Exploring Introductory University Mechanics Programs

An Interactive Qualifying Project Report

submitted to the Faculty

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WORCESTER POLYTECHNIC INSTITUTE

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Degree of Bachelor of Science

by

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Executive Summary

1. Motivation

- The IUPP (Introductory University Physics Project) report obtained the results shown in **Figure 1**

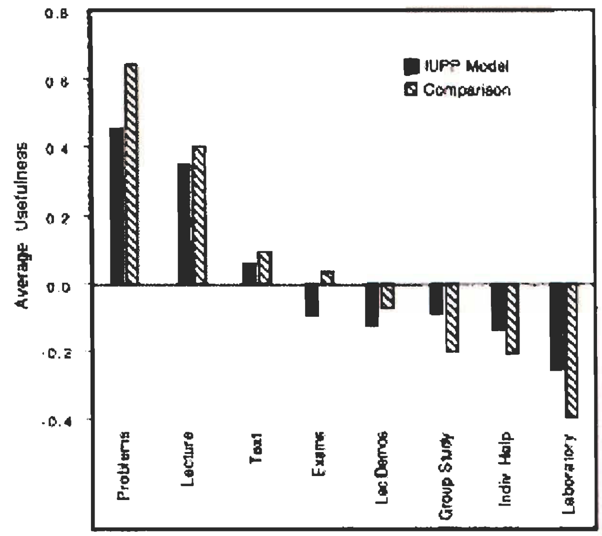

Figure 1[1]: Students at five different institutions were given a questionnaire asking them to rate the average usefulness of different aspects of introductory mechanics courses. Results are displayed above.

- The figure illustrates that **students feel** that **lecture and homework** are of primary importance in teaching introductory physics.
- I conducted a literature search that found **very little research material** devoted to the use of **homework** in teaching introductory mechanics.

2. Objective

- My objective was to study the online course material of introductory mechanics courses taught at eight different universities.
- The data is presented in tabulated form and also compares WPI's program to the other schools.

3. Qualitative Results

Relative to the Schools I Examined:

- WPI, despite being on a term based system, covers the **same core topics** as the others.
- WPI assigns the **most homework problems** per hour of class time.
- WPI has the **least class time**.
- WPI does not use calculus in their homework solutions.

4. Quantitative Results

- Over 60 megabytes of material was downloaded from the Internet. This material included syllabi and homework solutions for the eight universities.

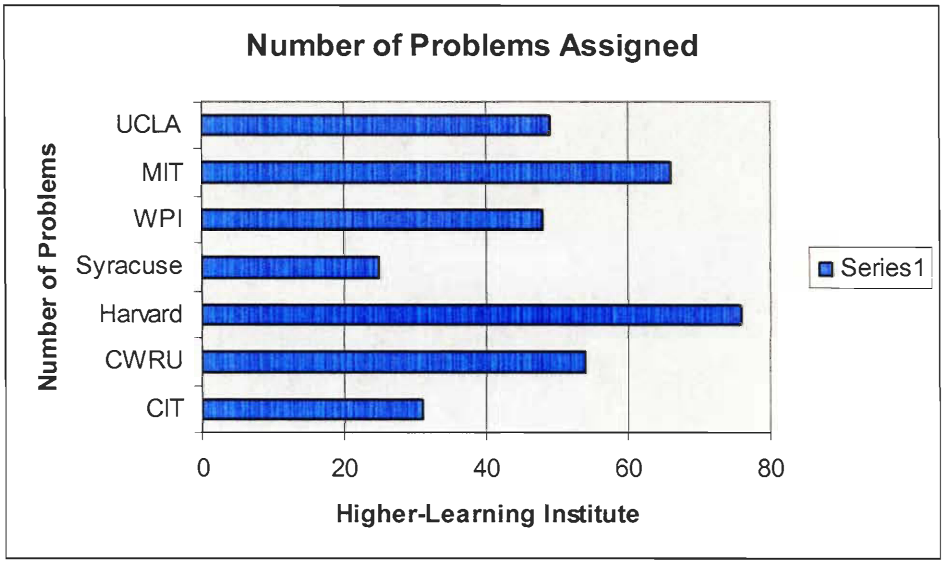

Figure 2: Total number of problems assigned for each higher-learning institute.

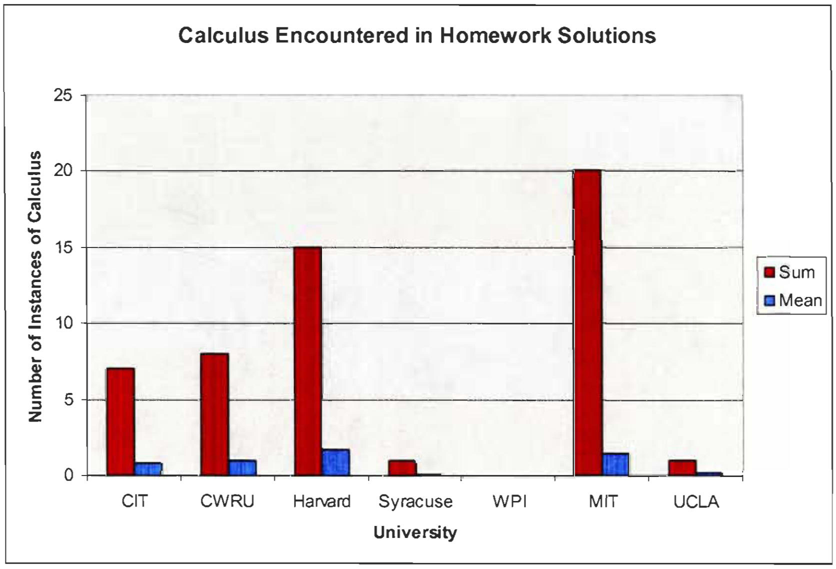

Figure 3: Calculus encountered in homework solutions at each school.

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1. Introduction

1.1 Introductory University Physics Project

In 1987, the physics community challenged itself to evaluate the introductory college mechanics curricula. This challenge was the origin of a project that became known as the Introductory University Physics Project (IUPP)[1]. Prior to the inception of this project, there were numerous inquiries into the state of introductory college mechanics courses. In 1956, a group of physicists gathered at the Carleton College Conference to discuss the current state of mechanics pedagogy[1]. At this conference the participants came to an interesting conclusion. They believed that teachers should drastically reduce the number of topics taught in mechanics courses. In addition, they touched on a few other aspects of teaching: content, apparatus, films, laboratory, examinations, and the teacher. Interestingly, there was no mention of homework in these conferences. In fact, it is evident that the physics community felt that the teacher should be the one shouldering the responsibility for failure in introductory mechanics.

The IUPP developed a set of premises related to the ideas set forth at prior conferences. The major points were as follows:

(1) The total course content should be reduced relative to the status quo.

(2) The course content should have coherence.

(3) Contemporary physics should be a prominent part of the course content.

From these premises, the IUPP developed four model courses that were tested at nine universities. The courses were "Structures and Interactions", "A Particles

Approach", "Physics in Context", and "Six Ideas that Shaped Physics" [1]. These model courses exemplify how research groups focus on the delivery of the course (teacher), opposed to practice and homework (student).

1.2 Additional Approaches to Introductory Mechanics Pedagogy and Homework

A literature search conducted during this research uncovered an interesting fact. The bulk of educational research is restricted to the structure of courses and how the teacher delivers the course. I found no instances of papers discussing how homework affects performance on exams and understanding of the material.

Journal Articles [2]	University Projects [3]	AAPT Projects [4]
224	20	6

Table 1: Time and effort expended on introductory university mechanics pedagogy since 2000.

Table 1 quantifies the efforts that have been dedicated to physics pedagogy. The majority of this effort has been focused on the delivery and content of the course. A publication describing the results of the IUPP opens with an introduction describing the concerns of physicists and educators:

> *First, research results demonstrate that the conceptual comprehension of students taking introductory physics falls significantly short of the hopes and expectations of physicists. Second, the content of the introductory course had become inflexible and standardized to the point of predictability. The quantity of material in the standard syllabus is burdensome and, as far as the student is concerned, arrayed as a sequence of topics without coherence [1].*

Other groups have focused on factors such as interactive engagement [5], semantics[6], “questions first approach”[7], use of computers[8], and demonstrations[9]. There is no doubt that each of these ideas contribute to the restructuring of a more efficient introductory physics course with respect to student cognition. However, all of these points tie into a broader problem, the engagement of the student with the material. An athlete trains his or her body with rigorous activity until the motions or activities become second nature. They train their bodies to react to stresses in an efficient manner, reflexes honed for success. This phenomenon is known as muscle memory. The student must train his or her brain in the same fashion, practicing problems until the material is knowledge. The majority of the literature is populated by papers suggesting that the teacher is responsible for the inadequacies of students in the course. Perhaps it is time to hold the student responsible for his or her success, requiring him or her to devote more out-of-class time to mastering the material.

