consistent difference in performance. Of the 12 problems spanning 3 common mid-term exams given to all students, *Viewers* achieved a higher average score on 11 problems (Table 4.8). The single problem on which *Non-Viewers* had a higher average was Gauss' Law, is the only module that did not have a dedicated conceptual video. Employing the independent t-test revealed that the differences in performance on the mid-term exams were statistically significant for three of the concepts (again, see Table 4.8: Ampere's Law, Faraday's Law, and Time-Dependent Circuits). These concepts comprised the majority of the material covered on the 3^{rd} mid-term exam, and are some of the most difficult ideas encountered in the E&M course. Other topics, including Electric Potential, Flux, and the Biot-Savart Law have low significance values, but do not quite reach statistical significance for the criteria employed in this study. Additional data in future terms could potentially yield a statistically significant difference for these topics as well. Overall, there is a consistent trend of higher performance through application of the concept and necessary problem solving skills for *Viewers*. This acts as an additional validation of the utility of the FPC resource.

Correlation does not imply causation. This is an often used phrased in science that reminds a researcher that a positive trend between two variables does not necessarily imply that one causes the other. This phrase is particularly relevant in examining the effect of the FPC resource on student performance. To address this point, and justify the causal link between enhanced performance on assessments and the FPC resource, the pre-course abilities of the student population was examined. Pre-course abilities in conceptual understanding is examined using the BEMA pre-test, while mathematical skills are examined using the SAT Math and MPE scores. Recall, the MPE is Math Placement Exam, a 33 item test given to entering students at TAMU to establish the most appropriate first math course they should enroll in. A summary of the SAT Math, MPE, BEMA pre-test and BEMA normalized gains is shown in Figure 5.8, where the figures have been reproduced from Figures 4.3, 4.7, and 4.9.

Distributions for the MPE and SAT Math scores of *Viewers* and *Non-Viewers* indicate similar levels of pre-course mathematical ability. The BEMA pre-test scores also indicate a comparable level of pre-course conceptual understanding between *Viewers* and *Non-Viewers*, as well as between the Spring 2017 cohort with the Spring 2015 & 2016 cohorts. Taken together these metrics show a high level of similarity, in conceptual knowledge and mathematical skills, at the beginning of the E&M course in Spring 2017. The single difference between the two populations of students, as a whole, is then the choice of some to make use of the FPC resource. Given that *Viewers* then have a higher normalized gain on



(a) MPE (b) SAT Math



(c) BEMA Pre-test (d) BEMA Normalized Gains

Figure 5.8: Reproduced from Chapter 4, these figures describe the distribution of *Viewer* and *Non-Viewer* scores on the (a) MPE, (b) SAT Math, (c) BEMA pre-test, and (d) normalized gains on BEMA.

BEMA (Figure 5.8) and higher scores on the mid-term exam problems, discussed above, it may reasonably be concluded that the FPC resource was responsible for this increased conceptual knowledge and problem solving skill.

Synthesizing the assessment results of the FPC resource shows a strong positive result from the initial deployment. Student survey responses rate the resource highly in terms of its helpfulness in both conceptual understanding and problem solving ability. Use of the resource is seen to be linked with improved academic performance on mid-term exams and increased conceptual learning during the course as measured by the normalized gain on BEMA.

5.3.2 Implications

The success of this resource has implications for student learning beyond this single deployment. The calculus-based introductory physics sequence at TAMU is a challenging pair of courses, with a historically high DFQ rate (as shown in Chapter 2). However, this sequence contains concepts and ideas that are vital to engineering majors, as they form the backbone of subsequent course work (detailed in Chapter 3). Educational efforts which focus on enhancing student performance and reducing the DFQ rate rely on resource heavy methods, such as centralized help sessions or mandatory remediation. In contrast, the FPC resource, as an open access, online set of videos, can contribute to student learning in a manner requiring minimal additional resources. With the ongoing increase in the enrollment of STEM majors at TAMU, the continued use of the FPC resource for both courses in the calculus-based introductory physics sequence could provide a significant benefit to students in future academic terms.

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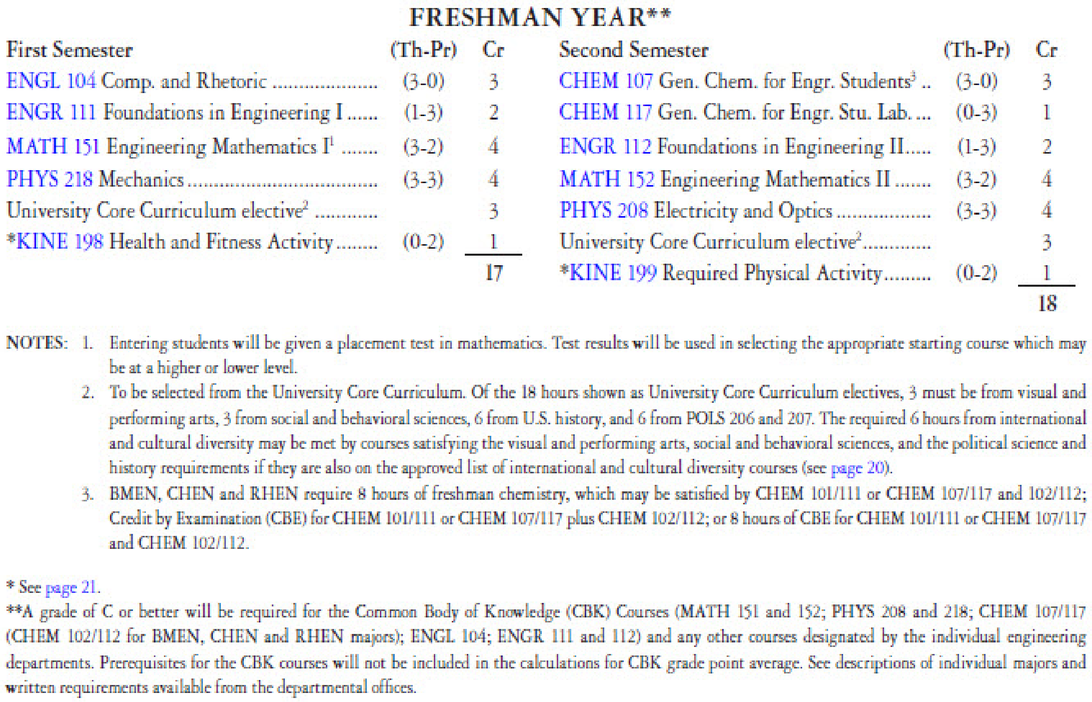
APPENDIX A

ENGINEERING DEGREE PLANS

This appendix contains the degree plans for many engineering degrees at Texas A&M University.



FRESHMAN YEAR**

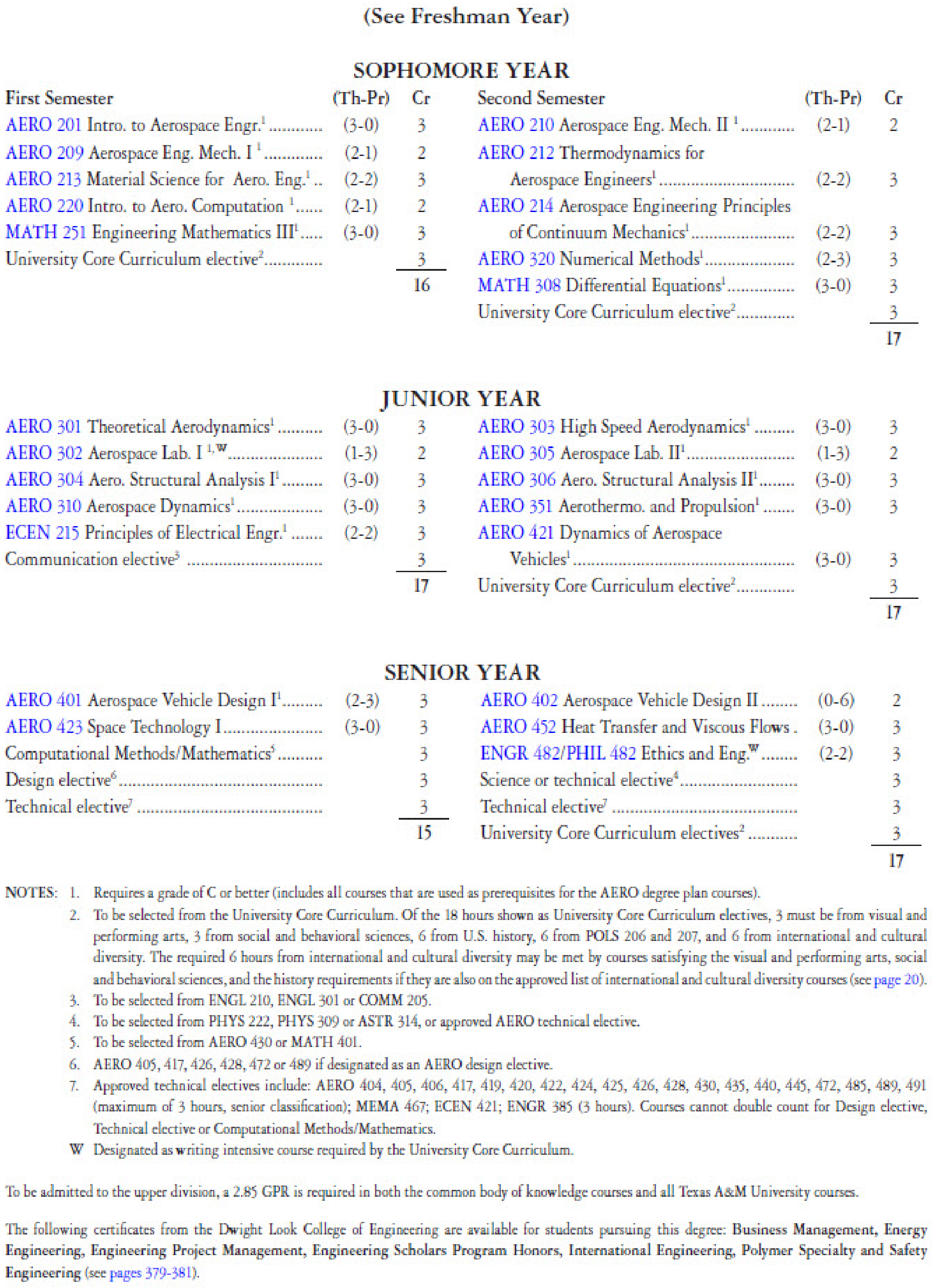
First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
ENGL 104 Comp. and Rhetoric	(3-0)	3	CHEM 107 Gen. Chem. for Engr. Students[3]	(3-0)	3
ENGR 111 Foundations in Engineering I	(1-3)	2	CHEM 117 Gen. Chem. for Engr. Stu. Lab.	(0-3)	1
MATH 151 Engineering Mathematics I[1]	(3-2)	4	ENGR 112 Foundations in Engineering II	(1-3)	2
PHYS 218 Mechanics	(3-3)	4	MATH 152 Engineering Mathematics II	(3-2)	4
University Core Curriculum elective[2]		3	PHYS 208 Electricity and Optics	(3-3)	4
*KINE 198 Health and Fitness Activity	(0-2)	1	University Core Curriculum elective[2]		3
		17	*KINE 199 Required Physical Activity	(0-2)	1
					18

NOTES:
1. Entering students will be given a placement test in mathematics. Test results will be used in selecting the appropriate starting course which may be at a higher or lower level.
2. To be selected from the University Core Curriculum. Of the 18 hours shown as University Core Curriculum electives, 3 must be from visual and performing arts, 3 from social and behavioral sciences, 6 from U.S. history, and 6 from POLS 206 and 207. The required 6 hours from international and cultural diversity may be met by courses satisfying the visual and performing arts, social and behavioral sciences, and the political science and history requirements if they are also on the approved list of international and cultural diversity courses (see page 20).
3. BMEN, CHEN and RHEN require 8 hours of freshman chemistry, which may be satisfied by CHEM 101/111 or CHEM 107/117 and 102/112; Credit by Examination (CBE) for CHEM 101/111 or CHEM 107/117 plus CHEM 102/112; or 8 hours of CBE for CHEM 101/111 or CHEM 107/117 and CHEM 102/112.

* See page 21.

**A grade of C or better will be required for the Common Body of Knowledge (CBK) Courses (MATH 151 and 152; PHYS 208 and 218; CHEM 107/117 (CHEM 102/112 for BMEN, CHEN and RHEN majors); ENGL 104; ENGR 111 and 112) and any other courses designated by the individual engineering departments. Prerequisites for the CBK courses will not be included in the calculations for CBK grade point average. See descriptions of individual majors and written requirements available from the departmental offices.

Figure A.1: Courses taken by the majority of engineering students in the first year of enrollment, reproduced from the 2010-2011 TAMU Undergraduate catalog [5].



(See Freshman Year)

SOPHOMORE YEAR

First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
AERO 201 Intro. to Aerospace Engr.[1]	(3-0)	3	AERO 210 Aerospace Eng. Mech. II [1]	(2-1)	2
AERO 209 Aerospace Eng. Mech. I [1]	(2-1)	2	AERO 212 Thermodynamics for Aerospace Engineers[1]	(2-2)	3
AERO 213 Material Science for Aero. Eng.[1]	(2-2)	3	AERO 214 Aerospace Engineering Principles of Continuum Mechanics[1]	(2-2)	3
AERO 220 Intro. to Aero. Computation [1]	(2-1)	2	AERO 320 Numerical Methods[1]	(2-3)	3
MATH 251 Engineering Mathematics III[1]	(3-0)	3	MATH 308 Differential Equations[1]	(3-0)	3
University Core Curriculum elective[2]		3	University Core Curriculum elective[2]		3
		16			17

JUNIOR YEAR

AERO 301 Theoretical Aerodynamics[1]	(3-0)	3	AERO 303 High Speed Aerodynamics[1]	(3-0)	3
AERO 302 Aerospace Lab. I [1,W]	(1-3)	2	AERO 305 Aerospace Lab. II[1]	(1-3)	2
AERO 304 Aero. Structural Analysis I[1]	(3-0)	3	AERO 306 Aero. Structural Analysis II[1]	(3-0)	3
AERO 310 Aerospace Dynamics[1]	(3-0)	3	AERO 351 Aerothermo. and Propulsion[1]	(3-0)	3
ECEN 215 Principles of Electrical Engr.[1]	(2-2)	3	AERO 421 Dynamics of Aerospace Vehicles[1]	(3-0)	3
Communication elective[3]		3	University Core Curriculum elective[2]		3
		17			17

SENIOR YEAR

AERO 401 Aerospace Vehicle Design I[1]	(2-3)	3	AERO 402 Aerospace Vehicle Design II	(0-6)	2
AERO 423 Space Technology I	(3-0)	3	AERO 452 Heat Transfer and Viscous Flows	(3-0)	3
Computational Methods/Mathematics[5]		3	ENGR 482/PHIL 482 Ethics and Eng.[W]	(2-2)	3
Design elective[6]		3	Science or technical elective[4]		3
Technical elective[7]		3	Technical elective[7]		3
		15	University Core Curriculum electives[2]		3
					17