1.3 Students' Viewpoint of the Importance of Homework

When the IUPP first began to assess the results of their plan, the project sent out a questionnaire to five institutions asking the students to rate the most important aspects of the respective course. Prior to this questionnaire, students taking either at traditional or IUPP course were asked to fill out weekly surveys. These surveys asked the students to rank, in terms of usefulness, different aspects of the course. Students were asked to assign numerical values (1-8; 8 being most useful) to entities like homework and the textbook. From these weekly questionnaires, a final figure was created depicting the average from these surveys. This is depicted below.

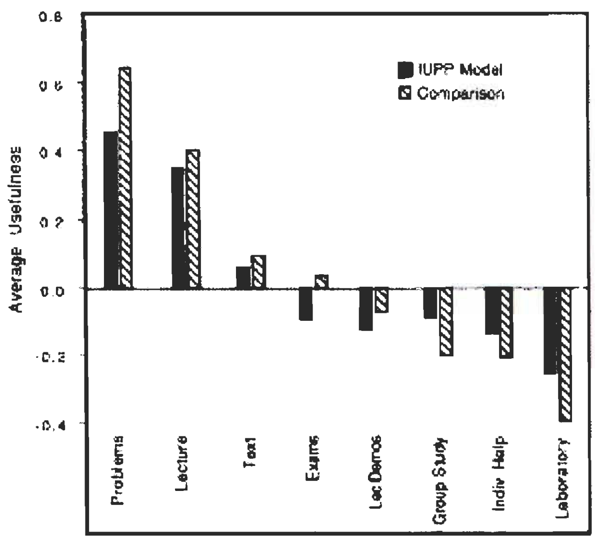

Figure 1: Figure depicting the average usefulness of different aspects of two different models of introductory physics. Values were collected and averaged from five different institutions. The vertical scale represents the fraction of students ranking the category either 1 or 2 (out of possible 8) minus the fraction ranking it 7 or 8. Thus a result of +.2 means that 20% more students ranked the category as a 1 or 2 than a 7 or 8. [1]

Students rated homework and lecture as the two most useful aspects of introductory mechanics pedagogy. This should come as no surprise considering that exams are usually the students' primary concern and exams usually reflect the students' ability to negotiate problems. However, what is surprising is that students did not rank any aspects of the course that utilize interactive engagement as useful. In fact, students ranked laboratory as the most useless part of their experience in introductory mechanics. This is exceptionally interesting considering that most of the literature discusses pedagogical methodologies with respect to interactive engagement. The above figure suggests that perhaps modern research in introductory mechanics teaching is misallocating its resources.

The scope of this paper is to analyze the course content and homework of eight introductory mechanics courses that satisfy the requirements for an engineering degree. The schools were chosen on a basis described below. This work presents an analysis of syllabi, homework, and topics covered. The research is presented in the form of a case-by-case analysis as well as a comparison.

2. Methodology

2.1 Higher-Learning Institute Selection

Initially, this project set out to analyze a large number of schools representing a broad cross-section of higher learning in the United States. Schools belonging to the Association of Independent Technological Universities (AITU) were especially important because they focus on and grant a large number of engineering degrees. In addition, the original scope also included schools that are Ivy League members, large state schools, and schools that promote the educational advancement of minorities. While these schools provide an excellent cross-section of higher education, most did not provide the content of their courses on the Internet. Without Internet content, there is no feasible or efficient way to analyze a number of mechanics courses.

University	**Reason for Exclusion**
Carnegie-Mellon University	Lack of Internet Resources
Clarkson University	Lack of Internet Resources
Cooper Union for the Advancement of Science and Art	Lack of Internet Resources
Drexel University	Lack of Internet Resources
Harvey Mudd College	Lack of Internet Resources
Illinois Institute of Technology	Lack of Internet Resources
Kettering University	Lack of Internet Resources
Milwaukee School of Engineering	Lack of Internet Resources
Polytechnic University	Lack of Internet Resources
Rochester Institute of Technology	Lack of Internet Resources
Rose-Hulman Institute of Technology	Lack of Internet Resources
Stevens Institute of Technology	Lack of Internet Resources
Cornell	Login Required for Access
Stanford	Login Required for Access
Williams	Lack of Internet Resources
Smith College	Lack of Internet Resources
Mt. Holyoke	Lack of Internet Resources

UMASS (Amherst)	Login Required for Access
Regis College	Lack of Internet Resources
Dartmouth	Login Required for Access
UPENN	Login Required for Access
Tufts	Lack of Internet Resources
Boston University	Lack of Internet Resources

Table 2: List of candidate universities and the reason why each was not included.

After researching the initial body of schools, the list was honed down to eight schools.

Worcester Polytechnic Institute
Case Western Reserve University
California Institute of Technology
University of California Santa Barbara
University of California Los Angeles
Syracuse University
Harvard University
Massachusetts Institute of Technology

Table 3: Higher-learning institutions covered in the scope of this report.

This list of schools does not represent the entire cross-section that was originally proposed; however, it does cover a number of areas. MIT and CIT are AITU members and represent the upper echelon of that category. WPI and CWRU also belong to the AITU and are in the upper middle realm of the category. UCSB, UCLA, and Syracuse are large schools that grant many degrees outside the fields of science and engineering. The Ivy League is represented by Harvard.

2.2 Data Collection

Analysis of the schools began by choosing which introductory mechanics course to study. In most cases, schools had three different freshman physics courses. These courses varied their content in order to satisfy requirements for different degrees. For example, the majority of schools offer a course that fulfills the requirements for a liberal arts degree. Other schools offer a course that satisfies the requirements for a non-engineering science degree. This report is focused on the introductory mechanics courses that satisfy the requirements for an engineering degree. In the case of schools that offer more than one course that satisfies the requirements of an engineering degree, the course that required a lower mathematical pre-requisite was chosen. These judgments were made by carefully reading the course descriptions, which are available on-line in most cases, and cross-referencing the description against the degree requirements for an electrical engineering curriculum.

The next step in collecting the data was to download all pertinent data from the appropriate website for the selected introductory mechanics course. This material included the syllabus, text, course content list, exam solutions, and homework solutions. Data was also collected on the length of the quarter, semester, or trimester, and the mathematical pre-requisites.

3. Results

I will now describe how the collected data was organized. The analysis for each school begins with the course number that the school utilizes to identify the course. The course number is followed by the URL that was used to obtain the information along with the textbook that is required by the course.

Data from the syllabi were analyzed and organized in a systematic fashion for all eight schools. The number of classes each week, the duration of the course, the number of exams, the duration of each exam, number of recitations each week, and the duration of the final exam were organized into a table for each institution.

The analysis of the homework solutions required a set protocol. Homework sets were analyzed individually and specific components and characteristics of each were tabulated. The tables include the following information: problem set number, number of problems in each set, the number of lines in the solution for each problem, number of figures in each set, number of solutions requiring pre-calculus, and the number of solutions containing calculus. A problem was said to use pre-calculus based on the use of polynomials and trigonometry. The calculus content was based on the use of derivatives and/or integrals in the solutions. The number of lines per solution was primarily based on type-written solution sets. Three possibilities exist in the tables. The solution could contain less than ten lines, between ten and thirty lines, or greater than thirty lines. In some cases the solutions were hand-written. These instances required a scaling factor which was determined from typing a few lines of the solution on a word processor and making a conversion. It is imperative to take into consideration the differences that are possible in writing size and style. Hand-written to type-written scales were determined on a case by case basis. In addition, solution lengths also incorporate lines that contain mathematical equations and derivations.

The mathematical components of the solution sets were analyzed based on the close reading of the solution and identifying occurrences of pre-calculus and calculus as defined above. Some solutions used both pre-calculus and calculus. In these instances, both columns were counted. The figure column of the tables includes any kind of visual representation of the problem. Figures in this category include schematics, force diagrams, and vector schemes. Lastly, the number of problems in each set was based on the problem number. Problems that contained a multitude of smaller parts were still only counted as a single problem.

3.1 California Institute of Technology[10]

Course #: Phys 1A

Course URL: http://www.its.caltech.edu/~tmu/ph1a/geninfo.htm

Text: Serway - **Physics for Scientists and Engineers**, Volume 1, 5th or 6th Edition

Mathematical Pre-Requisite: Ma 1a (Topics include: real and complex numbers, sequences and series, integration, applications, improper integrals, continuity, differentiability, tangents, the fundamental theorem of calculus, inverse functions, logarithms, Taylor expansions, sequences and series II, odds and ends.)

The introductory physics program at Caltech consists of one single course. This course, Phys 1a, is broken into three different groups. Group 1 consists of sections 1&2. These sections are geared towards students with a limited exposure to physics in high school. Sections 3-8 are considered typical sections and are the subject of this inquiry. Sections 9&10 are more advanced sections geared towards students who have seen a large quantity of physics in high school. A description of the topics covered in this course is listed below in **Table 4**.

Table 4. Topic Listing

Date	**Lecture Topic**	**Assigned Reading**
9/27/04		
9/29/04	Introduction	1,2
9/30/04		
10/1/04		
10/4/04		
10/6/04	Vectors	3,4,7.2,1
10/7/04		
10/8/04	Trajectories	
10/11/04		5,6.1,6.2
10/13/04	Newton's Laws	7.13,11.14,
10/14/04		
10/15/04	Forces	
10/18/04		6.3-6.5,7

10/20/04	Non-Inertial Frames	
10/21/04		
10/22/04	Work and Energy	
10/25/04		8,9
10/27/04	Energy Conservation	
10/28/04		
10/29/04		
11/1/04		10,11.1-11.4
11/3/04	Rigid Rotations	
11/4/04		
11/5/04	Angular Momentum	
11/8/04		11.5-11.7,13.1-13.5
11/10/04	Gyroscopes	10.28,10.64
11/11/04		
11/12/04	Harmonic Motion	
11/15/04		13.6-13.7,15
11/17/04	Resonance	
11/18/04		
11/19/04	Fluid Mechanics	
11/22/04		14.1-14.3
11/24/04	Gravity	12.22
11/25/04		
11/26/04		
11/29/04		14.4-14.8
12/1/04	Kepler Orbits	
12/2/04		
12/3/04	Law of Ellipses	
12/9/04		

Physics 1a meets four times a week and lasts 50 minutes. Over the course of the semester, students will spend 33.33 hours in lecture. Students are expected to choose a one-hour recitation from the available sections posted on the website. There is no laboratory section associated with this course.

Table 5. Course Logistics

Hrs/Term	Classes/Wk	Duration	Quizzes/Sem	Duration	Rec/Wk	Duration	Final Duration
33.33	2	50 min	4	Take Home	1	1 hr	Take Home

Grades are determined by the completion of four take-home quizzes and one final exam. The quizzes are typically two-problems long and require students to draw diagrams. These quizzes also require students to carry out mathematical derivations and answer qualitative questions about the material.

Physics 1a requires that students have a background in calculus. **Table 6** exemplifies this pre-requisite. Students are expected to utilize calculus as early as the first problem set. Students are required to complete nine problem sets that contain approximately three problems per set. The majority of these problems require solutions that are longer than ten lines.

Table 6: Homework Statistics

Set	Problems	<10	10-30	>30	Figures	Calc	Pre-Calc
1	3	0	2	1	2	1	2
2	5	0	4	1	0	1	5
3	4	0	2	2	5	2	4
4	3	0	2	1	3	0	3
5	4	0	2	2	1	1	4
6	4	0	4	0	2	0	4
7	3	0	2	1	2	1	3
8	3	2	1	0	1	1	3
9	2	0	1	1	0	0	2
Sum	31	2	22	9	16	7	30
Mean	3.44	0.22	2.44	1	1.77	0.77	3.33

3.2 Case Western Reserve University Mechanics Diagnostics[11]

Course #: Phys 121

Course URL: www.phys.case.edu/courses/p121

Text: "University Physics", by Reese

Mathematical Pre-Requisite: Math 121 ("Functions, analytic geometry of lines and polynomials, limits, derivatives of algebraic and trigonometric functions. Definite integral, anti-derivatives, fundamental theorem of calculus, change of variables.")

The introductory mechanics program at Case Western Reserve University consists of two different courses, Phys 121 and Phys 115. The Phys 115 course is geared towards a B.A. in science and emphasizes the life sciences. The topics covered include thermodynamics, ideal gas law, kinematics and simple harmonic motion. The Phys 121 course is more advanced and is taken by students on a path to receive a B.S. in science or engineering. A description of topics covered in this course is listed below in **Table 7**.

Table 7: Topic Listing

Wk	Reese Chpt	Subject
1	1&2	Vectors
2	3	1,2-D Kinematics
3	4	Parabolic, Centripetal Motion
4	5	Newton's Laws
5	5	Forces & Circular Motion
6	6	Universal Gravity
7	7	Springs and Oscillators
8	8	Work and Energy
9	8	Conservation Laws
10	9	Momentum and Collisions
11	10	Rotational Motion
12	10	Angular Momentum
13	11	Solids and Fluids
14	12	Waves
15	N/A	Gravity and Cosmology
16	N/A	Reading Period
17	N/A	Final Exam

The course itself consists of three classes in a week, each of which is 50 minutes in duration. This adds up to 37.5 hours of lecture during the term. In addition, there is an optional one hour recitation that occurs once a week. The course also includes a laboratory session that is required in order to pass the class. This segment of the course occurs every other week based on an "even or odd" assignment during the first week of class.

Table 8: Course Logistics

Hours/Term	Classes/Wk	Duration	Exams/Semester	Duration	Recitation/Wk	Duration	Final
37.5	3	50 min	3	1 hr	1 (Optional)	1 hr	3 hr

As noted above, there are three exams during the length of the course in addition to a final exam given on the last day of the semester. The three regular exams are an hour in duration and are given during scheduled class time. The final exam is three hours long and occurs on the last day of the semester.

Phys 121 at Case Western Reserve University is a calculus based introductory physics course. Students are expected to be proficient in negotiating problems using pre-calculus as well as first year calculus. There are eight homework sets that are passed in during the 17-week course. The average number of problems on a set is approximately seven. The majority of these problems are between one and thirty lines long, and the problems contain plenty of figures and pre-calculus.

Table 9: Homework Statistics

Set	Problems	<10	10-30	30+	Figures	Calculus	Pre-Calculus
1	5	2	2	1	3	0	5

2	8	6	2	0	3	0	7
3	9	3	6	0	7	0	8
4	7	1	2	0	3	1	7
5	6	5	1	0	1	0	6
6	5	4	1	0	1	4	1
7	8	3	4	0	2	2	6
8	6	1	5	0	3	1	5
Sum	54	25	23	1	23	8	45
Mean	6.75	3.13	2.88	0.13	2.88	1	5.63

3.3 Harvard University Mechanics Diagnostics[12]

Course #: Phys 11a

Course URL: www.icg.harvard.edu/~phys11a/

Text: "Physics for Scientists & Engineers", by Serway and Jewett. 6th ed. Vol.1

Mathematical Pre-Requisite: Math 1a&1b (single-variable differentiation and integration.)

Harvard University offers three choices for introductory mechanics courses, Phys 11a, Phys 15a and Phys 1a. The 1a course is deigned for students seeking a non-engineering bachelor's degree and does not require the use of calculus. The 11a course fulfills requirements for engineering degrees and does require the use of single-variable calculus. Physics 15a is meant for students who know that they want to major in physics. The course is more abstract than 1a and 11a. This research focuses on the physics 11a course. **Table 10** lists the topics that are covered in this course.

Table 10: Topic Listing

Lecture	Topic	Chapter
1,2	Motion in 1-D	1,2,3
3,4	Vectors, Motion 2-D	3,4
5,6	Newton's Laws, Friction	4,5
7,8	Chaos	5,6
8	Work and Energy, Midterm	7,8
9,10	Linear Momentum, Collisions	9
11,12	Rotational Motion	10
13,14	Angular Momentum, Statics	10,11
15	Statics, Midterm	12
16,17	Oscillations	15
18,19	Chaos	15
20,21	Waves	16,17
22,23	Waves	17,18
22	Fluids	14

Physics 11a at Harvard University meets twice a week during the semester. The lectures are 90 minutes in duration, in addition to recitation classes that meet once a week and last one hour. Students will spend approximately 33 hours in lecture periods. Students are graded based on their performance on the two midterm exams and one final exam. The midterms are administered during scheduled class time and are an hour in length. A three hour exam is passed out during the last week of classes in the semester. These exams along with homework grades constitute the students' final average.

Table 11: Course Logistics

Total Hrs	Classes/Week	Duration	Exams/Sem	Duration	Rec/Wk	Duration	Final
33	2	90 min	2	1 hr	1	1 hr	3 hr

Students are expected to complete nine homework sets. On average, each set contains approximately eight problems. All of these problems contained solutions that are less than thirty lines in length. Calculus was used as early as the first problem set and pre-calculus was required in all of the sets.