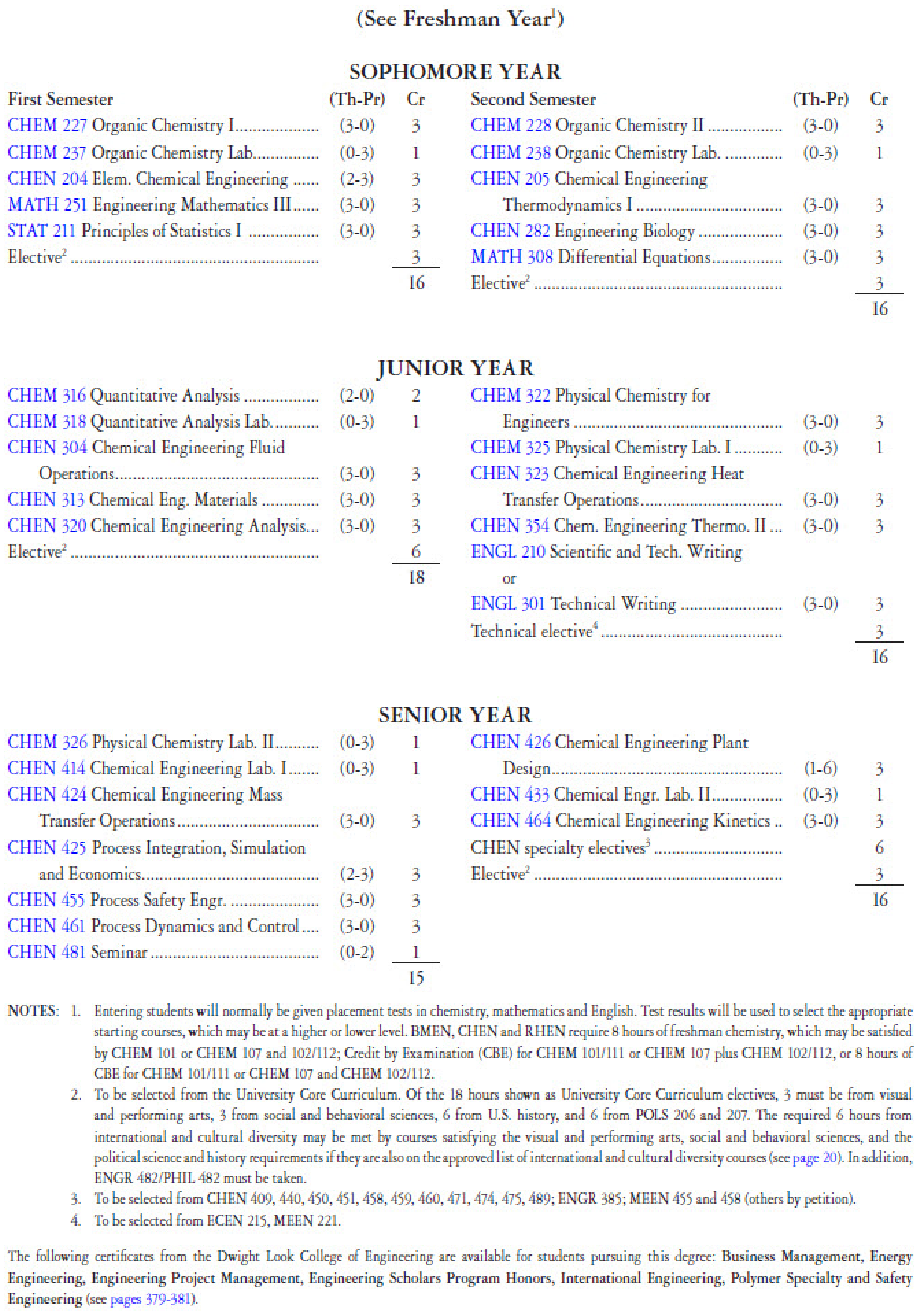
NOTES:
1. Requires a grade of C or better (includes all courses that are used as prerequisites for the AERO degree plan courses).
2. To be selected from the University Core Curriculum. Of the 18 hours shown as University Core Curriculum electives, 3 must be from visual and performing arts, 3 from social and behavioral sciences, 6 from U.S. history, 6 from POLS 206 and 207, and 6 from international and cultural diversity. The required 6 hours from international and cultural diversity may be met by courses satisfying the visual and performing arts, social and behavioral sciences, and the history requirements if they are also on the approved list of international and cultural diversity courses (see page 20).
3. To be selected from ENGL 210, ENGL 301 or COMM 205.
4. To be selected from PHYS 222, PHYS 309 or ASTR 314, or approved AERO technical elective.
5. To be selected from AERO 430 or MATH 401.
6. AERO 405, 417, 426, 428, 472 or 489 if designated as an AERO design elective.
7. Approved technical electives include: AERO 404, 405, 406, 417, 419, 420, 422, 424, 425, 426, 428, 430, 435, 440, 445, 472, 485, 489, 491 (maximum of 3 hours, senior classification); MEMA 467; ECEN 421; ENGR 385 (3 hours). Courses cannot double count for Design elective, Technical elective or Computational Methods/Mathematics.

W Designated as writing intensive course required by the University Core Curriculum.

To be admitted to the upper division, a 2.85 GPR is required in both the common body of knowledge courses and all Texas A&M University courses.

The following certificates from the Dwight Look College of Engineering are available for students pursuing this degree: **Business Management, Energy Engineering, Engineering Project Management, Engineering Scholars Program Honors, International Engineering, Polymer Specialty and Safety Engineering** (see pages 379-381).

Figure A.2: Degree plan for an Aerospace Engineering (AERO) major beginning in the 2010-2011 academic year, reproduced from the 2010-2011 TAMU Undergraduate catalog [5].



(See Freshman Year[1])

SOPHOMORE YEAR

First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
CHEM 227 Organic Chemistry I	(3-0)	3	CHEM 228 Organic Chemistry II	(3-0)	3
CHEM 237 Organic Chemistry Lab.	(0-3)	1	CHEM 238 Organic Chemistry Lab.	(0-3)	1
CHEN 204 Elem. Chemical Engineering	(2-3)	3	CHEN 205 Chemical Engineering Thermodynamics I	(3-0)	3
MATH 251 Engineering Mathematics III	(3-0)	3	CHEN 282 Engineering Biology	(3-0)	3
STAT 211 Principles of Statistics I	(3-0)	3	MATH 308 Differential Equations	(3-0)	3
Elective[2]		3	Elective[2]		3
		16			16

JUNIOR YEAR

CHEM 316 Quantitative Analysis	(2-0)	2	CHEM 322 Physical Chemistry for Engineers	(3-0)	3
CHEM 318 Quantitative Analysis Lab.	(0-3)	1	CHEM 325 Physical Chemistry Lab. I	(0-3)	1
CHEN 304 Chemical Engineering Fluid Operations	(3-0)	3	CHEN 323 Chemical Engineering Heat Transfer Operations	(3-0)	3
CHEN 313 Chemical Eng. Materials	(3-0)	3	CHEN 354 Chem. Engineering Thermo. II	(3-0)	3
CHEN 320 Chemical Engineering Analysis	(3-0)	3	ENGL 210 Scientific and Tech. Writing or ENGL 301 Technical Writing	(3-0)	3
Elective[2]		6	Technical elective[4]		3
		18			16

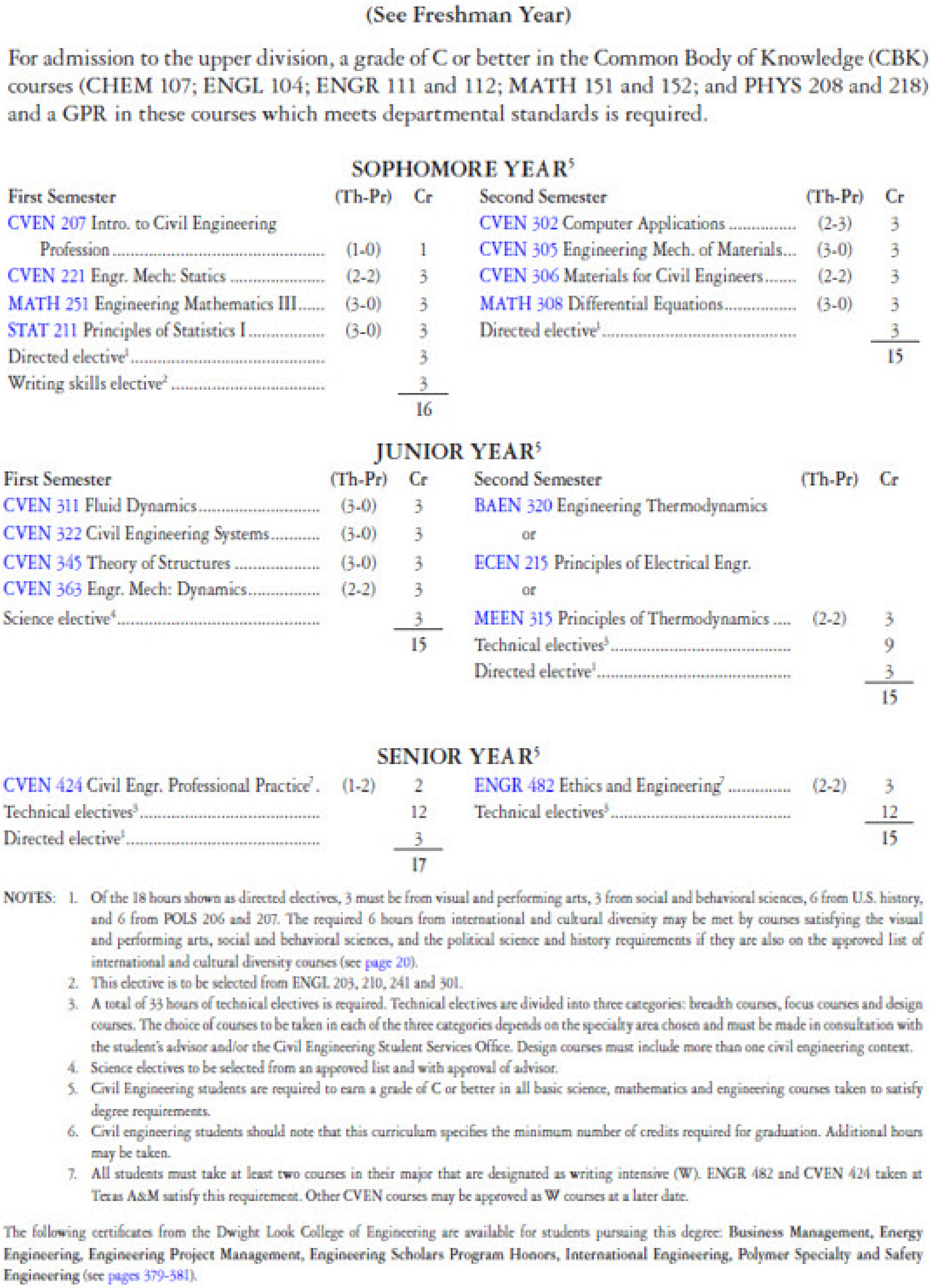
SENIOR YEAR

CHEM 326 Physical Chemistry Lab. II	(0-3)	1	CHEN 426 Chemical Engineering Plant Design	(1-6)	3
CHEN 414 Chemical Engineering Lab. I	(0-3)	1	CHEN 433 Chemical Engr. Lab. II	(0-3)	1
CHEN 424 Chemical Engineering Mass Transfer Operations	(3-0)	3	CHEN 464 Chemical Engineering Kinetics	(3-0)	3
CHEN 425 Process Integration, Simulation and Economics	(2-3)	3	CHEN specialty electives[3]		6
CHEN 455 Process Safety Engr.	(3-0)	3	Elective[2]		3
CHEN 461 Process Dynamics and Control	(3-0)	3			16
CHEN 481 Seminar	(0-2)	1			
		15			

NOTES:
1. Entering students will normally be given placement tests in chemistry, mathematics and English. Test results will be used to select the appropriate starting courses, which may be at a higher or lower level. BMEN, CHEN and RHEN require 8 hours of freshman chemistry, which may be satisfied by CHEM 101 or CHEM 107 and 102/112; Credit by Examination (CBE) for CHEM 101/111 or CHEM 107 plus CHEM 102/112, or 8 hours of CBE for CHEM 101/111 or CHEM 107 and CHEM 102/112.
2. To be selected from the University Core Curriculum. Of the 18 hours shown as University Core Curriculum electives, 3 must be from visual and performing arts, 3 from social and behavioral sciences, 6 from U.S. history, and 6 from POLS 206 and 207. The required 6 hours from international and cultural diversity may be met by courses satisfying the visual and performing arts, social and behavioral sciences, and the political science and history requirements if they are also on the approved list of international and cultural diversity courses (see page 20). In addition, ENGR 482/PHIL 482 must be taken.
3. To be selected from CHEN 409, 440, 450, 451, 458, 459, 460, 471, 474, 475, 489; ENGR 385; MEEN 455 and 458 (others by petition).
4. To be selected from ECEN 215, MEEN 221.

The following certificates from the Dwight Look College of Engineering are available for students pursuing this degree: **Business Management, Energy Engineering, Engineering Project Management, Engineering Scholars Program Honors, International Engineering, Polymer Specialty and Safety Engineering** (see pages 379-381).

Figure A.3: Degree plan for a Chemical Engineering (CHEN) major beginning in the 2010-2011 academic year, reproduced from the 2010-2011 TAMU Undergraduate catalog [5].



(See Freshman Year)

For admission to the upper division, a grade of C or better in the Common Body of Knowledge (CBK) courses (CHEM 107; ENGL 104; ENGR 111 and 112; MATH 151 and 152; and PHYS 208 and 218) and a GPR in these courses which meets departmental standards is required.

SOPHOMORE YEAR[5]

First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
CVEN 207 Intro. to Civil Engineering Profession	(1-0)	1	CVEN 302 Computer Applications	(2-3)	3
CVEN 221 Engr. Mech: Statics	(2-2)	3	CVEN 305 Engineering Mech. of Materials	(3-0)	3
MATH 251 Engineering Mathematics III	(3-0)	3	CVEN 306 Materials for Civil Engineers	(2-2)	3
STAT 211 Principles of Statistics I	(3-0)	3	MATH 308 Differential Equations	(3-0)	3
Directed elective[1]		3	Directed elective[1]		3
Writing skills elective[2]		3			15
		16			

JUNIOR YEAR[5]

First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
CVEN 311 Fluid Dynamics	(3-0)	3	BAEN 320 Engineering Thermodynamics		
CVEN 322 Civil Engineering Systems	(3-0)	3	or		
CVEN 345 Theory of Structures	(3-0)	3	ECEN 215 Principles of Electrical Engr.		
CVEN 363 Engr. Mech: Dynamics	(2-2)	3	or		
Science elective[4]		3	MEEN 315 Principles of Thermodynamics	(2-2)	3
		15	Technical electives[3]		9
			Directed elective[1]		3
					15

SENIOR YEAR[5]

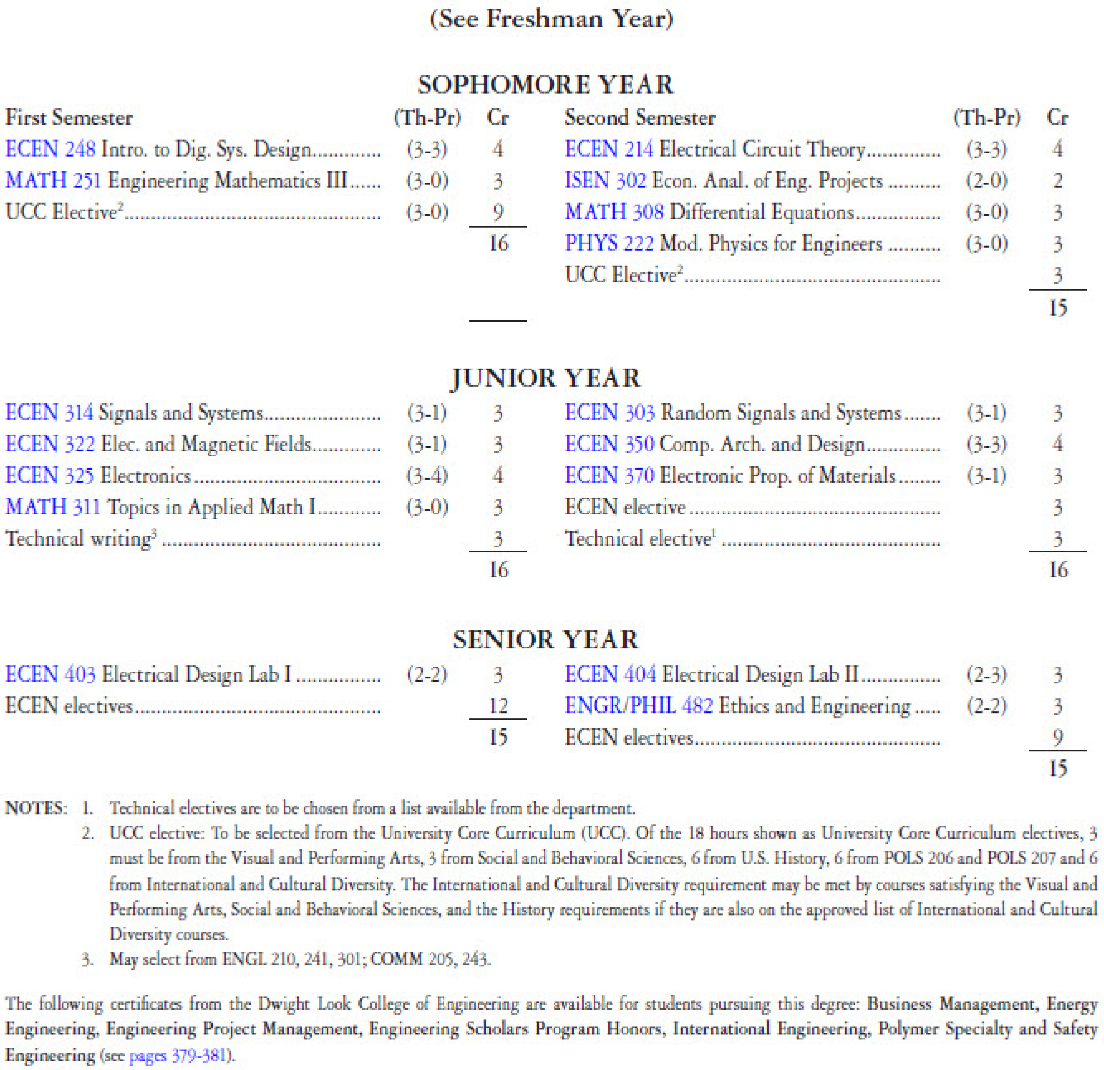
CVEN 424 Civil Engr. Professional Practice[7]	(1-2)	2	ENGR 482 Ethics and Engineering[7]	(2-2)	3
Technical electives[3]		12	Technical electives[3]		12
Directed elective[1]		3			15
		17			

NOTES:

1. Of the 18 hours shown as directed electives, 3 must be from visual and performing arts, 3 from social and behavioral sciences, 6 from U.S. history, and 6 from POLS 206 and 207. The required 6 hours from international and cultural diversity may be met by courses satisfying the visual and performing arts, social and behavioral sciences, and the political science and history requirements if they are also on the approved list of international and cultural diversity courses (see page 20).
2. This elective is to be selected from ENGL 203, 210, 241 and 301.
3. A total of 33 hours of technical electives is required. Technical electives are divided into three categories: breadth courses, focus courses and design courses. The choice of courses to be taken in each of the three categories depends on the specialty area chosen and must be made in consultation with the student's advisor and/or the Civil Engineering Student Services Office. Design courses must include more than one civil engineering context.
4. Science electives to be selected from an approved list and with approval of advisor.
5. Civil Engineering students are required to earn a grade of C or better in all basic science, mathematics and engineering courses taken to satisfy degree requirements.
6. Civil engineering students should note that this curriculum specifies the minimum number of credits required for graduation. Additional hours may be taken.
7. All students must take at least two courses in their major that are designated as writing intensive (W). ENGR 482 and CVEN 424 taken at Texas A&M satisfy this requirement. Other CVEN courses may be approved as W courses at a later date.