Table 12: Homework Statistics

Set	Problems	<10	10-30	>30	Figures	Calculus	Pre-Calculus
1	14	7	7	0	1	1	11
2	9	7	2	0	2	0	9
3	7	4	3	0	11	0	7
4	7	4	3	0	0	2	7
5	8	6	2	0	15	2	6
6	7	7	0	0	7	0	6
7	9	2	7	0	9	5	6
8	9	6	3	0	3	5	7
9	6	3	3	0	3	0	6
Sum	76	46	30	0	51	15	65
Mean	8.44	5.11	3.33	0	5.66	1.66	7.22

3.4 Syracuse Mechanics Diagnostics[13]

Course Name: PHY211

Course URL: http://www.phy.syr.edu/courses/PHY211.05Spring/index.html

Course Text: Young & Freedman, University Physics, Volume 1, 11th edition.

Mathematical Pre-Requisite: MAT 285 ("Functions and their graphs, derivatives and their applications, differentiation techniques, the exponential and logarithm functions, multivariable differential calculus including constrained optimization.")

Syracuse University offers two options for introductory mechanics. Students can choose between Phys 211 or 101. The physics 101 course is geared towards non-engineering majors. The course requires no existing knowledge of physics and hopes to introduce students to fundamentals topics in introductory physics. The physics 211 course is meant for students who are pursuing an engineering or physical science degree. The mathematical pre-requisite for this course is calculus.

The class meets twice a week. Each class is approximately 80 minutes in duration. This means students will spend 37 hours in lecture periods. Students are also expected to attend two 60 minute recitations a week. There is also a 1 hour laboratory session each week. Topics are listed in **Table 13**.

Table 13: Course Logistics

Hrs/Sem	Classes/Wk	Duration	Lab/Wk	Duration	Rec/Wk	Duration
37.33	2	80 min	1	60 min	2	60 min

Table 14: Topic Listing

Class	**Lecture**	**Reading**
1	Overview	1.3-1.5

2	Velocity & Acceleration	2.1-2.5
3	Motion & Vectors	1.7
4	Vector Components	1.8-1.9,3.1
5	Velocity/Acc. Vectors 2-D; Projectile Motion	3.1-3.3
6	Components of Acc.	3.2,3.4
7	Relative Motion	3.5
8	Exam	
9	Newton's Laws	4.1-4.6
10	Forces	5.1,12.1
11	Frictional Forces	5.3
12	Applying Newton's Laws	5.2
13	Circular Motion; Work	5.4,6.1-6.3
14	Work, Energy and Power	6.4
15	Mechanical Energy	7.1-7.5
16	Exam 2	
17	Impulse and Momentum	8.1-8.2
18	Collisions	8.3-8.4
19	Center of Mass	8.5,10.1
20	Rotation, Inertia	9.1-9.5
21	Torque, Ang. Moment.	10.1-10.2
22	Rolling	10.3
23	Ang. Moment.	10.5-10.6
24	Exam 3	
25	Static Equil.	11.1-11.3
26	Oscillations	13.1-13.8
27	Wave Motion	15.1-15.8
28	Sound Waves	16.1-16.8
29	Review	

Table 15: Exam Information

Exams/Sem	Duration	Final Exam Duration
3	80 min	120 min

Students are required to take three exams during the course of the semester. Students are allowed 80 minutes to complete the exam which is administered during regularly scheduled class time. Students are also required to take a 180 minute final exam at the end of the semester.

Homework at Syracuse consists of eight problem sets. These problem sets usually contain three problems each. All of the problems contain solutions that are less than thirty lines long. Calculus is not required to negotiate the problems; however, pre-calculus is encountered in every problem set. The problem sets also contain questions that require qualitative solutions and/or figures to support answers.

Table 16: Homework

Problem Set	# of Problems	<10	10-30	30+	Pre-Calc	Calculus	Figures
1	2	1	1	0	2	0	0
2	2	2	0	0	2	0	5
3	4	4	0	0	2	0	2
4	2	2	0	0	2	1	1
5	3	2	1	0	3	0	3
6	7	7	0	0	2	0	1
7	3	2	1	0	3	0	3
8	2	2	0	0	2	0	3
Sum	25	22	3	0	18	1	18
Mean	3.125	2.75	.375	0	2.25	.125	2.25

3.5 MIT Mechanics Diagnostics[14]

Course: 8.01

URL: http://web.mit.edu/8.01/www/Fall04/

Text: *University Physics*, 11th Edition 2003 by Young and Freedman

Mathematical Pre-Requisite: Concurrent multi-variable calculus

MIT offers four introductory mechanics courses for students. These courses are 8.01, 8.01L, 8.012, and 8.01T. The 8.01 and 8.01L both satisfy the requirements for an engineering degree. The main difference between the two courses is that 8.01L is taught over a longer period of time. This allows students to maximize their exposure to the material. When a student completes 8.01L, it appears as 8.01 on his/her transcript. 8.012 is geared towards students with an advanced background in calculus and physics. This course offers more topics and at a faster pace than the other two courses. MIT also offers a TEAL course (Technology Enabled Active Learning), 8.01T, for students who like to work in small groups and use laptops to watch demonstrations. The course covers the same content as 8.01 and 8.01L. The focus of this research is 8.01.

Table 17. General Properties

Hrs/Sem	Classes/Wk	Class Duration	Exams/Semester	Exam Duration	Recitation/Wk	Recitation Duration
36	3	1 Hr	3 & Final	50 Min & 3hrs.	2	50 Min

The course meets three times a week for one hour. Students will be exposed to 36 hours of lecture at the end of the semester. Students are expected to attend two recitation meetings each week. These meetings last approximately 50 minutes. Students are also required to attend a laboratory session every week.

Physics 8.01 covers a variety of topics, which are listed in **Table 19.** Students are required to take three exams during the semester and one cumulative final exam. The three exams are 50 minutes in duration. Students are given three hours to take the final examination.

Table 18.	**Homework**	**Properties**					
Set	Problems	<10	10-30	30+	Graph/Figure	Calculus	Pre-Calc
1	5	4	1	0	3	2	3
2	7	3	3	1	0	2	5
3	5	2	1	2	3	3	3
4	7	4	2	1	2	1	6
5	6	4	2	0	3	4	2
6	4	4	0	0	0	1	3
7	5	4	1	0	1	0	5
8	5	3	1	1	0	1	4
9	4	2	1	1	3	2	2
10	4	3	1	0	3	1	3
11	3	2	1	0	0	2	1
12	3	2	1	0	0	0	3
13	4	3	1	0	1	1	3
14	4	2	1	1	0	0	4
Sum	66	42	17	7	19	20	44
Mean	4.71	3	1.2	0.5	1.35	1.42	3.14

Students are required to complete 14 problem sets. These sets generally include five problems. The majority of these problems require solutions that are less than thirty lines long. Students are expected to negotiate these problems using both calculus and pre-calculus.

Table 19: Topic Listing

Class	**Lecture**	**Assigned Reading**
1	• Introduction • Classical Mechanics • Coordinate Systems • Units of Measurement • Changing Units • Dimensional Analysis	**1-13**
2	• Kinematics • Speed and Velocity • Constant Velocity Motion	**40-47**

3	• Acceleration • Constant Acceleration Problems • Acceleration of Gravity	**47-62**
4	• Vectors • Vector Addition • Vector Components • Unit Vectors • Vector Multiplication • Scalar Product	**14-27**
5	• Vector Product • Kinematics in 3D • 3D Velocity • 3D Acceleration • Acceleration: perpendicular • Acceleration: parallel	**27-30, 78-87**
6	• Projectile Motion	**87-97**
7	• Uniform Circular Motion • Non-uniform Circular Motion • Galilean Relativity • Coordinate Transformations • Velocity Transformations • Acceleration transformation • Relative Velocity Problems	**98-106**
8	• Newton's Laws • Forces • Fundamental Forces in Nature • Newton's First Law • Newton's Second Law • Mass • Superposition of Forces	**119-138**
9	• Newton's Third Law • Gravitational Force • Satellite/Force • Gravitational/Inertial Mass • Hooke's Law/Springs • Motion with a Constant Force	**138-146**
10	• Motion Examples • Pulleys	**153-171**
11	• Friction • Kinetic Friction • Static Friction • Drag Force and Terminal Speed • Resistive Force Proportional to Velocity	**171-181**
12	• Dynamics of Uniform Circular Motion • Motion in a Vertical Circle • Conical Pendulum • Work and Energy • Work/Variable Force	**181-189, 207-213**
13	• Kinetic Energy • Gravitational Potential Energy • Gravity and Other Forces • Power	**213-229, 241-253**
14	• Conservation of Energy • Conservative Forces • Potential Energy of Conservative Forces	
15	• Spring Potential Energy • Gravitational Potential Energy • Non-conservative Forces	**253-268**

	• Force and Potential Energy	
16	• Potential Energy Curves • Equilibrium and Stability • Forms of Energy	**268-270**
17	• Particle Momentum • Conservation of Momentum • Newton's Laws and Momentum • Momentum for a System • Momentum and Forces • Center-of-Mass	**282-292**
18	• Center-of-Mass Motion • Energy of a System of Particles • Rocket Motion	**309-313**
19	• Variable Mass Problems • Impulse/Collisions • Inelastic Collisions • Elastic Collisions	**295-305**
20	• 2D-Elastic Collisions • Ballistic Pendulum • Center-of-Mass Collisions	**305-308**
21	• Rigid Body Kinematics • Right Hand Rule • Constant Angular Acceleration • Relation between Angular and Linear Motion • Rotational Kinetic Energy • Moment of Inertia	**327-345**
22	• Parallel Axis Theorem • Perpendicular Axis Theorem • Particle Angular Momentum • Straight Line Angular Momentum • Circular Motion Angular Momentum • Angular Momentum and Forces • Conservation of Angular Momentum • Angular Momentum and Central Forces	**345-349**
23	• Dynamics of a Rigid Body • Torque • Angular Momentum and Torque • Conical Pendulum: Torque and Angular Momentum • Torque and Angular Acceleration • Torque and Gravity • Rigid Body Angular Momentum • Conservation of Angular Momentum	**361-370**
24	• Work and Energy in Rotational Motion • Angular Impulse • Translation and Rotation • Rolling Motion of a Rigid Body	**370-386**
25	• Rolling Cylinders/Spheres • Angular Momentum and Collisions • Gyroscopes	**386-389**
26	• Forces in Equilibrium	**406-421**
27	• Law of Universal Gravitation	**436-451**

	• Newton's Law of Gravity • Gravitational Potential Energy • Potential Energy of a Spherical Shell • Cavendish Experiment	
28	• Potential Energy of a Sphere and Particle • Gravitational Forces and Extended Bodies • Force between Two Spheres • Tidal Forces • Weight and Gravitational Force • Planetary Motion • Circular Orbits	**456-464**
29	• General Planetary Motion • Generalized Orbits • Kepler's Laws	**452-456**
30	• Oscillations • Simple Harmonic Motion • Mass-Spring Systems • Energy in SHM	**476-494**
31	• Simple Pendulum • Physical Pendulum • Torsional Pendulum • Percussion • Damped Oscillations	**495-502**
32	• Special Relativity • Galilean Transformations • Light/Theory of Waves • Stellar Aberration • Michelson-Morley	
33	• Paradox; Light Spheres • Einstein's Special Relativity • Postulates of Special Relativity • Relativity and Measurements • Space-Time Coordinates • Relativity of Simultaneity • Lorentz Transformations • Simultaneity/Time	**1403-1411**
34	• Time dilation • Length Contraction • Perpendicular Lengths • Orientation; Moving Rod • Paradox: Pole-Vaulter • Headlight Effect	**1412-1419**
35	• Relativistic Velocity Transformation • Doppler Effect • Transverse Doppler Effect • Twin Paradox • Shape of Moving Objects • Relativity and Forces	**1420-1425**
36	• Relativistic Momentum • Relativistic Energy • Energy-Momentum • Massless Particles • Space-Time Invariant • General Relativity	**1426-1434**

3.6 UCLA Mechanics Diagnostics[15]

Course Name: Physics 1A

Url: http://www.physics.ucla.edu/class/05W/1A_CORBIN/

Text: Physics for Scientists and Engineers 3rd Edition, Volume I

Mathematical Pre-Requisite: No pre-requisite listed.

UCLA offers two courses for introductory mechanics students. These courses are physics 1A and 6A. The 1A course is meant for students pursuing engineering and physical science degrees. The 6A course is geared toward life science majors. The course description for physics 1A did not list a mathematical pre-requisite. Ironically, there are instances of calculus in the homework solutions. A list of topics covered is presented in **Table 20**.

Students registered for this course are expected to attend four classes a week. These lectures last approximately fifty minutes. Students are also required to attend two fifty-minute recitations a week. When students register for this course they are also expected to register for the lab component as well.

Students are required to take two examinations during the semester and one final exam. The two mid-term exams last fifty minutes. Students are permitted two hours to complete the final examination.

The homework data is incomplete because I could not gain access to all of the sets that were assigned during the semester. The numbers in **Table 21** do not reflect an accurate representation of this course's workload. The numbers are provided strictly to depict the characteristics of the problems.

Table 20: List of Topics[15]

	Monday	Tuesday	Wednesday	Thursday	Friday
1	1/10 Vectors	1/11 Vector Products	1/12 Position Velocity Acceleration	1/13	1/14 1-D Kine
2	1/17 **Holiday**	1/18 1-D Kine 2-D Kine	1/19 2-D Kine	1/20	1/21 Relative Velocity Centripetal Motion
3	1/24 Forces Newton's Laws	1/25 Force Examples	1/26 Friction	1/27	1/28 Force Examples
4	1/31 Work	2/1 $\Delta K = W_{net}$	2/2 Potential Energy $\Delta E = W_{nc}$	2/3	2/4 **Midterm 1**
5	2/7 $\Delta E = W_{nc}$ Examples	2/8 Work-Energy Examples	2/9 Center-of-Mass Newton's 2nd Law	2/10	2/11 Conservation of Momentum Collisions
6	2/14 Elastic Collisions	2/15 2-D Collisions	2/16 Momentum Examples	2/17	2/18 Rotational Variables
7	2/21 **Holiday**	2/22 Rotational Kinematics	2/23 Moment of Inertia	2/24	2/25 Torque
8	2/28 Torque	3/1 Work-Energy	3/2 Examples	3/3	3/4 **Midterm 2**
9	3/7 Angular Momentum	3/8 Angular Momentum	3/9 Statics	3/10	3/11 Gravitation
10	3/14 Gravitation	3/15 Examples	3/16 Examples	3/17 Reading Day	3/18
FE	3/21 **Final Exam** 3:00-6:00	3/22	3/23	3/24	3/25

Table 21: Homework Diagnostics

Set	# Prob	<10	10-30	30+	Figures	Pre-Calc	Calc
1	11	2	8	1	9	9	0
2	10	4	6	0	5	7	0
3	10	4	6	0	12	5	0
4	6	0	6	0	6	3	0
5	12	4	8	0	9	5	1
Sum	49	14	34	1	41	29	1
Mean	9.8	2.8	6.8	0.2	8.2	5.8	0.20

Table 22: Logistics

Classes/Wk	Duration	Recitation/Wk	Duration	Exams/Sem	Duration	Final	Duration
4	50 min	2	50 min	2	50 min	1	2 hrs

3.7 Worcester Polytechnic Institute Mechanics Diagnostics[16]

Course #: PH 1110

Course URL: http://wpi.edu/Academics/Depts/Physics/Courses/ph1110c05

Course Text: Young and Freedman, University Physics, 11th edition, (Addison Wesley, 2004).

Mathematical Pre-Requisite: Concurrent study of calculus.

Students taking introductory mechanics at WPI have two options: PH 1110 or PH1111. PH1110 fulfills the requirements for an engineering degree; however, the course contains much less calculus than does PH 1111. PH 1111 requires students to have taken a semester of multi-variable calculus.

PH 1110 meets three times a week. Each class is fifty minutes in duration. This adds up to approximately 21 hours of lecture in the term. The course covers a broad selection of topics that are listed in **Table 23**. Students are expected to attend two recitations a week that last fifty minutes. The course also has a laboratory section that lasts one hour and meets about three times during the term.

Table 23: Topic Listing

Class	Lecture	Assigned Reading
1	Introduction	1.7-1.9
2	Displacement, Velocity, Acceleration	2.1-2.4
3	Motion in One-D	2.2-2.5
4	Motion in 1-D,2-D & Projectiles	3.1-3.3
5	Circular Motion, Newton's Laws	3.4, 4.1-4.5
6	Q&A	
7	Exam 1	
8	Using Newton's Laws	4.5-4.6, 5.1-5.2
9	Using Newton's Laws	5.1-5.4
10	Using Newton's Laws	5.1-5.4
11	Q&A	

12	Exam 2	
13	Work, Energy and Power	6.1-6.2
14	Conservation of Energy	6.3, 7.1-7.3
15	Momentum and Impulse	8.1-8.4
16	Elastic and Inelastic Collisions	8.1-8.4
17	Torque, Static Equilibrium	10.1, 11.1-11.3
18	Q&A	
19	Exam 3	
20	Rotational Kinematics	9.1-9.3
21	Rotational Dynamics	9.4, 10.1-10.4
22	Angular Momentum	10.5-10.6
23	Conservation of Angular Momentum	
24	Q&A	
25	Exam 4	

Table 24: Course Logistics

Classes/Wk	Duration	Exams/Sem	Duration	Recitation/Wk	Duration	Final
3	50 min	4	50 min	2	50 min	50 min

Students are required to take four exams during the course of the term. These exams are taken during scheduled class time, thus they are fifty minutes in duration. The final exam is included in the four exams.