The following certificates from the Dwight Look College of Engineering are available for students pursuing this degree: **Business Management, Energy Engineering, Engineering Project Management, Engineering Scholars Program Honors, International Engineering, Polymer Specialty and Safety Engineering** (see pages 379-381).

Figure A.4: Degree plan for a Civil Engineering (CVEN) major beginning in the 2010-2011 academic year, reproduced from the 2010-2011 TAMU Undergraduate catalog [5].



(See Freshman Year)

SOPHOMORE YEAR

First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
ECEN 248 Intro. to Dig. Sys. Design	(3-3)	4	ECEN 214 Electrical Circuit Theory	(3-3)	4
MATH 251 Engineering Mathematics III	(3-0)	3	ISEN 302 Econ. Anal. of Eng. Projects	(2-0)	2
UCC Elective[2]	(3-0)	9	MATH 308 Differential Equations	(3-0)	3
		16	PHYS 222 Mod. Physics for Engineers	(3-0)	3
			UCC Elective[2]		3
					15

JUNIOR YEAR

ECEN 314 Signals and Systems	(3-1)	3	ECEN 303 Random Signals and Systems	(3-1)	3
ECEN 322 Elec. and Magnetic Fields	(3-1)	3	ECEN 350 Comp. Arch. and Design	(3-3)	4
ECEN 325 Electronics	(3-4)	4	ECEN 370 Electronic Prop. of Materials	(3-1)	3
MATH 311 Topics in Applied Math I	(3-0)	3	ECEN elective		3
Technical writing[3]		3	Technical elective[1]		3
		16			16

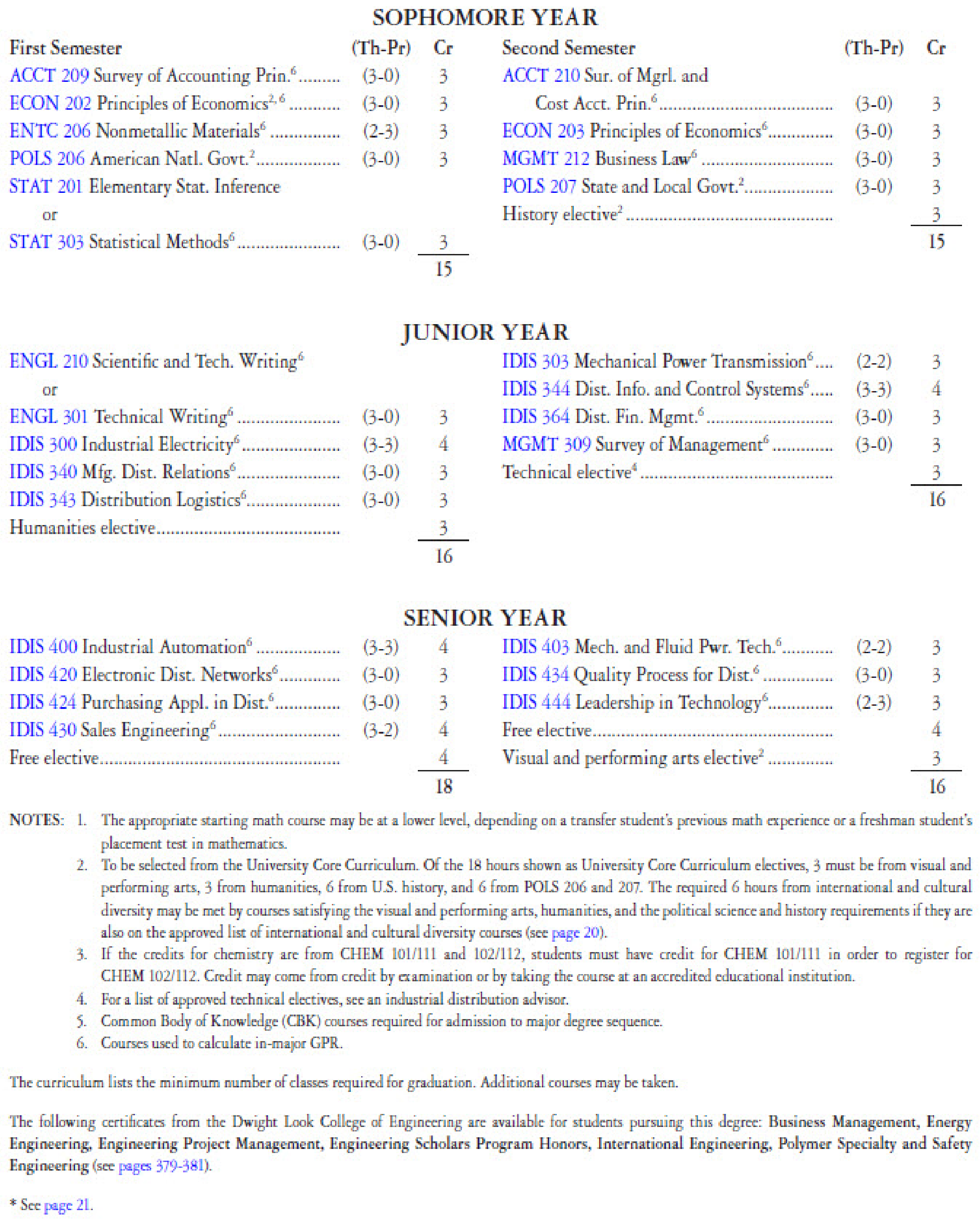
SENIOR YEAR

ECEN 403 Electrical Design Lab I	(2-2)	3	ECEN 404 Electrical Design Lab II	(2-3)	3
ECEN electives		12	ENGR/PHIL 482 Ethics and Engineering	(2-2)	3
		15	ECEN electives		9
					15

NOTES:
1. Technical electives are to be chosen from a list available from the department.
2. UCC elective: To be selected from the University Core Curriculum (UCC). Of the 18 hours shown as University Core Curriculum electives, 3 must be from the Visual and Performing Arts, 3 from Social and Behavioral Sciences, 6 from U.S. History, 6 from POLS 206 and POLS 207 and 6 from International and Cultural Diversity. The International and Cultural Diversity requirement may be met by courses satisfying the Visual and Performing Arts, Social and Behavioral Sciences, and the History requirements if they are also on the approved list of International and Cultural Diversity courses.
3. May select from ENGL 210, 241, 301; COMM 205, 243.

The following certificates from the Dwight Look College of Engineering are available for students pursuing this degree: **Business Management, Energy Engineering, Engineering Project Management, Engineering Scholars Program Honors, International Engineering, Polymer Specialty and Safety Engineering** (see pages 379-381).

Figure A.5: Degree plan for an Electrical Engineering (ECEN) major beginning in the 2010-2011 academic year, reproduced from the 2010-2011 TAMU Undergraduate catalog [5].



SOPHOMORE YEAR

First Semester	(Th-Pr)	Cr
ACCT 209 Survey of Accounting Prin.[6]	(3-0)	3
ECON 202 Principles of Economics[2, 6]	(3-0)	3
ENTC 206 Nonmetallic Materials[6]	(2-3)	3
POLS 206 American Natl. Govt.[2]	(3-0)	3
STAT 201 Elementary Stat. Inference or STAT 303 Statistical Methods[6]	(3-0)	3
		15

Second Semester	(Th-Pr)	Cr
ACCT 210 Sur. of Mgrl. and Cost Acct. Prin.[6]	(3-0)	3
ECON 203 Principles of Economics[6]	(3-0)	3
MGMT 212 Business Law[6]	(3-0)	3
POLS 207 State and Local Govt.[2]	(3-0)	3
History elective[2]		3
		15

JUNIOR YEAR

First Semester	(Th-Pr)	Cr
ENGL 210 Scientific and Tech. Writing[6] or ENGL 301 Technical Writing[6]	(3-0)	3
IDIS 300 Industrial Electricity[6]	(3-3)	4
IDIS 340 Mfg. Dist. Relations[6]	(3-0)	3
IDIS 343 Distribution Logistics[6]	(3-0)	3
Humanities elective		3
		16

Second Semester	(Th-Pr)	Cr
IDIS 303 Mechanical Power Transmission[6]	(2-2)	3
IDIS 344 Dist. Info. and Control Systems[6]	(3-3)	4
IDIS 364 Dist. Fin. Mgmt.[6]	(3-0)	3
MGMT 309 Survey of Management[6]	(3-0)	3
Technical elective[4]		3
		16

SENIOR YEAR

First Semester	(Th-Pr)	Cr
IDIS 400 Industrial Automation[6]	(3-3)	4
IDIS 420 Electronic Dist. Networks[6]	(3-0)	3
IDIS 424 Purchasing Appl. in Dist.[6]	(3-0)	3
IDIS 430 Sales Engineering[6]	(3-2)	4
Free elective		4
		18

Second Semester	(Th-Pr)	Cr
IDIS 403 Mech. and Fluid Pwr. Tech.[6]	(2-2)	3
IDIS 434 Quality Process for Dist.[6]	(3-0)	3
IDIS 444 Leadership in Technology[6]	(2-3)	3
Free elective		4
Visual and performing arts elective[2]		3
		16

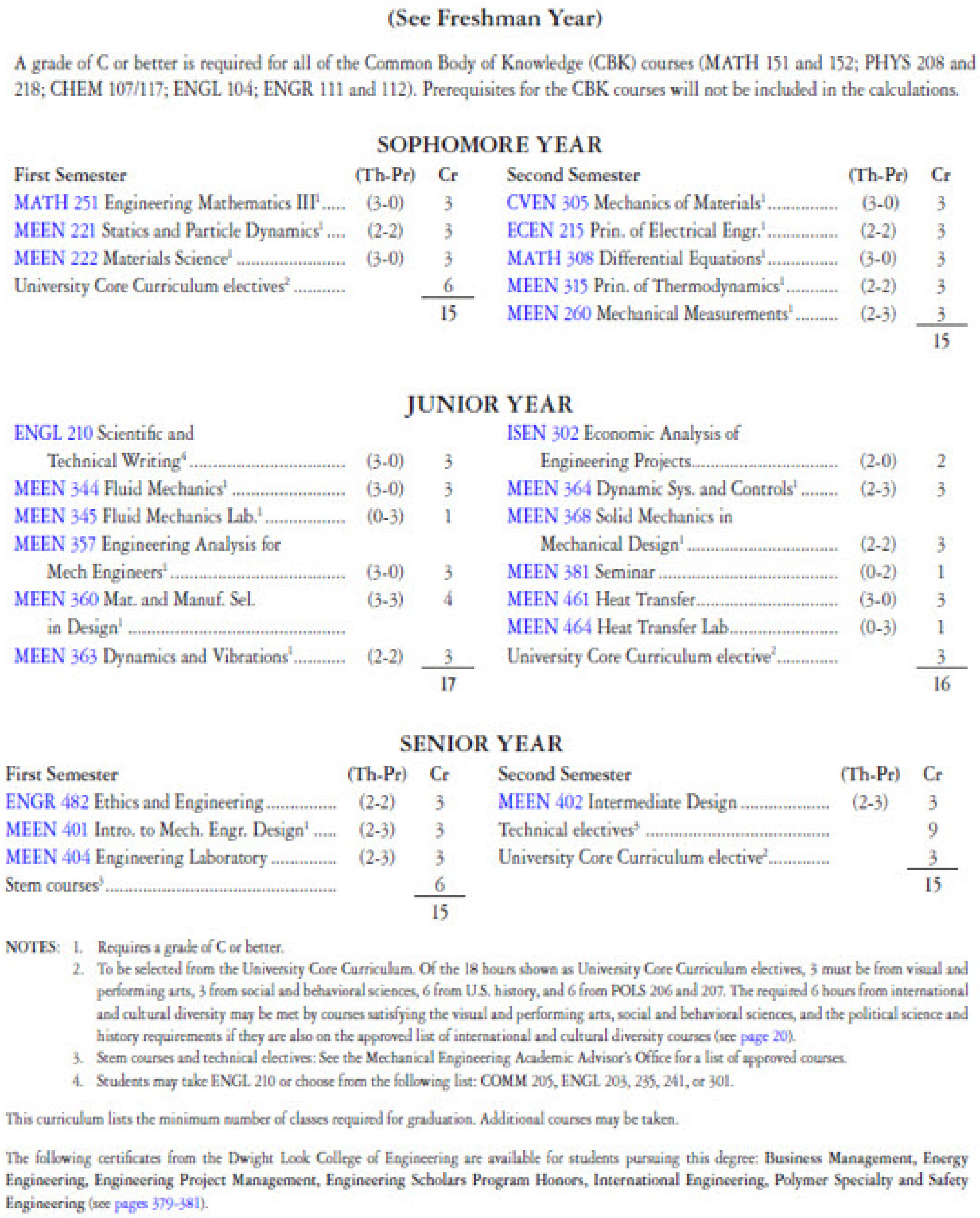
NOTES:
1. The appropriate starting math course may be at a lower level, depending on a transfer student's previous math experience or a freshman student's placement test in mathematics.
2. To be selected from the University Core Curriculum. Of the 18 hours shown as University Core Curriculum electives, 3 must be from visual and performing arts, 3 from humanities, 6 from U.S. history, and 6 from POLS 206 and 207. The required 6 hours from international and cultural diversity may be met by courses satisfying the visual and performing arts, humanities, and the political science and history requirements if they are also on the approved list of international and cultural diversity courses (see page 20).
3. If the credits for chemistry are from CHEM 101/111 and 102/112, students must have credit for CHEM 101/111 in order to register for CHEM 102/112. Credit may come from credit by examination or by taking the course at an accredited educational institution.
4. For a list of approved technical electives, see an industrial distribution advisor.
5. Common Body of Knowledge (CBK) courses required for admission to major degree sequence.
6. Courses used to calculate in-major GPR.

The curriculum lists the minimum number of classes required for graduation. Additional courses may be taken.

The following certificates from the Dwight Look College of Engineering are available for students pursuing this degree: **Business Management, Energy Engineering, Engineering Project Management, Engineering Scholars Program Honors, International Engineering, Polymer Specialty and Safety Engineering** (see pages 379-381).

* See page 21.

Figure A.6: Degree plan for an Industrial Distribution (IDIS) major beginning in the 2010-2011 academic year, reproduced from the 2010-2011 TAMU Undergraduate catalog [5].



(See Freshman Year)

A grade of C or better is required for all of the Common Body of Knowledge (CBK) courses (MATH 151 and 152; PHYS 208 and 218; CHEM 107/117; ENGL 104; ENGR 111 and 112). Prerequisites for the CBK courses will not be included in the calculations.