Homework at WPI consists of 16 problem sets. These sets contain three problems each and require solutions that are less than thirty lines long. Calculus is not required to negotiate any of the problems. Pre-calculus; however, is used in every problem set.

Table 25: Homework Statistics

Set	Problems	<10	10-30	>30	Pre-Calc	Fig	Calc
1	3	3	0	0	3	1	0
2	3	3	0	0	3	4	0
3	NA	NA	NA	NA	NA	NA	NA
4	3	0	3	0	3	4	0
5	NA	NA	NA	NA	NA	NA	NA
6	3	2	1	0	1	3	0
7	3	0	3	0	3	5	0
8	NA	NA	NA	NA	NA	NA	NA
9	3	1	2	0	3	6	0
10	3	0	3	0	3	6	0

11	3	2	1	0	3	3	0
12	3	0	3	0	2	3	0
13	3	2	1	0	2	3	0
14	NA	NA	NA	NA	NA	NA	NA
15	3	0	3	0	2	5	0
16	3	0	3	0	2	4	0
Sum	48	13	23	0	30	47	0
Mean	3	0.81	1.44	0	1.88	2.94	0

4. Discussion

4.1 Topics Covered and Text

There was no significant variation in the material covered by the introductory university mechanics courses analyzed in this paper. All of the schools covered basic topics indicated in the table below.

Vectors
Kinematics
Newton's Laws
Forces
Springs and Oscillators
Work and Energy
Conservation Laws
Momentum
Collision
Rotational Motion
Angular Momentum

Table 26: Topics covered by all schools analyzed in this study.

Massachusetts Institute of Technology covered additional topics. These topics included special relativity, Galilean transformations, space-time coordinates, relativistic velocity, and general relativity. California Institute of Technology includes topics such as the Law of Ellipses, fluid mechanics, and Kepler orbits. Worcester Polytechnic Institute, in a term length environment, covers all of the topics listed in **Table 26**. This is significant considering that WPI students only have approximately seven weeks to digest the material that a Case-Western student has 16 weeks to digest.

Another important aspect to consider is the amount of text that students are expected to cover for a given topic. There were five different texts that were used by the eight chosen schools.

		AUTHOR OF TEXT				
		Serway	Reese	Young	Giancoli	Halliday
	CIT	X				
	CWRU		X			
S	Harvard	X				
C	Syracuse			X		
H	WPI			X		
O	MIT			X		
O	UCLA				X	
L	UCSB					X

Table 27: Table depicting the text used for a given school.

As the above table demonstrates, the Young text is the most popular. The three schools that use this text, each utilized different sections of the text for similar topics. This is shown in detail in **Table 28**. Although there is considerable overlap for the majority of topics covered, the schools chose to use different sections of the same book for the same topics.

Topic	**WPI**	**MIT**	**Syracuse**
Vectors	2.1-2.4	1.7-1.10	1.8-1.9, 2.1-2.5
Kinematics	3.1-3.3	2-2.3, 3.1-3.3	3.1-3.3
Newton's Laws	4.5-4.6, 5.1-5.4	4.1-4.6	4.1-4.6
Forces	4.5-4.6, 5.1-5.4	4.1-4.6	5.1, 12.1
Springs and Oscillators	4.5-4.6	4.5-4.6	4.5-4.6
Work and Energy	6.1-6.2	5.4-5.5, 6.3	6.4
Conservation Laws	6.3, 7.1-7.3	N/A	7.1-7.5
Momentum	8.1-8.4	8.1-8.4	8.1-8.2
Collision	8.1-8.4	8.1-8.4	8.3-8.4
Rotational Motion	9.1-9.3	9.1-9.5	9.1-9.5

Angular Momentum	10.5-10.6	10.2	10.5-10.6

Table 26: Section listing for each topic covered by the respective school.

Another interesting comparison can be made between Caltech and Harvard. Both of these schools use the Serway text, but not to the same extent. **Table 29** exemplifies these differences.

Topic	**CalTech**	**Harvard**
Vectors	1, 3, 4, 7.2	3, 4
Kinematics	5, 6.1, 6.2	1, 2, 3, 4
Newton's Laws	7.13, 11.14	4, 5
Forces	6.3-6.5, 7	5, 6
Springs and Oscillators	N/A	N/A
Work and Energy	8, 9	7, 8
Conservation Laws	8,9	8, 9
Momentum	10, 11.1-11.4	9
Collision	10, 11.1-11.4	9
Rotational Motion	11.5-11.7, 13.1-13.5	10
Angular Momentum	11.5-11.7, 13.1-13.5	10, 11

Table 29: Section listing for each topic covered by the respective school.

As the above table depicts, these schools chose to use different sections of the text to complement different topics covered in class. In fact, there is very little overlap between these two schools besides when covering topics such as work, energy, and momentum.

4.2 Homework Analysis

The most important aspect of this study is the breakdown and analysis of the homework sets each school required of their students. Each school required different levels of effort and mathematical knowledge in order to complete the assignments. This point is exemplified by the total number of problems that each school required (**Figure 2**).

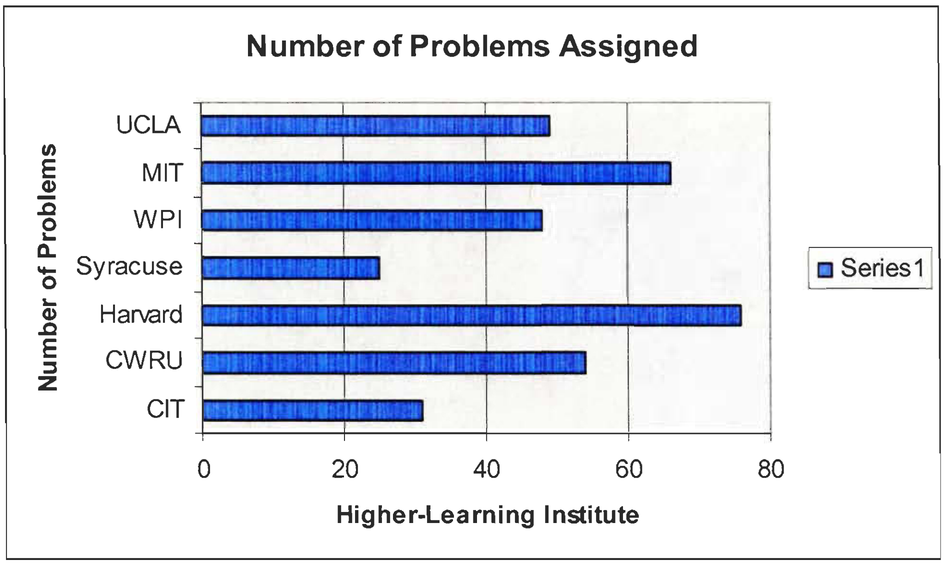

Figure 2: Total number of problems assigned for each higher-learning institute

Figure 2 illustrates the amount of homework each school assigns during the semester. Harvard requires students to do 76 problems compared to Syracuse's 25 problems. Of interest here is the fact that WPI requires students to do 48 problems in a seven week period. If we multiply WPI's total by two, we notice that WPI would have assigned the largest amount of homework during a 14 week semester.

Some schools posted solutions that were, on average, much longer than other schools. For example, MIT and Caltech posted the most solutions that were greater than thirty lines in length. **Figures 3** and **4** illustrate this point.

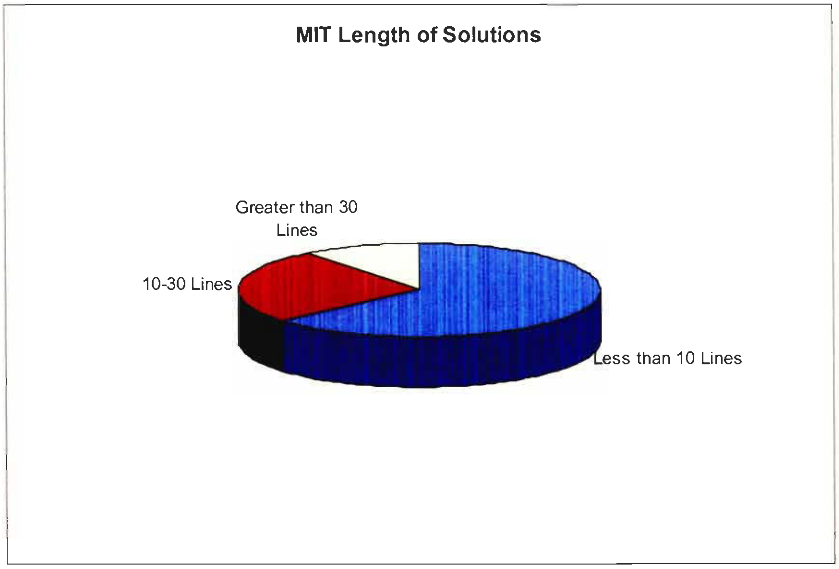

Figure 3: Pie chart describing the distribution of solution lengths in the introductory physics course offered at MIT.