SOPHOMORE YEAR

First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
MATH 251 Engineering Mathematics III[1]	(3-0)	3	CVEN 305 Mechanics of Materials[1]	(3-0)	3
MEEN 221 Statics and Particle Dynamics[1]	(2-2)	3	ECEN 215 Prin. of Electrical Engr.[1]	(2-2)	3
MEEN 222 Materials Science[1]	(3-0)	3	MATH 308 Differential Equations[1]	(3-0)	3
University Core Curriculum electives[2]		6	MEEN 315 Prin. of Thermodynamics[1]	(2-2)	3
		15	MEEN 260 Mechanical Measurements[1]	(2-3)	3
					15

JUNIOR YEAR

ENGL 210 Scientific and Technical Writing[4]	(3-0)	3	ISEN 302 Economic Analysis of Engineering Projects	(2-0)	2
MEEN 344 Fluid Mechanics[1]	(3-0)	3	MEEN 364 Dynamic Sys. and Controls[1]	(2-3)	3
MEEN 345 Fluid Mechanics Lab.[1]	(0-3)	1	MEEN 368 Solid Mechanics in Mechanical Design[1]	(2-2)	3
MEEN 357 Engineering Analysis for Mech Engineers[1]	(3-0)	3	MEEN 381 Seminar	(0-2)	1
MEEN 360 Mat. and Manuf. Sel. in Design[1]	(3-3)	4	MEEN 461 Heat Transfer	(3-0)	3
MEEN 363 Dynamics and Vibrations[1]	(2-2)	3	MEEN 464 Heat Transfer Lab	(0-3)	1
		17	University Core Curriculum elective[2]		3
					16

SENIOR YEAR

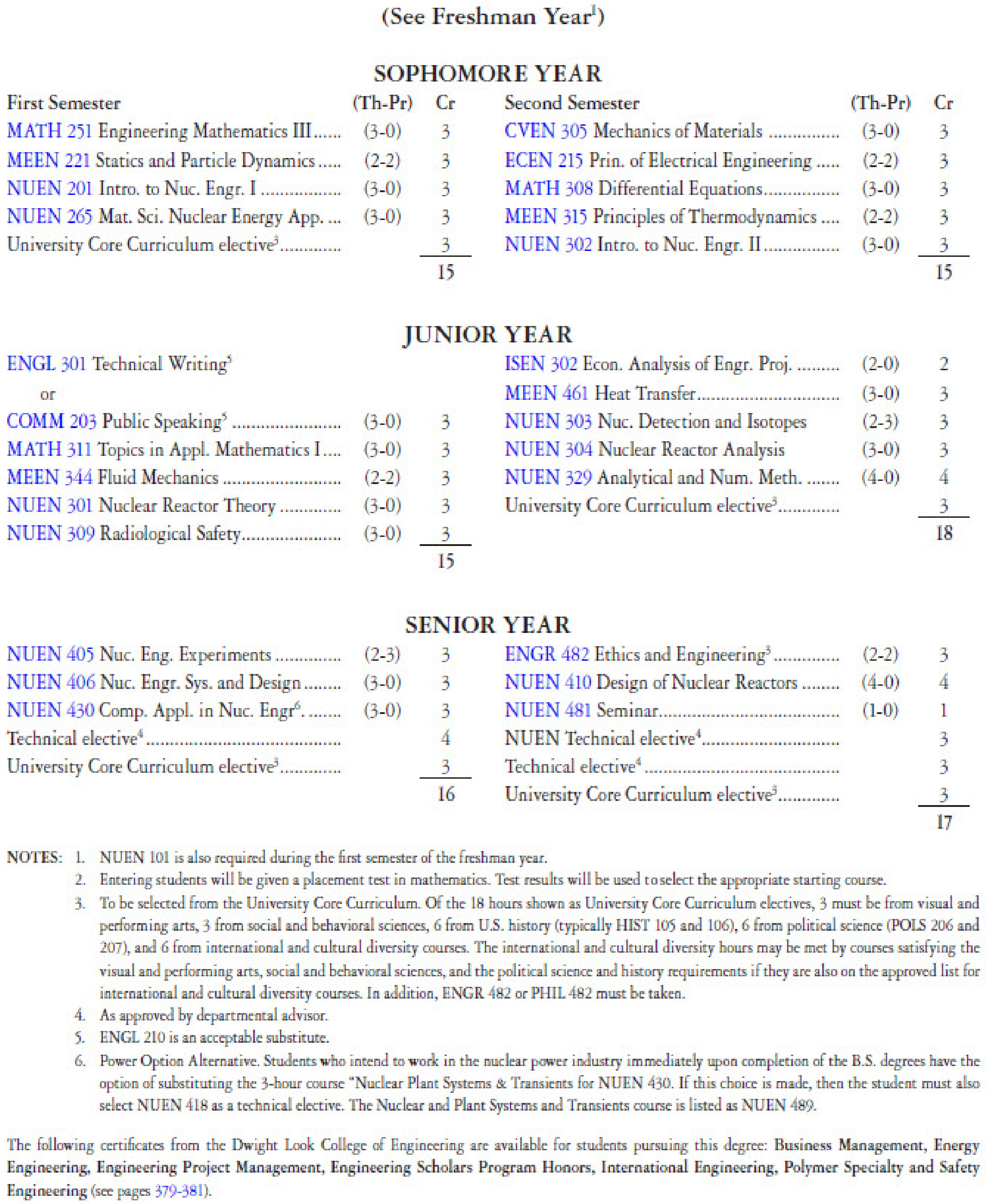
First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
ENGR 482 Ethics and Engineering	(2-2)	3	MEEN 402 Intermediate Design	(2-3)	3
MEEN 401 Intro. to Mech. Engr. Design[1]	(2-3)	3	Technical electives[3]		9
MEEN 404 Engineering Laboratory	(2-3)	3	University Core Curriculum elective[2]		3
Stem courses[3]		6			15
		15			

NOTES:
1. Requires a grade of C or better.
2. To be selected from the University Core Curriculum. Of the 18 hours shown as University Core Curriculum electives, 3 must be from visual and performing arts, 3 from social and behavioral sciences, 6 from U.S. history, and 6 from POLS 206 and 207. The required 6 hours from international and cultural diversity may be met by courses satisfying the visual and performing arts, social and behavioral sciences, and the political science and history requirements if they are also on the approved list of international and cultural diversity courses (see page 20).
3. Stem courses and technical electives: See the Mechanical Engineering Academic Advisor's Office for a list of approved courses.
4. Students may take ENGL 210 or choose from the following list: COMM 205, ENGL 203, 235, 241, or 301.

This curriculum lists the minimum number of classes required for graduation. Additional courses may be taken.

The following certificates from the Dwight Look College of Engineering are available for students pursuing this degree: **Business Management, Energy Engineering, Engineering Project Management, Engineering Scholars Program Honors, International Engineering, Polymer Specialty and Safety Engineering** (see pages 379-381).

Figure A.7: Degree plan for an Mechanical Engineering (MEEN) major beginning in the 2010-2011 academic year, reproduced from the 2010-2011 TAMU Undergraduate catalog [5].



(See Freshman Year[1])

SOPHOMORE YEAR

First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
MATH 251 Engineering Mathematics III	(3-0)	3	CVEN 305 Mechanics of Materials	(3-0)	3
MEEN 221 Statics and Particle Dynamics	(2-2)	3	ECEN 215 Prin. of Electrical Engineering	(2-2)	3
NUEN 201 Intro. to Nuc. Engr. I	(3-0)	3	MATH 308 Differential Equations	(3-0)	3
NUEN 265 Mat. Sci. Nuclear Energy App.	(3-0)	3	MEEN 315 Principles of Thermodynamics	(2-2)	3
University Core Curriculum elective[3]		3	NUEN 302 Intro. to Nuc. Engr. II	(3-0)	3
		15			15

JUNIOR YEAR

ENGL 301 Technical Writing[5]			ISEN 302 Econ. Analysis of Engr. Proj.	(2-0)	2
or			MEEN 461 Heat Transfer	(3-0)	3
COMM 203 Public Speaking[5]	(3-0)	3	NUEN 303 Nuc. Detection and Isotopes	(2-3)	3
MATH 311 Topics in Appl. Mathematics I	(3-0)	3	NUEN 304 Nuclear Reactor Analysis	(3-0)	3
MEEN 344 Fluid Mechanics	(2-2)	3	NUEN 329 Analytical and Num. Meth.	(4-0)	4
NUEN 301 Nuclear Reactor Theory	(3-0)	3	University Core Curriculum elective[3]		3
NUEN 309 Radiological Safety	(3-0)	3			18
		15			

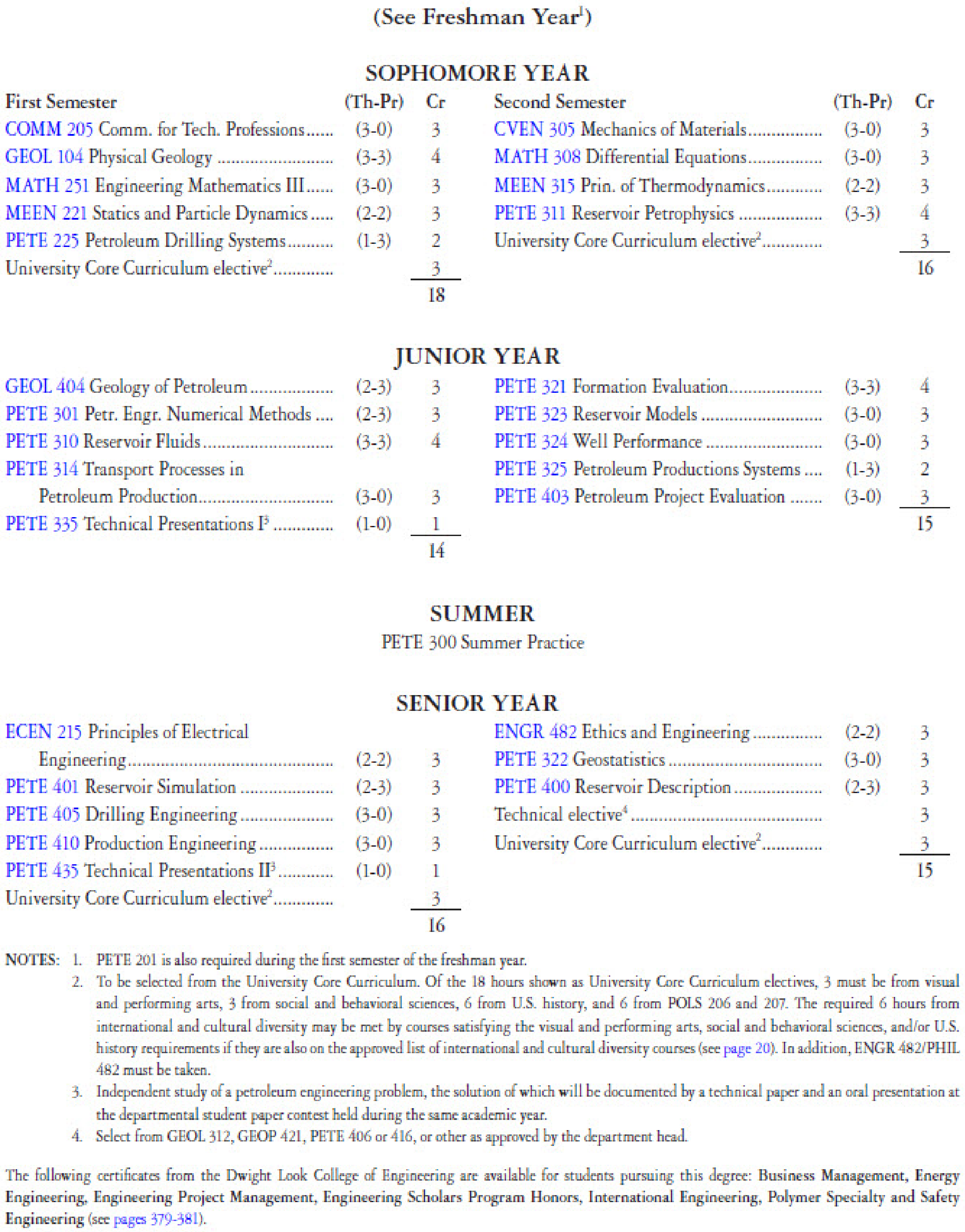
SENIOR YEAR

NUEN 405 Nuc. Eng. Experiments	(2-3)	3	ENGR 482 Ethics and Engineering[3]	(2-2)	3
NUEN 406 Nuc. Engr. Sys. and Design	(3-0)	3	NUEN 410 Design of Nuclear Reactors	(4-0)	4
NUEN 430 Comp. Appl. in Nuc. Engr[6].	(3-0)	3	NUEN 481 Seminar	(1-0)	1
Technical elective[4]		4	NUEN Technical elective[4]		3
University Core Curriculum elective[3]		3	Technical elective[4]		3
		16	University Core Curriculum elective[3]		3
					17

NOTES:
1. NUEN 101 is also required during the first semester of the freshman year.
2. Entering students will be given a placement test in mathematics. Test results will be used to select the appropriate starting course.
3. To be selected from the University Core Curriculum. Of the 18 hours shown as University Core Curriculum electives, 3 must be from visual and performing arts, 3 from social and behavioral sciences, 6 from U.S. history (typically HIST 105 and 106), 6 from political science (POLS 206 and 207), and 6 from international and cultural diversity courses. The international and cultural diversity hours may be met by courses satisfying the visual and performing arts, social and behavioral sciences, and the political science and history requirements if they are also on the approved list for international and cultural diversity courses. In addition, ENGR 482 or PHIL 482 must be taken.
4. As approved by departmental advisor.
5. ENGL 210 is an acceptable substitute.
6. Power Option Alternative. Students who intend to work in the nuclear power industry immediately upon completion of the B.S. degrees have the option of substituting the 3-hour course "Nuclear Plant Systems & Transients for NUEN 430. If this choice is made, then the student must also select NUEN 418 as a technical elective. The Nuclear and Plant Systems and Transients course is listed as NUEN 489.

The following certificates from the Dwight Look College of Engineering are available for students pursuing this degree: **Business Management, Energy Engineering, Engineering Project Management, Engineering Scholars Program Honors, International Engineering, Polymer Specialty and Safety Engineering** (see pages 379-381).

Figure A.8: Degree plan for an Nuclear Engineering (NUEN) major beginning in the 2010-2011 academic year, reproduced from the 2010-2011 TAMU Undergraduate catalog [5].



(See Freshman Year[1])

SOPHOMORE YEAR

First Semester	(Th-Pr)	Cr	Second Semester	(Th-Pr)	Cr
COMM 205 Comm. for Tech. Professions	(3-0)	3	CVEN 305 Mechanics of Materials	(3-0)	3
GEOL 104 Physical Geology	(3-3)	4	MATH 308 Differential Equations	(3-0)	3
MATH 251 Engineering Mathematics III	(3-0)	3	MEEN 315 Prin. of Thermodynamics	(2-2)	3
MEEN 221 Statics and Particle Dynamics	(2-2)	3	PETE 311 Reservoir Petrophysics	(3-3)	4
PETE 225 Petroleum Drilling Systems	(1-3)	2	University Core Curriculum elective[2]		3
University Core Curriculum elective[2]		3			
		18			16

JUNIOR YEAR

GEOL 404 Geology of Petroleum	(2-3)	3	PETE 321 Formation Evaluation	(3-3)	4
PETE 301 Petr. Engr. Numerical Methods	(2-3)	3	PETE 323 Reservoir Models	(3-0)	3
PETE 310 Reservoir Fluids	(3-3)	4	PETE 324 Well Performance	(3-0)	3
PETE 314 Transport Processes in Petroleum Production	(3-0)	3	PETE 325 Petroleum Productions Systems	(1-3)	2
PETE 335 Technical Presentations I[3]	(1-0)	1	PETE 403 Petroleum Project Evaluation	(3-0)	3
		14			15

SUMMER

PETE 300 Summer Practice

SENIOR YEAR

ECEN 215 Principles of Electrical Engineering	(2-2)	3	ENGR 482 Ethics and Engineering	(2-2)	3
PETE 401 Reservoir Simulation	(2-3)	3	PETE 322 Geostatistics	(3-0)	3
PETE 405 Drilling Engineering	(3-0)	3	PETE 400 Reservoir Description	(2-3)	3
PETE 410 Production Engineering	(3-0)	3	Technical elective[4]		3
PETE 435 Technical Presentations II[3]	(1-0)	1	University Core Curriculum elective[2]		3
University Core Curriculum elective[2]		3			
		16			15

NOTES:
1. PETE 201 is also required during the first semester of the freshman year.
2. To be selected from the University Core Curriculum. Of the 18 hours shown as University Core Curriculum electives, 3 must be from visual and performing arts, 3 from social and behavioral sciences, 6 from U.S. history, and 6 from POLS 206 and 207. The required 6 hours from international and cultural diversity may be met by courses satisfying the visual and performing arts, social and behavioral sciences, and/or U.S. history requirements if they are also on the approved list of international and cultural diversity courses (see page 20). In addition, ENGR 482/PHIL 482 must be taken.
3. Independent study of a petroleum engineering problem, the solution of which will be documented by a technical paper and an oral presentation at the departmental student paper contest held during the same academic year.
4. Select from GEOL 312, GEOP 421, PETE 406 or 416, or other as approved by the department head.

The following certificates from the Dwight Look College of Engineering are available for students pursuing this degree: **Business Management, Energy Engineering, Engineering Project Management, Engineering Scholars Program Honors, International Engineering, Polymer Specialty and Safety Engineering** (see pages 379-381).

Figure A.9: Degree plan for an Petroleum Engineering (PETE) major beginning in the 2010-2011 academic year, reproduced from the 2010-2011 TAMU Undergraduate catalog [5].

APPENDIX B

EXAMPLE MID-TERM EXAMS

B.1 University Physics

The following pages contain an example mid-term exam, the 1^{st} of three, for the UP flavor of IP Mechanics. Topics on this mid-term include one-dimensional motion, vectors, two-dimensional motion, relative motion, and Newton's laws. The solutions included were provided by the faculty member who created and administered the test during the Fall 2010 term.

Part 1: Basic ideas of units, conversions, and vectors.

Problem 1.1: (1p) What system of units is used in this course? What are the basic units of mass, length, and time of that system ?

International System (SI), Kilogram, meter, seconds.

Problem 1.2: Joule, erg and eV are units of energy defined as:

1 J (Joule) = 1 Kg m^2/s^2

1 erg (erg) = 1 gram cm^2/s^2

1 eV (electron-Volt) = 1.6 10^{-12} erg

Question 1.2.1: (2p) Express 1 erg in units of Joules.

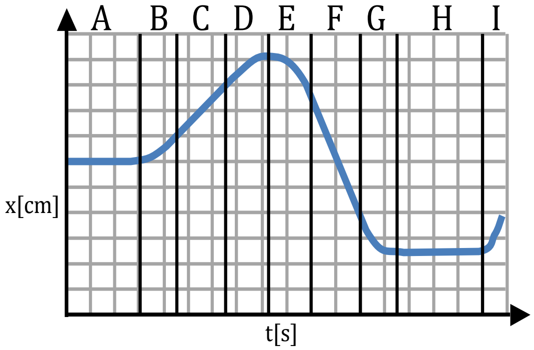
$$\boxed{1erg = 1\frac{gcm^2}{s^2} = 1\frac{Kg}{s^2 1000}\left(\frac{m}{100}\right)^2 = \frac{1}{1000*100*100}\frac{Kgm^2}{s^2} = 10^{-7}J}$$

Question 1.2.2: (2p) The LHC accelerator in Switzerland accelerates protons to the world's largest energy of 3.5x10^{12} eV. Express that energy in Joules.

$$\boxed{3.5\ 10^{12}eV = 3.5\ 10^{12}\ 1.6\ 10^{-12}erg = 3.5\ 1.6\ \text{erg} = 3.5\ 1.6\ 10^{-7}\ J = 5.6\ 10^{-7}J}$$

Problem 1.3: The following plot shows the position x as a function of time

Question 1.3.1: (5p) For each time range A,B,C…I, fill the table below writing in each cell whether the velocity and acceleration are <0, >0, or =0.



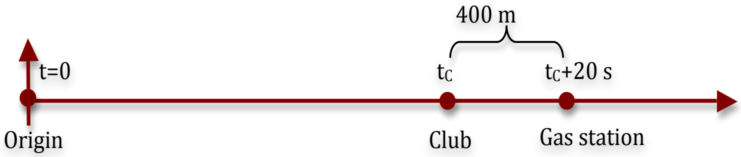
Region	Velocity	Acceleration
A	=0	=0
B	>0	>0
C	>0	=0
D	>0	<0
E	<0	<0
F	<0	=0
G	<0	>0
H	=0	=0
I	>0	>0

Question 1.3.2: (2p) Is the magnitude of the velocity greater in region C than it is in F ? Why ?

The magnitude of the velocity at a given time is the magnitude of the slope of the tangent line in the above graph at that given time. The slope at time range C is about +2 squares/2 squares, with a magnitude of +1. The slope at time range F is about -4 squares/2 squares with a magnitude of -2. Hence, the answer is NO; the magnitude of the velocity at region C is smaller than that at region F.

Part 2: A car departs from rest under a constant acceleration of 1 m/s^2 moving in a straight line. After travelling some distance it passes first a dancing club and 20 seconds later a gas station. The distance between the dancing club and the gas station is 400meters.

Question 2.1.1: (6p) In the space below draw a schematic diagram of the problem and write any associated times. In addition choose and draw a coordinate system and clearly indicate its origin.



Question 2.1.2: (4p) Write the equations of motion of the accelerating car according to your coordinate system.

$$\boxed{X_T(t) = \frac{1m}{2s^2}t^2}$$

Question 2.1.3: (6p) Find the time it took the car to travel from the original point of departure to the club. (Hint: use the fact that you know the distance and the time between the Club and the gas station)

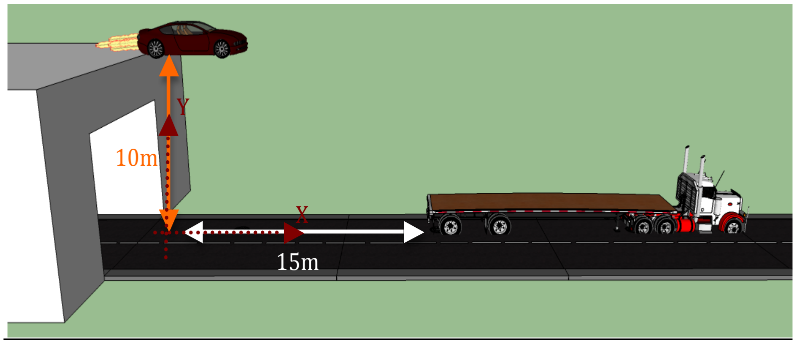
$$\boxed{\begin{array}{l} X_T(t_c+20s) - X(t_C) = 400m \quad \Rightarrow \quad \frac{1m}{2s^2}(t_c+20s)^2 - \frac{1m}{2s^2}t_C^2 = \frac{1m}{2s^2}400s^2 + \frac{1m}{2s^2}2t_C 20s = 400m \\ 200m + \frac{20m}{s}t_C = 400m \quad \Rightarrow \quad \mathrm{t_C} = \frac{200ms}{20m} = 10s \end{array}}$$

Question 2.1.4: (4p) Find the distance between the dancing club and the original point from where the car departed.

$$\boxed{X_T(t_c) = \frac{1m}{2s^2}t_C^2 = \frac{1m}{2s^2}100s^2 = 50m}$$

Part 3: Acceleration in both components.

Problem 3.1: A car is fitted with a rocket propulsion engine that provides the car with a constant acceleration in the horizontal direction. As depicted below the car must jump of a 10m high bridge and land on a flatbed truck moving with a constant velocity of 20 m/s. At the moment the car leaves the bridge the truck is at a distance of 15m from the bridge and the car has an initial velocity of 20 m/s. Ignore the height of the flatbed, air resistance and any mass loss due to the rocket. <u>The following questions must be answered in the form of a number with proper units.</u>



Question 3.1.1: (3p) Choose and draw your coordinate system on the figure above and associate times to the different events.

Question 3.1.2: (5p) Write the position of the car and the truck as a function of time

$$\boxed{\begin{array}{l}\text{For the truck :}\\ X_T(t) = 15m + 20\frac{m}{s}t\\ Y_T(t) = \ 0\end{array}}$$

$$\boxed{\begin{array}{l}\text{For the car :}\\ X_C(t) = 20\frac{m}{s}t + \frac{a_x}{2}t^2\\ Y_C(t) = 10m - \frac{g}{2}t^2\end{array}}$$

Question 3.1.3: (5p) Find the time at which the car lands on the truck.

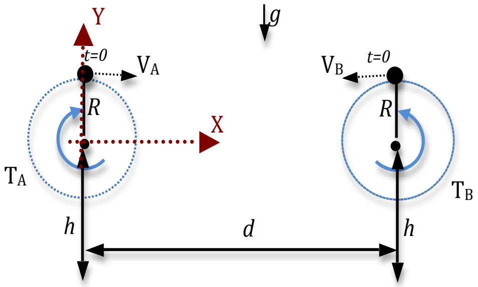
$$\boxed{Y_C(t_L) = 10m - \frac{g}{2}t_L^2 = 0 \quad \Rightarrow \quad t_L = \sqrt{\frac{20m}{g}} = 1.43\text{ s}}$$

Question 3.1.4: (7p) Find the minimum horizontal acceleration that the rocket propulsion engine in the car needs to give the car so it can successfully land on the truck.

$$\boxed{\begin{array}{l}\mathrm{X}_C(t_L) = X_T(t_L)\ \text{replacing we get}\\ 20\ \frac{\mathrm{m}}{\mathrm{s}}t_L + \frac{a_x}{2}t_L^2 = 15\mathrm{m}\ +\ 20\frac{\mathrm{m}}{\mathrm{s}}t_L \quad \Rightarrow a_x = \frac{30\mathrm{m}}{t_L^2} = \mathrm{g}\frac{30\mathrm{m}}{20\mathrm{m}}\ =\ 14.7\ \frac{\mathrm{m}}{\mathrm{s}^2}\end{array}}$$

Part 4: A more complex problem.

Problem 4.1: A ball is tied up to a rod of radius ***R*** connected to a motor that makes it spin in the vertical plane with a uniform motion once every T_A seconds. A second similar device is located at a distance ***d*** and rotating in opposite direction with period T_B as shown in the picture below. Gravity is present and the center of both devices is located a distance ***h*** with respect to the ground. All answers must be expressed in terms of known parameters.



Question 4.1.1: (2p) Find the ratio of the speeds of the balls in their movement around their respective circles.

$$\boxed{\frac{|v_A|}{|v_B|} = \frac{2\pi R/T_A}{2\pi R/T_B} = \frac{T_B}{T_A}}.$$

Question 4.1.2: (2p) Find the ratio of the magnitude of the acceleration of the balls in their movement around their respective circles. In general, what is the direction of the acceleration?

$$\boxed{\frac{|a_A|}{|a_B|} = \frac{v_A^2/R}{v_B^2/R} = \frac{T_B^2}{T_A^2}}$$

The acceleration vector of the balls point towards the center of their respective circles.

Question 4.1.3: (7p) When both balls are simultaneously at their maximum heights the balls break free of their respective rods and start moving against each other. Find the time it takes the balls to collide assuming the height ***h*** is big enough.

$$\boxed{X_A(t_c) = X_B(t_c) \;\Rightarrow\; \mathrm{v}_A t_c = d - \mathrm{v}_B t_c \;\Rightarrow t_c = \frac{\mathrm{d}}{\mathrm{v}_A + \mathrm{v}_B} = \frac{\mathrm{d}}{2\pi R\left(\frac{1}{T_A} + \frac{1}{T_B}\right)} \;\Rightarrow t_c = \frac{T_A T_B d}{2\pi R(T_B + T_A)}}$$

Question 4.1.4: (4p) In your coordinate system find the horizontal position at which both balls collide.

$$\boxed{X_A(t_c) = \frac{2\pi R}{T_A} t_c = \frac{2\pi R}{T_A} \frac{T_A T_B d}{2\pi R(T_B + T_A)} = \frac{T_B d}{(T_A + T_B)}}$$

Question 4.1.5: (5p) Find the minimum vertical distance ***h*** necessary for the balls to collide in the air.

The vertical position where the particles collide is given by $Y_A(t_c)$ Since I put my coordinate system at the center of the circle which is from where ***h*** is measured it follows ***h***$=-Y_A(t_c)$

$$\boxed{h = -Y_A(t_c) = -R + \frac{g}{2} t_C^2 = -R + \frac{g}{2}\left(\frac{T_A T_B d}{2\pi R(T_B + T_A)}\right)^2}$$

B.2 Don't Panic

The following pages contain a reprint of an example mid-term exam, the 1^{st} of three, for the DP flavor of IP Mechanics. Topics covered on this mid-term exam include one-dimensional motion, vectors, two-dimensional motion, and Newton's laws [107]. The answers, provided by one of the faculty who taught this class, are also provided. This test was administered during the Fall 2010 term.

1. (33 points)This is a one dimensional problem. An object is dropped from a height H above the ground. Defining vertically up to be the positive direction the object experiences an acceleration

$$a(t) = \beta t - g$$

where β is a known constant.

a. Obtain an algebraic equation for the velocity as a function of time.

b. Obtain an algebraic equation for the height as a function of time.

c. Find the time, T, at which the object reaches its lowest point, assuming this occurs before it hits the ground.

2. (33 points) A small block of mass m is placed on the frictionless floor which we define to be the x, y plane. There are two forces, $\vec{F}_1$ and $\vec{F}_2$.acting on the block that have components only in the x, y plane. Because of these forces the block moves in a very strange way so that its position vector is observed to be

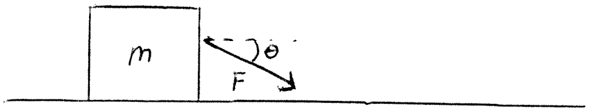
$$\vec{r}(t) = (c_1 t^3 + c_2 t)\vec{i} + (c_3 t^2 + c_4 t)\vec{j}.$$

Here all the $c's$ are known constants. One of the forces is known to be given by

$$\vec{F}_1 = k_1 \vec{i} + k_2 t \vec{j}.$$

Here k_1 and k_2 are known constants. What is the other force?

3. (33 points) A block of mass m is at rest on a table. A force of known magnitude $|\vec{F}| = F$ acts on the block, at the known angle θ as shown:



a. Assuming no friction between the table and the block, isolate the block and show all forces acting on it. (In other words draw the free body diagram for the block.)

b. Find the acceleration of the block.

c. Now assume there is a coefficient of friction μ between the table and the block. Find the acceleration of the block assuming the force $\vec{F}$ is large enough to make the block move.

d. Find the minimum value that $|\vec{F}|$ must have in order to cause the block to move.

Answers Test 1 2010

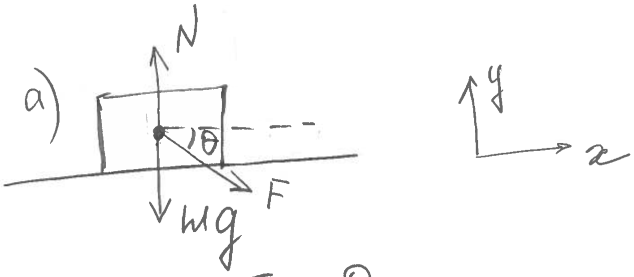
1. a) $v(t) = \frac{\beta t^2}{2} - gt$

b) $x(t) = \frac{\beta t^3}{6} - \frac{gt^2}{2} + H$

c) $t^* = \frac{2g}{\beta}$

2. $\vec{F} = (6mC_1 t - k_1)\vec{i} + (2mC_3 - k_2 t)\vec{j}$

3. a)



b) $a_x = \frac{F\cos\theta}{m}$

c) $a_x = \frac{F\cos\theta - \mu F\sin\theta - \mu mg}{m}$

d) $F = \frac{\mu mg}{\cos\theta - \mu\sin\theta}$

B.3 Transfer

The following pages contain reprinted pages of an old mid-term exam, the 1^{st} of three, for the Transfer flavor of IP Mechanics. This exam was administered by a faculty member at Blinn College, a two-year institution located in College Station, Texas, frequently attended by TAMU students seeking additional credits [108]. Topics covered on this exam include one-dimensional motion, vectors, two-dimensional motion, circular motion, and Newton's Laws. This test was administered during the Spring 2014 term, but is similar to tests administered in previous terms. A special acknowledgment is given to Professor Jeff Bronson for providing this exam and other materials from his course.

Physics 2425 **Exam 1** Bronson

Spring 2014

Name ______________________ Date__________

Circle your answers on the multiple choice page. **For the problems show the formulas you are using before putting in numbers and include units with the answers where appropriate.**

1. (3 points) Which of the following situations is impossible?

A. An object has velocity directed east and acceleration directed west.

B. An object has velocity directed east and acceleration directed east.

C. An object has zero velocity but non-zero acceleration.

D. An object has constant non-zero acceleration and changing velocity.

E. An object has constant non-zero velocity and changing acceleration.

2. (3 points) Which of the ideas is helpful in understanding projectile motion?

A. $v_x^2 + v_y^2 = \text{constant}$

B. The velocity is zero at the point of maximum elevation.

C. The horizontal motion is independent of the vertical motion.

D. Acceleration is +g when the object is rising and –g when it is falling.

E. In the absence of friction the trajectory will depend on the object's mass as well as its initial velocity and launch angle.

3. (3 points) If you were to move into outer space far from any stellar objects,

A. your mass would change, but your weight would not change.

B. your weight would change, but your mass would not change.

C. both your weight and mass would change.

D. neither your weight nor your mass would change.

4. (3 points) A man pushes against a rigid, immovable wall. Which of the following is the most accurate statement concerning this situation?