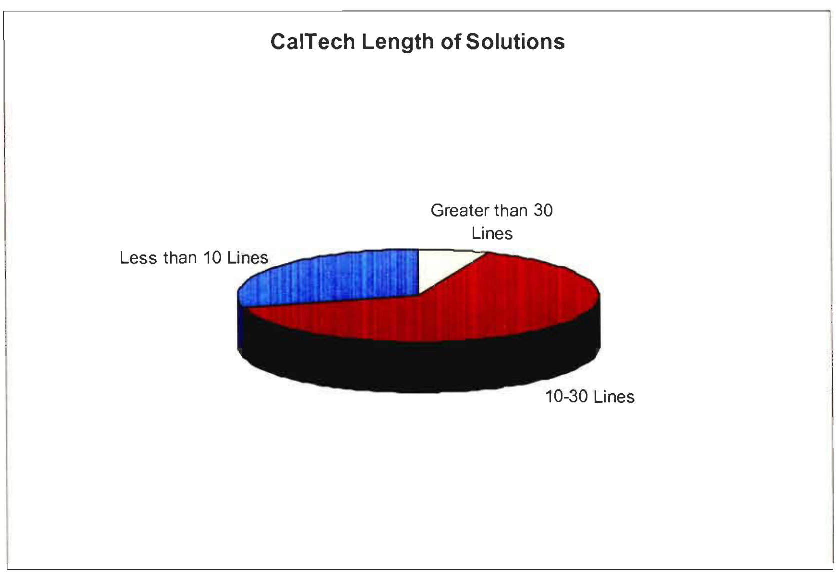

Figure 4: Pie chart describing the distribution of solution lengths in the introductory physics course offered at CalTech.

Other schools, such as Harvard and Syracuse, posted solutions that were generally less than ten lines in length. This can mean a few things. First, one could conclude that the homework sets at Harvard and Syracuse are easier than those assigned at MIT and

Caltech. One could alternatively conclude that Harvard and Syracuse provide condensed solutions that require the student to derive the simpler points contained in the solution.

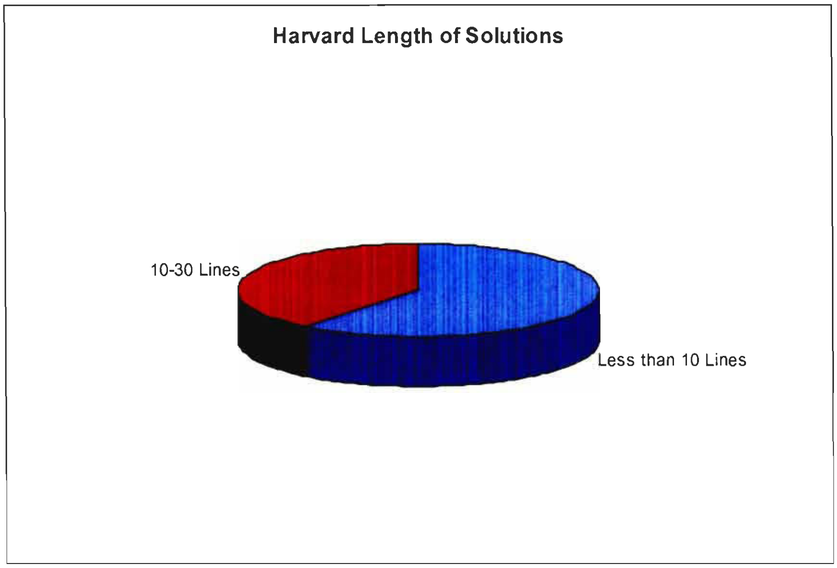

Figure 5: Pie chart describing the distribution of solution lengths in the introductory physics course offered at Harvard.

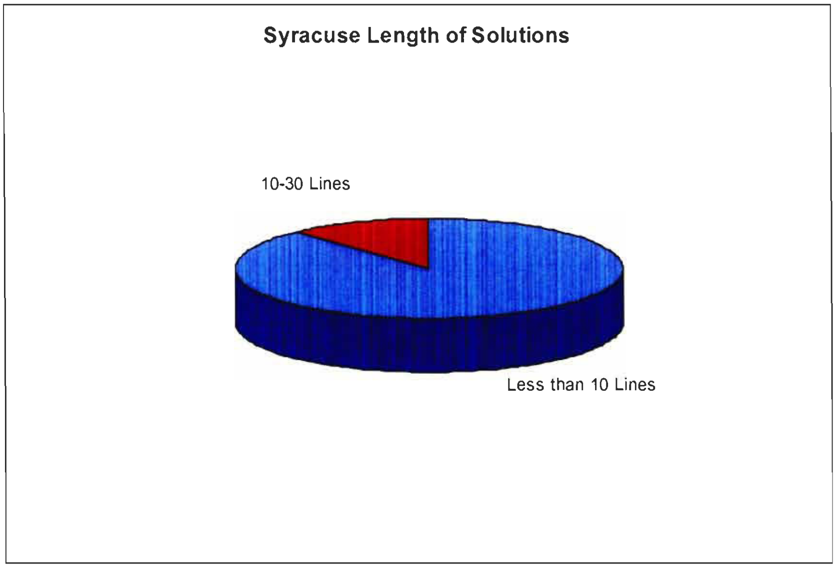

Figure 6: Pie chart describing the distribution of solution lengths in the introductory physics course offered at Syracuse.

WPI, and Case-Western fall in the middle of the two categories described above. These schools have distributions mostly in the ten to thirty line region.

The mathematical component of the homework also presents an interesting comparison. Some schools required students to use calculus at an early stage in the course. Other schools used calculus primarily at the end of the course. WPI did not require students to use calculus at all for homework assignments. **Figure 7** illustrates this point.

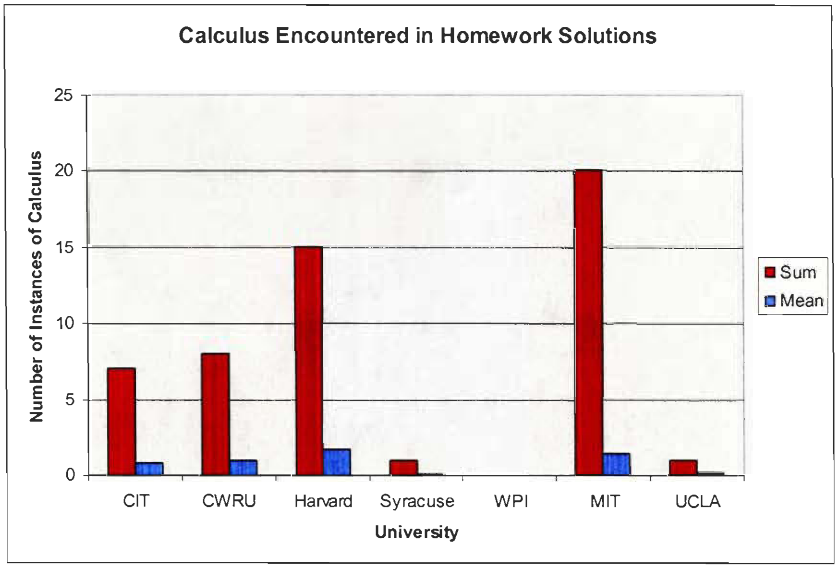

Figure 7: Calculus encountered in homework solutions at each school.

The use of pre-calculus was also analyzed and recorded. The use of pre-calculus was almost universal at all of the schools. It was difficult to find problems at any school that did not require students to use trigonometry or advanced algebra.