A. The man can never exert a force on the wall which exceeds his weight.

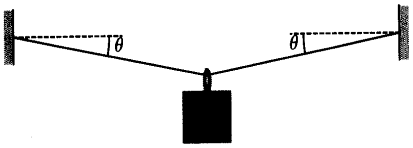
B. If the man pushes on the wall with a force of 200 N, we can be sure the wall is pushing back with a force of exactly 200 N on him.

C. Since the wall can't move it cannot exert any force on the man.

D. The man cannot be in equilibrium since he is exerting a net force on the wall.

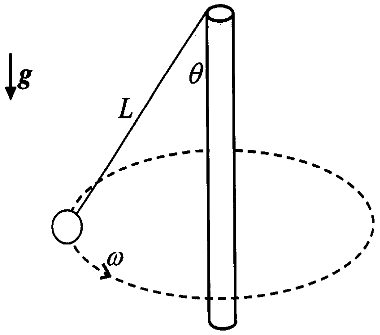
E. The friction force on the man's feet is directed to the left.

5. (10 points) A weight W hangs on a frictionless ring over a rope as shown. The rope makes the same angle θ from horizontal on either side. What is the tension in the rope?

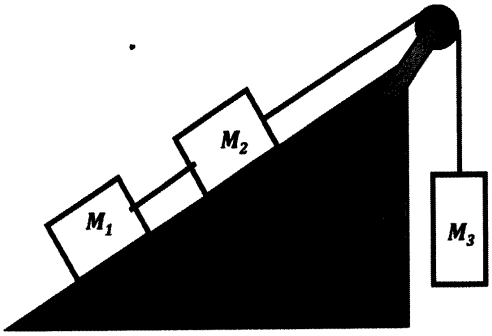


6. (10 points) Bubba drives his pickup at 85 mi/hr. He throws his beer bottle out the window, directly to his left, at 24 mi/hr relative to the truck. What is the speed of the bottle with respect to the road and what angle does this velocity make with respect to the truck's velocity?

7. (12 points) After a tetherball is struck, it rotates with a constant period of **2.50 seconds**. The rope connecting the ball to the pole has length ***L* = 2.00 m**. What angle, **θ**, does the rope make with respect to the pole?



8. (12 points) A system comprising 3 blocks with $M_1 = 6.00\ kg$ and $M_2 = 4.00\ kg$, a light frictionless pulley, a frictionless incline, and massless connecting ropes as shown. $M_3 = 12.0\ kg$ accelerates downward when the system is released from rest. What is the acceleration of the system? What is the tension in the rope connecting **M_1 and M_2?**

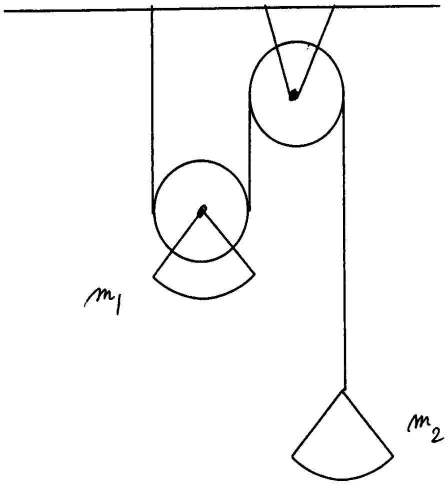


9. (10 points) The position of a 3.50×10^5-N training helicopter is given by:
$\vec{r} = (0.030\ \text{m/s}^3)t^3\,\hat{\imath} + (2.4\ \text{m/s})t\,\hat{\jmath} - (0.40\ \text{m/s}^2)t^2\,\hat{k}$.
Find the net force on the helicopter.

10. (12 points) A man throws a ball at an angle of 57° above horizontal with a speed of 18 m/s toward a wall 16 m away. How much time does it take to hit the wall and how high on the wall does it hit?

11. (10 points) The displacement of a particle is given by:
$\vec{r} = (8.0\,t^2 - 40\,t)\,\hat{i} + (-2.0\,t^3 + 30)\,\hat{j}$ (in SI units).
What is the average acceleration of the particle between 2s and 4s?

12. (12points) A rope is attached to the ceiling at one end. It then loops under a pulley holding a mass $m_1 = 5.0$ kg. It then loops over a pulley fixed to the ceiling. Then it is attached to a mass $m_2 = 5.0$ kg. When released, what is the acceleration of m_2 and what is the tension in the rope?



APPENDIX C

AVAILABLE FORMULA

C.1 University Physics

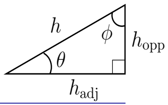
The following pages contain a reprint of the equation sheet available to students taking the UP flavor of IP Mechanics at TAMU [109].

Phys 218 — Final Exam Formulae

Trigonometry and Vectors:

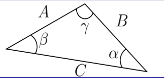
$h_{\text{adj}} = h\cos\theta = h\sin\phi$ $\qquad h^2 = h_{\text{adj}}^2 + h_{\text{opp}}^2$

$h_{\text{opp}} = h\sin\theta = h\cos\phi$ $\qquad \tan\theta = \frac{h_{\text{opp}}}{h_{\text{adj}}}$



Law of cosines: $C^2 = A^2 + B^2 - 2AB\cos\gamma$

Law of sines: $\dfrac{\sin\alpha}{A} = \dfrac{\sin\beta}{B} = \dfrac{\sin\gamma}{C}$



$$\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k} \qquad \hat{A} = \frac{\vec{A}}{|\vec{A}|}$$

$$\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y + A_zB_z = AB\cos\theta = A_{\parallel}B = AB_{\parallel}$$

$$\vec{A}\times\vec{B} = (A_yB_z - A_zB_y)\hat{i} + (A_zB_x - A_xB_z)\hat{j} + (A_xB_y - A_yB_x)\hat{k}$$

$|\vec{A}\times\vec{B}| = AB\sin\theta = A_{\perp}B = AB_{\perp}$ (direction via right-hand rule)

Kinematics:

translational	**rotational**
$\langle\vec{v}\rangle = \frac{\vec{r}_2-\vec{r}_1}{t_2-t_1} \quad \vec{v} = \frac{d\vec{r}}{dt}$	$\langle\omega\rangle = \frac{\theta_2-\theta_1}{t_2-t_1} \quad \omega = \frac{d\theta}{dt}$
$\langle\vec{a}\rangle = \frac{\vec{v}_2-\vec{v}_1}{t_2-t_1} \quad \vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2}$	$\langle\alpha\rangle = \frac{\omega_2-\omega_1}{t_2-t_1} \quad \alpha = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2}$
$\vec{r}(t) = \vec{r}_0 + \int_0^t \vec{v}(t')\,dt'$	$\theta(t) = \theta_0 + \int_0^t \omega(t')\,dt'$
$\vec{v}(t) = \vec{v}_0 + \int_0^t \vec{a}(t')\,dt'$	$\omega(t) = \omega_0 + \int_0^t \alpha(t')\,dt'$

— constant (linear/angular) acceleration only —

$\vec{r}(t) = \vec{r}_0 + \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$	$\theta(t) = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$
$\vec{v}(t) = \vec{v}_0 + \vec{a}t$	$\omega(t) = \omega_0 + \alpha t$
$v_x^2 = v_{x,0}^2 + 2a_x(x - x_0)$ (and similarly for y and z)	$\omega_f^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$
$\vec{r}(t) = \vec{r}_0 + \frac{1}{2}(\vec{v}_i + \vec{v}_f)t$	$\theta(t) = \theta_0 + \frac{1}{2}(\omega_i + \omega_f)t$

Energy and Momenta:

translational	**rotational**
	$\vec{\tau} = \vec{r}\times\vec{F}$ and $\lvert\vec{\tau}\rvert = F_{\perp}r = Fl$
$K = \frac{1}{2}Mv^2$	$K_{\text{rot}} = \frac{1}{2}I_{\text{tot}}\omega^2$
$W = \int \vec{F}\cdot d\vec{r} \xrightarrow[\text{force}]{\text{const}} \vec{F}\cdot\Delta\vec{r}$	$W = \int \tau d\theta \xrightarrow[\text{torque}]{\text{const}} \tau\,\Delta\theta$
$P = \frac{dW}{dt} = \vec{F}\cdot\vec{v}$	$P = \frac{dW}{dt} = \vec{\tau}\cdot\vec{\omega}$
	$\vec{L} = \sum \vec{r}\times\vec{p}$
$\vec{p}_{\text{cm}} = m_1\vec{v}_1 + m_2\vec{v}_2 + \ldots$	$= I_1\vec{\omega}_1 + I_2\vec{\omega}_2 + \ldots$
$= M\vec{v}_{\text{cm}}$	$= I_{\text{tot}}\vec{\omega}$
$\vec{J} = \int \vec{F}dt = \Delta\vec{p}$	
$\sum \vec{F}_{\text{ext}} = M\vec{a}_{\text{cm}} = \dfrac{d\vec{p}_{\text{cm}}}{dt}$	$\sum \vec{\tau}_{\text{ext}} = I_{\text{tot}}\vec{\alpha} = \dfrac{d\vec{L}}{dt}$
$\sum \vec{F}_{\text{int}} = 0$	$\sum \vec{\tau}_{\text{int}} = 0$
if $\sum F_{\text{ext},x} = 0,\ p_{\text{cm},x} = \text{const}$	if $\sum \tau_{\text{ext},z} = 0,\ L_z = \text{const}$

— Work-energy and potential energy —

$$W = \Delta K \qquad E_{\text{tot},i} + W_{\text{other}} = E_{\text{tot},f}$$

$$U = -\int \vec{F}\cdot d\vec{r}\ ; \quad U_{\text{grav}} = Mgy_{\text{cm}}\ ; \quad U_{\text{elas}} = \tfrac{1}{2}k\Delta x^2$$

$$F_x(x) = -dU(x)/dx \qquad \vec{F} = -\vec{\nabla}U = -\left[\tfrac{\partial U}{\partial x}\hat{i} + \tfrac{\partial U}{\partial y}\hat{j} + \tfrac{\partial U}{\partial z}\hat{k}\right]$$

Quadratic:

$$ax^2 + bx + c = 0 \quad\Rightarrow\quad x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Derivatives:

$$\tfrac{d}{dt}\,(at^n) = nat^{n-1}$$

$$\tfrac{d}{dt}\sin at = a\cos at$$

$$\tfrac{d}{dt}\cos at = -a\sin at$$

Integrals:

if $f(t) = at^n$, then $\begin{cases} \int_{t_1}^{t_2} f(t)dt = \frac{a}{n+1}(t_2^{n+1} - t_1^{n+1}) \\ \int f(t)dt = \frac{a}{n+1}t^{n+1} + C \end{cases}$

$(n \neq -1)$

$$\int \sin at\,dt = \tfrac{-1}{a}\cos at$$

$$\int \cos at\,dt = \tfrac{1}{a}\sin at$$

Constants/Conversions:

$g = 9.80\ \text{m/s}^2 = 32.15\ \text{ft/s}^2$ (Earth, sea level)

$G = 6.674\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$ $\qquad$ 1 mi = 1609 m

1 lb = 4.448 N $\qquad$ 1 ft = 12 in

$\Leftrightarrow$ 0.454 kg (Earth, sea level) $\qquad$ 1 in = 2.54 cm

1 rev = 360° = 2π radians

Circular motion: $a_{\text{rad}} = \dfrac{v^2}{R}$ $\qquad a_{\tan} = \dfrac{d|\vec{v}|}{dt} = R\alpha$

$$T = \frac{2\pi R}{v} \qquad s = R\theta \qquad v_{\tan} = R\omega$$

Relative velocity: $\vec{v}_{A/C} = \vec{v}_{A/B} + \vec{v}_{B/C}$

$\vec{v}_{A/B} = -\vec{v}_{B/A}$

Forces:

Newton's: $\sum\vec{F} = m\vec{a},\ \ \vec{F}_{B\text{ on }A} = -\vec{F}_{A\text{ on }B}$

Hooke's: $F_x = -k\Delta x$

friction: $|\vec{f}_s| \leq \mu_s|\vec{n}|,\ \ |\vec{f}_k| = \mu_k|\vec{n}|$

Centre-of-mass:

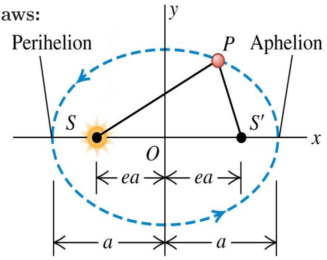
$$\vec{r}_{\text{cm}} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2 + \ldots + m_n\vec{r}_n}{m_1 + m_2 + \ldots + m_n}$$

(and similarly for $\vec{v}$ and $\vec{a}$)

Gravity: $\vec{F}_{\text{grav}} = -G\dfrac{M_1M_2}{r^2}\hat{r}$ $\qquad U_{\text{grav}} = -G\dfrac{M_1M_2}{r}$

Kepler's Laws:

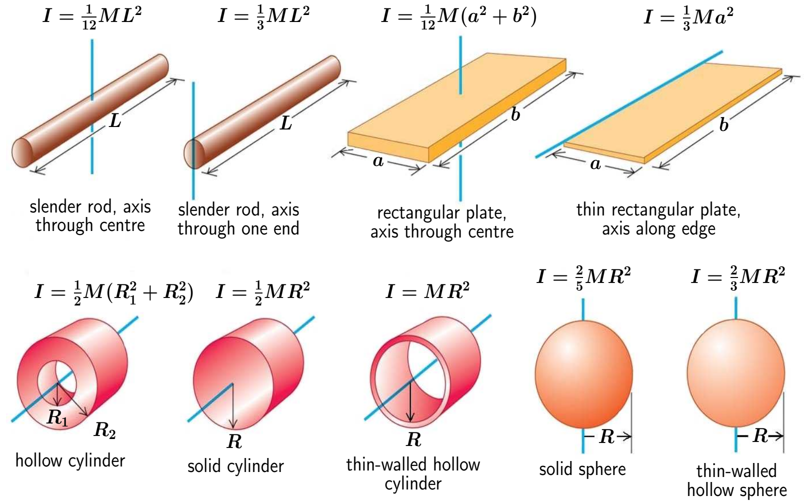
1^{st}:



2^{nd}: $\vec{r}\times\vec{v} = \text{constant}$

3^{rd}: $T = \dfrac{2\pi a^{3/2}}{\sqrt{GM}}$

Moments of inertia:



⇝ For a point-like particle of mass M a distance R from the axis of rotation: $I = MR^2$

⇝ Parallel axis theorem: $I_p = I_{\text{cm}} + Md^2$

Periodic motion:

$$\omega = 2\pi f = 2\pi/T$$

$$\text{pendulum:}\quad T = 2\pi\sqrt{L/g} = 2\pi\sqrt{I_P/mgd}$$

$$\text{spring:}\quad T = 2\pi\sqrt{m/k}$$

$$\text{torsion:}\quad T = 2\pi\sqrt{I/\kappa}$$

Simple harmonic motion: $\dfrac{d^2x}{dt^2} + \omega^2 x = 0$

$$\Leftrightarrow \quad a(t) = -\omega^2 x(t)$$

$$\text{or} \quad \alpha(t) = -\omega^2 \theta(t)$$

$$x(t) = A\cos(\omega t + \phi_0)$$

$$v(t) = -\omega A\sin(\omega t + \phi_0)$$

$$a(t) = -\omega^2 A\cos(\omega t + \phi_0)$$

C.2 Don’t Panic

No formula sheet is provided to students enrolled in the DP flavor of IP Mechanics at TAMU. Students are expected to be able to recall and use a limited number of important formulae from the text.

C.3 Transfer

The following pages contain reprinted copies of the equation sheet available to students taking the Transfer flavor of IP Mechanics at Blinn College, a local two-year institution frequently attended by TAMU students [110].

Physics 2425 - Formula List

1D Kinematics

General 1D Motion: x as a function of t

$$\bar{v} = \frac{\Delta x}{\Delta t}. \quad v = \frac{dx}{dt}, \quad \bar{a} = \frac{\Delta v}{\Delta t}. \quad a = \frac{dv}{dt}$$

Constant Vel.: $x(t) = x_0 + v\,t \implies \Delta x = v\,t$

Constant Acc.: $v(t) = v_0 + a\,t$ and $x(t) = x_0 + v_0\,t + \frac{1}{2}\,a\,t^2$

$$v = v_0 + a\,t \qquad \Delta x = \frac{1}{2}\,(v_0 + v)\;t$$

$$\Delta x = v_0\,t + \frac{1}{2}\,a\,t^2 \qquad v^2 - v_0^2 = 2\,a\,\Delta x$$

Free Fall : $x \to y$ (y is up) and $a = -g$

General Vectors $\vec{A} = A_x\,\hat{x} + A_y\,\hat{y} = \langle A_x, A_y \rangle$

Mag. & Dir. angle $\implies$ Components $A_x = A\cos\theta$ and $A_y = A\sin\theta$.

Components $\implies$ Mag. & Dir. angle

$$A = \sqrt{A_x^2 + A_y^2} \text{ and } \theta = \begin{cases} \tan^{-1}\left(\frac{A_y}{A_x}\right) & \text{for } A_x > 0 \\ 180\,° + \tan^{-1}\left(\frac{A_y}{A_x}\right) & \text{for } A_x < 0 \end{cases}$$

General 2D Kinematics $\vec{r}$ as a function of t

$$\bar{\vec{v}} = \frac{\Delta\vec{r}}{\Delta t}\,, \quad \vec{v} = \frac{d\vec{r}}{dt}\,, \quad \bar{\vec{a}} = \frac{\Delta\vec{v}}{\Delta t}\,, \quad \vec{a} = \frac{d\vec{v}}{dt}, \quad \text{Ave. Speed} = \frac{\text{Total Distance}}{\text{Total Time}}$$

Constant Acc.: $\vec{v}(t) = \vec{v}_0 + \vec{a}\,t$ and $\vec{r}(t) = \vec{r}_0 + \vec{v}_0\,t + \frac{1}{2}\,\vec{a}\,t^2$

Projectiles

Horizontal: $a_x = 0 \implies v_x$ is const. Vertical: $a_y = -g$

$v_{0x} = v_0\cos\theta$ and $v_{0y} = v_0\sin\theta$.

$$R = \frac{{v_0}^2}{g}\sin(2\,\theta), \quad (R = \Delta x \text{ when } \Delta y = 0)$$

Relative Motion $\vec{v} = \vec{v}\,' + \vec{v}_0$

Newton's Laws

First Law: $\vec{v}$ is const., unless net force.

Second Law: $\vec{F}_{\text{net}} = m\,\vec{a}$

Third Law: $\vec{F}_{12} = -\vec{F}_{21}$

Weight $\propto$ Mass: $W = m\,g$

Friction between surfaces $f_s \le \mu_s\,N$ (static), $f_k = \mu_k\,N$ (kinetic)

Circular Motion

Uniform Circular Motion: $a_c = \frac{v^2}{r}$, Also $v = \frac{2\,\pi\,r}{T} \implies a_c = \left(\frac{2\,\pi}{T}\right)^2 r$

General Circular Motion: $a_c = \frac{v^2}{r}\,,\; a_t = \frac{dv}{dt}$

Accelerated Frames $\vec{g}_{\text{art}} = -\vec{a}$ (artificial gravity)

accelerated frame $\implies$ false force opposite acc.

Dot or Scalar Product

$$\vec{A}\cdot\vec{B} = A\,B\cos\theta \quad \text{where } A = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

$$\vec{A}\cdot\vec{B} = A_x\,B_x + A_y\,B_y + A_z\,B_z$$

Work $W = \int\vec{F}\cdot d\vec{r}$

const. force: $W = F\,\Delta x$ (1D) $W = \vec{F}\cdot\Delta\vec{r}$ (2D or 3D)

$W_{\text{grav}} = -m\,g\,\Delta y$ (work done by gravity)

$W = \int_{x_i}^{x_f} F(x)\,dx$ (variable force in 1D)

Springs: Hooke's Law and Work

$F = -k\,x$ (Hooke's Law), $W = -\frac{1}{2}\,k\left(x_f^2 - x_i^2\right)$

Work-Energy Theorem $W_{\text{net}} = \Delta K$

W_{net} (net work). $K = \frac{1}{2}\,m\,v^2$ (kinetic energy)

$\vec{F}$ is conservative $\iff 0 = \oint\vec{F}\cdot d\vec{r}$

conservative forces $\implies \Delta U = -W$ (U is potential energy)

Gravity: $U = m\,g\,y$ Spring: $U = \frac{1}{2}\,k\,x^2$

W_{nc} is work of all nonconservative forces.

$E = E^{\text{mech}} = K_{\text{tot}} + U_{\text{tot}} \implies E_i + W_{\text{nc}} = E_f,\; W_{\text{nc}} = 0 \implies E_i = E_f$

$W_{\text{nc}} = 0$, one mass, gravity is only cons. force

$\implies E_{\text{bottom}} = E_{\text{top}} \implies v_{\text{bottom}}^2 = v_{\text{top}}^2 + 2\,g\,h$

Power: $\mathcal{P} = \frac{dW}{dt} = \vec{F}\cdot\vec{v}$

Potential Energy $\implies$ Force

1D: $F = -\frac{d}{dx}\,U$, 3D: $F_x = -\frac{\partial}{\partial x}\,U\,, F_y = -\frac{\partial}{\partial y}\,U\,, F_z = -\frac{\partial}{\partial z}\,U$

Momentum and Impulse-Momentum Theorem

$\vec{p} = m\,\vec{v}$ (mom.) $\vec{I} = \int_{t_i}^{t_f}\vec{F}\,dt$ (impulse)

$$\bar{\vec{F}}_{\text{net}}\,\Delta t = \vec{I}_{\text{net}} = \Delta\,\vec{p} = m\left(\vec{v}_f - \vec{v}_i\right)$$

Center of Mass for a System of Particles

Discrete : $M = \sum_i m_i$ $\qquad \vec{r}_{\text{cm}} = \frac{1}{M}\sum_i m_i\,\vec{r}_i$

Continuous : $M = \int dm$ $\qquad \vec{r}_{\text{cm}} = \frac{1}{M}\int\vec{r}\,dm$

Second Law for a Particle and System

particle : $\vec{F}_{\text{net}} = m\,\vec{a}$ $\qquad \vec{F}_{\text{net}} = \frac{d}{dt}\vec{p}$

system : $\vec{F}_{\text{net}}^{\text{ext}} = M\,\vec{a}_{\text{cm}}$ $\qquad \vec{F}_{\text{net}}^{\text{ext}} = \frac{d}{dt}\vec{p}_{\text{tot}}$

$$\vec{p}_{\text{tot}} = m_1\,\vec{v}_1 + m_2\,\vec{v}_2 + \ldots = M\,\vec{v}_{\text{cm}}$$

Conservation of Momentum

$\vec{F}_{\text{net}}^{\text{ext}} = 0 \implies \Delta\,\vec{p}_{\text{tot}} = 0 \implies \vec{p}_{\text{tot},i} = \vec{p}_{\text{tot},f}$

$F_{\text{net},x}^{\text{ext}} = 0 \implies \Delta p_{\text{tot},x} = 0 \implies p_{\text{tot},i,x} = p_{\text{tot},f,x}$

Collisions

$\vec{p}_{\text{tot},i} = \vec{p}_{\text{tot},f} \implies m_1\,\vec{v}_{1i} + m_2\,\vec{v}_{2i} = m_1\,\vec{v}_{1f} + m_2\,\vec{v}_{2f}$

Elastic $\iff K_{\text{tot},i} = K_{\text{tot},f}$

1D Elastic trick: $K_{\text{tot},i} = K_{\text{tot},f} \implies v_{1i} + v_{1f} = v_{2i} + v_{2f}$

Totally Inelastic: $\vec{v}_{1\,f} = \vec{v}_{2\,f} = \vec{v}_f \implies m_1\,\vec{v}_{1i} + m_2\,\vec{v}_{2i} = (m_1 + m_2)\,\vec{v}_f$

General Rotations about fixed axis:

$$\bar{\omega} = \frac{\Delta\theta}{\Delta t}\,, \quad \omega = \frac{d\theta}{dt}\,, \quad \bar{\alpha} = \frac{\Delta\omega}{\Delta t}\,, \quad \alpha = \frac{d\omega}{dt}$$

Constant Angular Accelation

$$\omega = \omega_0 + \alpha\,t \qquad \Delta\theta = \frac{1}{2}\,(\omega + \omega_0)\,t$$

$$\Delta\theta = \omega_0\,t + \frac{1}{2}\,\alpha\,t^2 \qquad \omega^2 - \omega_0^2 = 2\,\alpha\,\Delta\theta$$

■ Rotational and Linear Quantities

$\vec{v} = r\,\omega\,\hat{u}_t$ or $v_t = r\,\omega$, $v_c = 0$

$\vec{a} = r\,\alpha\,\hat{u}_t + \omega^2 r\ \hat{u}_c$ or $a_t = r\,\alpha$, $a_c = \omega^2 r$

$\alpha = 0 \iff \omega = \text{const} = \frac{2\pi}{T}$

■ Moment of Inertia

I for a distribution - r is $\perp$ dist. from axis

Discrete: $I = \sum m_i r_i^2$, Continuous: $I = \int r^2\,dm$

Perpendicular-axis Theorem: Planar object in xy-plane: $I_z = I_x + I_y$

Parallel-axis Theorem: $I = I_{\text{cm}} + M\,d^2$

Moments for uniform bodies:

Thin rod about $\perp$ axis

thru. end: $I = \frac{1}{3} M L^2$, thru. center: $I = \frac{1}{12} M L^2$

$a \times b$ rectangular plate about $\perp$ axis thru. center: $I = \frac{1}{12} M\left(a^2 + b^2\right)$

Sphere about axis thru. center:

thin shelled hollow: $I = \frac{2}{3} M R^2$, solid: $I = \frac{2}{5} M R^2$

Hoop about $\perp$ axis thru. center: $I = M R^2$
(same as thin-shelled hollow cylinder)

Disk about $\perp$ axis thru. center: $I = \frac{1}{2} M R^2$ (same as solid cylinder)

■ Rotational Energy

$K = \frac{1}{2} I\,\omega^2$, $U = M\,g\,y_{\text{cm}}$, $K_{\text{tot}} = \frac{1}{2} I_{\text{cm}}\,\omega^2 + \frac{1}{2} M\,v_{\text{cm}}^2$

■ Cross or Vector Product $\vec{A}\times\vec{B} = \hat{u}\,A\,B\sin\theta$, right hand rule ⇒ $\hat{u}$

$$\vec{A}\times\vec{B} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix} = \hat{x}\begin{vmatrix} A_y & A_z \\ B_y & B_z \end{vmatrix} - \hat{y}\begin{vmatrix} A_x & A_z \\ B_x & B_z \end{vmatrix} + \hat{z}\begin{vmatrix} A_x & A_y \\ B_x & B_y \end{vmatrix}$$

■ Torque

About Origin: $\vec{\tau} = \vec{r}\times\vec{F}$, About Axis: $\tau = r\,F_\perp = r_\perp F = r\,F\sin\theta$

Torque due to gravity: $\vec{\tau}_{\text{gravity}} = \vec{r}_{\text{cm}}\times M\,\vec{g}$

■ Angular Momentum of Particle

About Origin: $\vec{L} = \vec{r}\times\vec{p}$, About Axis: $L = r\,p_\perp = r_\perp\,p = r\,p\sin\theta$

■ General Rigid Body Dynamics

2nd Law: $\tau_{\text{net}} = I\,\alpha$ and $\tau_{\text{net}} = \frac{dL}{dt}$

Angular Momentum: $L = I\,\omega$

■ System of Particles $\vec{\tau}_{\text{net}}^{\text{ext}} = \frac{d\vec{L}_{\text{tot}}}{dt}$

$\vec{\tau}_{\text{net}}^{\text{ext}} = 0 \implies \Delta\vec{L}_{\text{tot}} = 0$ (Conservation)

■ Equilibrium $\vec{F}_{\text{net}} = \vec{0}$ and $\vec{\tau}_{\text{net}} = \vec{0}$

■ Newton's Law of Gravity

Magnitude: $F = G\,\frac{m_1 m_2}{r^2}$, Vector: $\vec{F}_{21} = -G\,\frac{m_1 m_2}{r_{12}^2}\,\hat{r}_{12}$

Discrete Distribution: $\vec{F} = -G\,m\sum\frac{m_i}{r_i^2}\,\hat{r}_i$

Continuous Distribution: $\vec{F} = -G\,m\int\frac{\hat{r}}{r^2}\,dm$

Sph. Shell: $F = G\,\frac{M\,m}{r^2}$ $(r > R)$, $F = 0$ $(r < R)$

$g = G\,\frac{M}{R^2}$ (at surface of spherical planet)

■ Gravitational Potential Energy

Two masses: $U = -G\,\frac{M\,m}{r}$, Several masses: $U = -G\sum_{i<j}\frac{m_i m_j}{r_{ij}}$

Escape speed: $v_{\text{esc}} = \sqrt{\frac{2\,G\,M}{R}}$

■ Circular Orbits $v^2 = G\,\frac{M}{r}$ and $T^2 = \frac{4\pi^2}{G\,M}\,r^3$

■ Simple Harmonic Motion $\frac{d^2x}{dt^2} = -\omega^2 x$, $\omega = 2\pi f = \frac{2\pi}{T}$

$x(t) = A\cos(\omega t + \phi) = x_0\cos\omega t + \frac{v_0}{\omega}\sin\omega t$

■ Energy $E = \frac{1}{2} m\,v^2 + \frac{1}{2} k\,x^2 = \begin{cases} \frac{1}{2} k\,A^2 \\ \frac{1}{2} m\,v_{\text{max}}^2 \end{cases}$ (mass/spring)

$v = \pm\omega\sqrt{A^2 - x^2}$ and $v_{\text{max}} = \omega\,A$ (in general)

■ Examples of Simple Harmonic Motion

Mass/Spring: $\omega = \sqrt{k/m}$

Physical Pendulum: $\omega = \sqrt{m\,g\,d/I}$

Simple Pendulum: $\omega = \sqrt{g/L}$

■ 1D Wave Equation $\frac{\partial^2}{\partial x^2}u = \frac{1}{v^2}\frac{\partial^2}{\partial t^2}u$

General Solution: $u(x,t) = f(x - v\,t) + g(x + v\,t)$

■ Sinusoidal Waves $u(x,t) = A\cos(k\,x \pm \omega\,t + \phi)$

$\lambda = \frac{2\pi}{k}$, $f = \frac{\omega}{2\pi}$, $v = f\,\lambda = \frac{\omega}{k}$

■ Waves on a String $u(x,t) \Rightarrow y(x,t)$

Speed: $v = \sqrt{T/\mu}$ where T = Tension, Power: $\mathcal{P} = \frac{1}{2}\mu\,v\,\omega^2 A^2$

■ Temperature Scales

$T_F = \frac{9}{5} T_C + 32$, $\Delta T_F = \frac{9}{5}\Delta T_C$, $T_K = T_C + 273$

■ Heat Q = Heat added to system

$Q = m\,c\,\Delta T$ (Temp. change), $Q = \pm m\,L$ (phase change)

■ Ideal Gas Law $P\,V = N\,k\,T$ and $P\,V = n\,R\,T$

n = # of moles, $N = N_A\,n$ = # of molecules

Masses: $m_{\text{tot}} = n\,m_{\text{mole}} = N\,m_{\text{molecule}}$

■ Work $W = \int P\,dV = \pm\text{Area}$ (done by system)

Constant P: $W = P\,\Delta V$,

Ideal gas at constant T: $W = n\,R\,T\ln(V_{\text{f}}/V_{\text{i}})$

■ First Law

$\Delta U = Q - W$, $dU = \delta Q - \delta W$, (δ is inexact differential)

■ Entropy $dS = \frac{\delta Q}{T} \implies \Delta S = \int\frac{\delta Q}{T}$

Const. T: $\Delta S = \frac{Q}{T}$, Changing T: $\Delta S = m\,c\ln\frac{T_{\text{f}}}{T_{\text{i}}}$

■ Second Law For a thermally isolated system: $\Delta S_{\text{tot}} \geq 0$

■ Heat Engines $Q_H = Q_C + W$, Efficiency: $e = \frac{W}{Q_H} = 1 - \frac{Q_C}{Q_H}$

Max. Eff.: $e_{\text{max}} = 1 - \frac{T_C}{T_H}$ (Carnot Engine is H.E. of max. eff.)

APPENDIX D

PHYSICS CONCEPTS & MATHEMATICAL SKILLS

This appendix contains a detailed list, with descriptions, of all the physical concepts and mathematical skills which were used in the q-matrix evaluation of courses for Chapter 3. This list was created through discussions between a former graduate student within the Department of Physics & Astronomy at TAMU, Landon Chambers, and various engineering faculty. The physical concepts present on this list represent the topics both major and minor covered during the course of IP Mechanics, regardless of the flavor taken. Mathematical skills present represent the majority of the necessary math used in the solution of problems beyond introductory algebra. Some simple skills (*e.g.* addition/subtraction, multiplication/division, solve a single equation for a single variable) have been omitted from this list.

D.1 Physical Concepts

1. Position/Velocity/Acceleration- Relating one of the quantities of position, velocity, or acceleration to any of the other quantities. This includes average quantities in addition to kinematic motion.