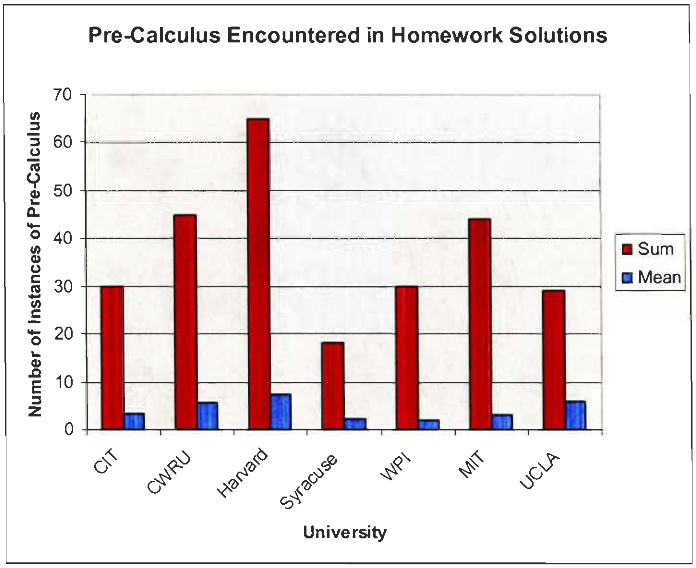

Figure 8:Pre-calculus encountered in homework solutions at each school.

The use of figures in the solutions sets was also monitored. This information does not translate into a useful comparison or discussion because the solution sets are generally authored by a professor or a graduate student. These people will include figures as a supplement to their mathematical or qualitative explanations. Students were not usually required to answer questions using figures.

4.3 WPI Against the World

It is of utmost importance to evaluate how WPI's mechanics course compares to the other schools studied herein. WPI, unlike any of the other schools, uses a term based schedule. The terms last seven weeks compared to a semester that lasts approximately fourteen weeks.

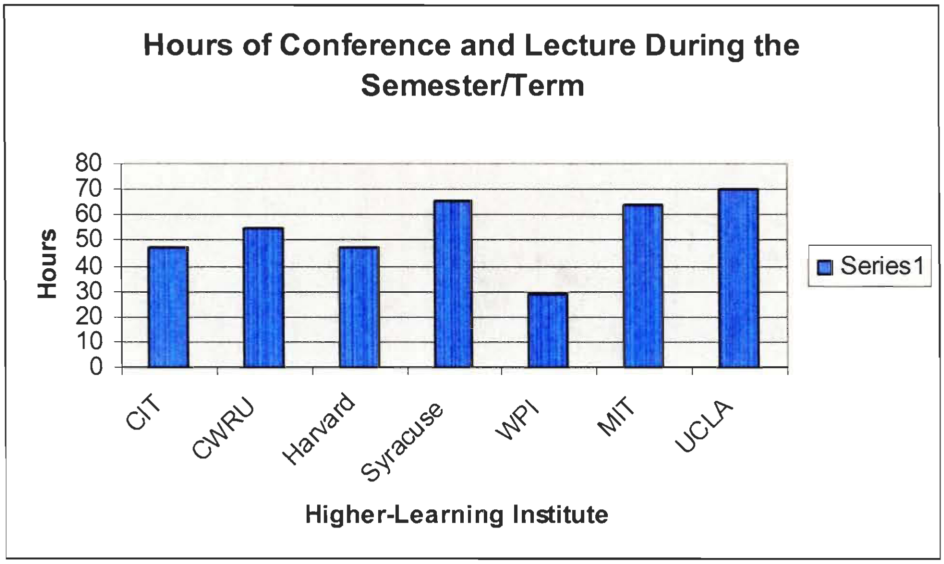

Figure 9: Bar graph depicting the hours of class time each school requires for their introductory mechanics course.

First and foremost, WPI covers the same topics as the other schools do except that this is accomplished in half the time. Schools such as MIT and Caltech cover additional topics that WPI does not; however, the remaining schools cover the same number of topics as WPI. WPI ranks fifth for total number of problems assigned category. However, if we look at a comparison of problems assigned versus number of hours of class time it becomes evident that WPI students complete the most homework problems per hour of class time.

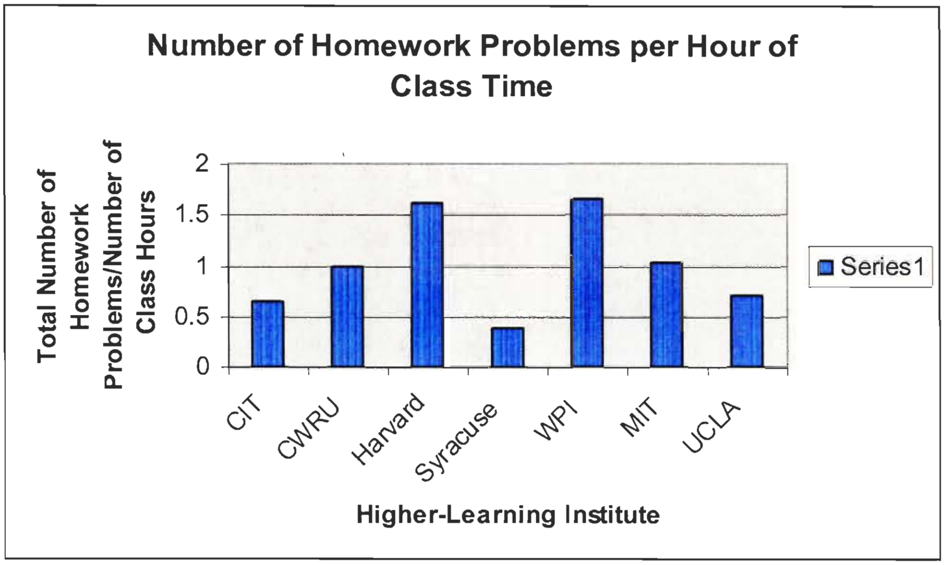

Figure 10: Number of homework problems assigned versus hours of class time for each school.

In addition, WPI does not require students to use calculus when solving problems. All of the assigned problems require students to use pre-calculus. The majority of solutions at WPI required solutions that were between ten and thirty lines long. The average solution lengths at WPI are comparable to Caltech and MIT, but much longer than Syracuse or Harvard.

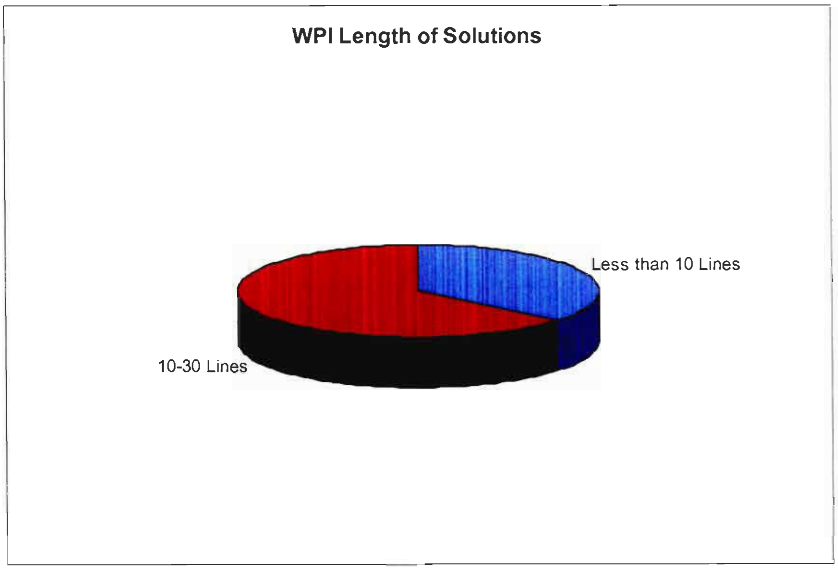

Figure 11: Pie chart describing the solution lengths at WPI.

5. Conclusion

This paper presented an analysis of eight different introductory university mechanics courses. The analysis consisted of tabulated recordings of homework data, exam data, and syllabi data. The purpose of this analysis was to highlight the importance of a neglected component of introductory mechanics-homework. Pedagogical research focuses on the teacher's delivery of the material. I found no record of research that explores the effort that students are expending on homework as an indicator of success.

WPI uses homework more extensively than the other schools. Moreover, WPI covers the same core topics that the other schools do except that WPI accomplishes this in seven weeks.

In addition, students have strongly indicated their feeling that homework is the most important aspect of introductory mechanics pedagogy[1]. Although the eight different schools vary in many properties (classes/week, exams, length of course), the homework is presented in an extremely similar fashion. With these points in mind, it is evident that introductory mechanics courses have been restructured in a way that ignores the most important aspect that is important to the student- the homework.

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7. Appendix

The appendix consists of all the downloaded material that I retrieved from the Internet. The material is organized in folders that correspond to each school. In each folder there is a syllabus and all of the homework solutions that I have studied. The material is not saved in a uniform file format. Parts of the material are in .pdf format, .jpg format, and .doc format. The total size of this material is approximately 64 megabytes uncompressed.