2. One-dimensional Motion- A change of position or velocity of an object due to constant or non-constant acceleration which may be described with a single unit vector.

3. Two-dimensional Motion- A change of position or velocity of an object due to constant or non-constant acceleration which may be described through two unit vectors.

4. Relative Motion, Velocity- Calculating the velocity of one or more objects in a different reference frame relative to the initial value(s) given.

5. Relative Motion, Acceleration- Calculating the acceleration of one or more objects in a different reference frame relative to the initial value(s) given.
6. Newton's 1^{st} Law- An object in motion (or at rest) will tend to stay in motion (or at rest) unless acted upon by an unbalanced force. This concept sometimes permits students to determine themselves whether the acceleration of an object or system is zero.
7. Newton's 2^{nd} Law-Summing the forces on an object or system and relating them to the product of the mass and the acceleration of the same object or system, $\vec{F} = m\vec{a}$.
8. Newton's 3^{rd} Law- For every action there is an equal, but opposite, reaction. To employ this, a problem must require the application of forces between two bodies to both be accounted for.
9. Newtonian Gravity- Applying the fundamental form of the gravitational force $\vec{F}_g = G\frac{m_1 m_2}{r^2}\hat{r}$.
10. Gravity Near Earth- The weight force on an object with a certain mass, using the approximation of acceleration due to gravity at the surface of Earth. This non-contact force has the form $w = mg$, where $g = 9.8m/s^2$ or $g = 32.2ft/s^2$, depending on the units used in a problem.
11. Unknown Reaction Force- A normal force present within a system that has an unknown magnitude and direction due to a combination of other forces present within the system.
12. Friction- A contact force applied at the contact point between two surfaces which resists relative (or attempted relative) motion between the surfaces. This force may

be *static friction* ($f_s \leq \mu_s N$) or kinetic friction ($f_k = \mu_k N$), where N is the normal force applied where the two surfaces meet.

13. Hooke's Law- A law describing the resulting force due to displacement from an equilibrium position of a spring, or other system that can be said to have a *spring-like force*. In equation form, this law is $\vec{F}_{sp} = -k\vec{x}$, where $\vec{x}$ is the vector displacement from an equilibrium position.

14. Tension- A contact force which is applied to an object through a rope, cable, string or similar type object, which exerts a force along the material.

15. Free-Body Diagram- A sketch of an object of system with labeled vectors representing all contact and non-contact forces acting on that object or system.

16. Work- Applying the equation $W = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r}$ to a force or forces within a system. Simplifications of this fundamental equation, $W = \vec{F} \cdot \vec{r}$, or $W = Fdcos(\theta)$ are included in this concept.

17. Work-Energy Theorem- Applying the law $W_{total} = \Delta K$, where the left-hand side is the total work due to the net force ($W_{total} = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F}_{net} \cdot d\vec{r}$) and the right-hand side is the change of kinetic energy ($\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$).

18. Kinetic Energy- Quantifying the energy of motion for an object or system using the *translational kinetic energy* ($K = \frac{1}{2}mv^2$) and/or the *rotational kinetic energy* ($K = \frac{1}{2}I\omega^2$).

19. Potential Energy- Quantifying the energy of position for an object or system using the *gravitational potential energy* ($U = mgy$), the *spring potential energy* ($U = \frac{1}{2}kx^2$), or relating the potential energy function to a conservative force ($U = -\int \vec{F} \cdot d\vec{r}$).

20. Conservation of Energy- Relation of the energy at one physical state (point) in a problem to the energy of another physical state. The energy at either point is the sum of the energy of motion (kinetic) and the energy of position (potential), $E = K + U$. The conservation law then follows the form $K_i + U_i + W_{NC} = K_f + U_f$, where W_{NC} is the work done by *non-conservative forces* between the initial and final points.

21. Power- The rate at which work is used within a system. This include calculation using either $P = \frac{W}{t}$ or $P = \vec{F} \cdot \vec{v}$, where W is the work, t is the time, $\vec{F}$ is a constant force, and $\vec{v}$ is a constant velocity.

22. Conservation of Linear Momentum- Application of the fact that $\vec{p}_{system} = constant$ for problems in which the external force is zero ($\vec{F}_{system} = 0$). Typically this equation is seen applied as $\Sigma \vec{p}_{i,before} = \Sigma \vec{p}_{i,after}$.

23. Moments/Torques- Application of the equation $\vec{\tau} = \vec{r} \times \vec{F}$ to calculate the torque due to a single force.

24. Moment of Inertia- Determining the moment of inertia of a body or system using direct calculation, formulae, or solving for it through a system of equations.

25. Parallel-Axis Theorem- Calculation of the moment of inertia of some body for an axis of rotation parallel to an axis about which there is a known moment of inertia for the object, $I_{par} = I_0 + md^2$.

26. $\Sigma \tau = I\alpha$- Using the sum of torques applied to a system to determine either the angular acceleration of a system, or the moment of inertia.

27. Center of Mass- Finding the geometric center of mass of a system or distribution using some form of the following: $\vec{r}_{cm} = \frac{\Sigma m_i \vec{r}_x}{\Sigma m_i}$, $\vec{r}_{cm} = \frac{\int \vec{r} \rho(\vec{r}) dr}{\int \rho(\vec{r}) dr}$.

28. ω & α- Employing the definitions of $\omega = \frac{d\theta}{dt}$ and $\alpha = \frac{d\omega}{dt}$.

29. Radial acceleration- Use of the centripetal acceleration within the solution of the problem, $a_r = \frac{v^2}{r}$ or $a_r = r\omega^2$.

30. Rotational Motion- A change of the angular position or angular velocity due to a constant or non-constant angular acceleration.

31. Rolling without Slipping- The point of contact between two bodies does not slip or slide while one body rotates. This condition permits the use of simple relations between *translation* and *angular* variables using $s = r\theta$, $v = r\omega$, and $a = r\alpha$.

32. Conservation of Angular Momentum- Application of the fact that $\vec{L}_{system} = constant$ for problems in which the external torque is zero($\vec{\tau}_{system} = 0$). Typically this equation is seen applied as $\Sigma\vec{L}_{i,before} = \Sigma\vec{L}_{i,after}$.

33. Simple Harmonic Motion (SHM)- Periodic motion of an object or system where the restoring force is directly proportional to the displacement, acting in the opposite direction of that displacement. The amplitude (maximum displacement) of this motion is constant.

34. Damped Oscillations- A system undergoing oscillatory motion in which a frictional type force is applied in addition to the restoring force of the system. The amplitude of such systems decreases depending on whether the system is underdamped, *critically damped*, or *overdamped*.

35. Forced Oscillations- A system undergoing oscillatory motion in which a driving force (constant or time-dependent) is applied to the system.

36. Natural Frequency- Using the relation of $\omega = \sqrt{\frac{k}{m}}$ (spring-mass systems), $\omega = \sqrt{\frac{g}{L}}$ (point-mass pendulums), or $\omega = \sqrt{\frac{I}{mgd}}$ (physical pendulums) for a problem in which oscillatory motion appears.

D.2 Mathematical Skills

37. Define Coordinates- Used when the solution to a problem requires a student to define their own system of axes to non-trivially combine vector quantities.

38. Cartesian Coordinates- A system that defines each point uniquely in a plane by a pair of numerical (or symbolic) coordinates which are signed distances to the point from two, fixed, perpendicular directed lines.

39. Polar Coordinates- A system that defines each point uniquely in a plane by a pair of numerical (or symbolic) coordinates which are the magnitude of the distance from the origin (radial coordinate) and a polar coordinate measuring angular distance from a certain direction defined as the zero angle (*e.g.* the positive x-axis from a Cartesian Coordinate system).

40. Vectors- A way of numerically or symbolically representing a quantity which must be expressed with both magnitude and direction. The particular use here includes any form of representation of multiple components of a vector within a single equation or line of math. Typically this involves the use of unit vectors in the Cartesian or Polar Coordinate systems.

41. Dot Product- Also known as the *scalar product*, this measures how much of one vector is parallel to another. In equation form, this means applying some combination of the definition $\vec{A} \cdot \vec{B} = ABcos(\theta) = A_x B_x + A_y B_y$.

42. Cross Product- Also known as the *vector product*, this measures how much of one vector is perpendicular to another. In equation form, this means applying some combination of the definition $|\vec{A} \times \vec{B}| = ABsin(\theta)$, where the direction is given by the right hand rule, or evaluated with unit vectors.

43. Geometry/Trig- The application of geometric or trigonometric rules to shapes and angles. The most common form of this involves using trigonometric functions such as $sine, cosine$, and $tangent$. Inverse trigonometric functions, areas, and volumes are also included in this.

44. Differentiation- Taking the derivative, $\frac{d}{dx}f(x)$, of any function. This includes but is not limited to application of derivative rules such as: $\frac{d}{dx}kx^n = knx^{n-1}$, $\frac{d}{dx}cos(x) = -sin(x)$, and chain rules ($\frac{d}{dx}f(g(x)) = f'(g(x))g'(x)$).

45. Integration- Applying the integral operator to a function, $\int f(x)dx$. This is the inverse mathematical operation of differentiation.

46. Simultaneous Equations- Solving for two or more variables using a system of two or more equations. Employing a substitution for one unknown to find the answer.

47. 1^{st} Order ODE- An equation of a form such as $\frac{dy}{dx} + p(x)y = q(x)$ in which the student is expected to solve for $y(x)$, or verify the validity of a given solution with undetermined coefficients.

48. 2^{nd} Order ODE- An equation of a form such as $\frac{d^2y}{dx^2} + p(x)\frac{dy}{dx} + q(x) = r(x)$ in which the student is expected to solve for $y(x)$, or verify the validity of a given solution with undetermined coefficients.

49. Small angle approximation- Taking the first term of a Taylor Series expansion as a substitution for the original function (*e.g.* $sin(x) \approx x$, $cos(x) \approx 1$).

50. Interpretation/Sketch Graph- Using the points or function of a graph to yield information about a physical quantity, or using an equation derived from physical relations to plot points or a function on a coordinate plane.

51. Find Limiting Case- Letting one or more variables tend towards a maximum or minimum value to find a convergent value for an equation.

APPENDIX E

FRESHMAN PHYSICS CLASSROOM- ELECTRICITY & MAGNETISM VIDEO LIST

This appendix contains a list of the videos created for the E&M content of the FPC resource. Each video is accompanied by a brief description of the content, along with its direct link to Vimeo.

Coulomb’s Law

Conceptual

An introduction video on the concept of Coulomb’s Law.

`https://vimeo.com/200217386/27fd15d164`

Example Problem #1

A basic example of the application of Coulomb’s Law to a series of point charges, include the principle of superposition.

`https://vimeo.com/200217747/1a4a198ca4`

Example Problem #2

An application of Coulomb’s Law to a charge distributed along the horizontal axis.

`https://vimeo.com/200218101/9b73383dc2`

Electric Field

Conceptual

An introduction to the somewhat complex topic of electric fields and their calculation.

`https://vimeo.com/200751073/b11c4f18d1`

Example Problem #1

An example problem on calculating the electric field of two point charges in a dipole arrangement.

`https://vimeo.com/200751358/5a2c61839d`

Example Problem #2

Example for finding the electric field due to a charge distributed along the arc of a quarter circle.

`https://vimeo.com/200751524/b753914436`

Electric Potential

Conceptual

A brief overview of the definition of electric potential.

`https://vimeo.com/200253867/8aa90683ba`

Example Problem #1

Obtaining the electric potential function from a given electric field.

`https://vimeo.com/200254133/034d99cccd`

Example Problem #2

Determining the electric potential function due to a point charge.

`https://vimeo.com/200254490/730499cae2`

Example Problem #3

Here the important steps are shown for finding the electric potential function for a charge distributed along the horizontal axis.

`https://vimeo.com/200254934/6b060d4f4e`

Flux/Gauss' Law

Conceptual

An introduction to the idea of finding the quantity flux from a vector field.

`https://vimeo.com/202770675/a7d9e9d25d`

Flux Example Problem #1

A basic example of the application of finding flux from a vector field, using a cube.

`https://vimeo.com/202771096/0f16d2b61c`

Flux Example Problem #2

An example of finding the flux due to a radially symmetric vector field through the surface of a sphere. `https://vimeo.com/202771476/c042124440`

Gauss Example Problem #1

Application of Gauss' Law to find the electric field both inside, and outside a sphere with uniform charge distribution.

`https://vimeo.com/202771804/20668dde82`

Gauss Example Problem #2

Finding the electric field for a infinite line of charge using cylindrical symmetry in Gauss' Law.

`https://vimeo.com/202772391/fd8c72a432`

Capacitors

Conceptual

An introduction to the use of capacitors, and the definition of capacitance.

`https://vimeo.com/205302045/3a28fd91d1`

Example Problem #1

Calculating the capacitance of large, parallel, conducting plates.

`https://vimeo.com/205302744/df09f91f35`

Example Problem #2

Calculating the capacitance for two nested conducting spheres.

`https://vimeo.com/205303299/f8a3f16baf`

Ohm's Law

Conceptual

An introduction to two definitions of Ohm's Law.

`https://vimeo.com/205620976/84a6e3929d`

Example Problem #1

An application of Ohm's Law for a resistivity which depends on position for a cylindrical resistor.

`https://vimeo.com/205621308/7810f475cb`

Example Problem #2

Calculating the resistance of a resistor in the shape of a spherical shell, with a constant resistivity.

`https://vimeo.com/205621563/4898149fa1`

Simple Circuits

Conceptual

An introduction to the analysis of simple, time independent circuits.

`https://vimeo.com/207125650/e4f9bb49d4`

Example Problem #1

An application of the simple circuits equations to two resistors in series.

`https://vimeo.com/207126187/68b6f926c4`

Example Problem #2

An application of the simple circuits equations to two resistors in parallel.

`https://vimeo.com/207126504/e1355db2ac`

Example Problem #3

Application of the simple circuits equations to a circuit with a resistor, and a capacitor in parallel with each other.

`https://vimeo.com/207328392/711ac14e40`

Magnetic Forces

Introduction to the magnetic force equations, and how to determine the direction of the force using the right hand rule.

`https://vimeo.com/210263546/990ffd0dd2`

Example Problem #1

An application of magnetic forces to a charged particle moving in a region of constant magnetic field.

`https://vimeo.com/210263946/7a7b08f0fa`

Example Problem #2

Application of the magnetic force equations to three straight segments of a current carrying wire.

`https://vimeo.com/210271150/e1a7c9348b`

Biot-Savart Law

Here Biot-Savart Law is introduced. This law is one of two ways to determine the magnetic field generated due to a current carrying wire.

`https://vimeo.com/210286143/41c80a2415`

Example Problem #1

An application of the Biot-Savart Law finding the magnetic field at the center of a semi-circular section of a current carrying wire.

`https://vimeo.com/210286478/0dd87455a1`

Ampere's Law

An introduction to the application of Ampere's Law for finding the magnetic field around current carrying wires with particular symmetries.

`https://vimeo.com/211345785/8586b23408`

Example Problem #1

Using Ampere's Law to find the magnitude of the magnetic field in the middle of two infinitely long, parallel, current carrying wires.

`https://vimeo.com/211352708/fb62b1dcbd`

Example Problem #2

Using Ampere's Law to find the magnetic field for a cylindrical, current carrying wire in all regions.

`https://vimeo.com/211355118/62f5f44c40`

Faraday's Law

Conceptual

An introduction to the concept of electromagnetic induction, and Faraday's Law.

`https://vimeo.com/212314437/db3e2447bc`

Example Problem #1

Applying Faraday's law to a loop, containing a resistor, out of a region of constant magnetic field.

`https://vimeo.com/212315420/25863d5f94`

Example Problem #2

A walk through of the steps to apply Faraday's Law to a small loop, containing a resistor near an infinitely long, current carrying wire.

`https://vimeo.com/212603017/93d0c0e106`

Time-Dependent Circuits

Conceptual

Explains the application of Faraday's Law to circuits containing voltage sources, resistors, capacitors, and inductors. When correctly applied Faraday's Law gives a time dependent differential equations for which the charge, or current may be solved for as a function of time.

`https://vimeo.com/213125533/a6d1bfd4f4`

Example Problem #1

Applying Faraday's Law to a circuit containing a charged capacitor, and a resistor in order to find the charge as a function of time.

`https://vimeo.com/213125925/ab412909c7`

Example Problem #2

Applying Faraday's Law to a circuit containing a voltage source, resistor, and inductor, in order to solve for the current as a function of time.

`https://vimeo.com/213126027/d9cdd24f81`

Example Problem #3

Using Faraday's Law to find the charge as a function of time for a circuit containing a charged capacitor, and an inductor.

`https://vimeo.com/213252245/bbbbb94ef2`