Using research on student motivation as well as Project-Based Learning as a theoretical framework, this thesis outlines the creation process for a set of curricula. These curricula were designed to address topics of markedly low student motivation in the first term of an introductory physics with calculus course (PH 211) at Oregon State University. This process began with the creation and distribution of multiple surveys. The formal validation process as well as non-parametric statistical analysis of these surveys is outlined. These surveys were used to identify “Vectors and Vector Mathematics” as well as “Coordinate System Choices” as topics of particularly low student motivation. Through an iterative process of collaboration and refinement, carbon nanotubes were selected as the platform for these activities. Six 30-60 minute activities were presented in
Studio of PH 211 during spring term 2012. A combination of Professor Dedra Demaree's in-class observations and my own reflections on the creation process of these activities are presented. Student feedback will also be collected and included in future research.

Key Words: student motivation, Project-Based Learning, curriculum design, survey validation and non-parametric statistics.

Corresponding e-mail address: settelms@onid.orst.edu
Student Motivation, Introductory Calculus Based Physics

(PH 211) and Project Based Learning, Oh my!

by

Samuel T. Settelmeyer

A PROJECT

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Dean, University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

______________________________
Samuel T. Settelmeyer, Author
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INTRODUCTION

Education research has generated many ways of modeling student learning. All models present different traits or conditions as “the key” or “the basis” for student learning. “If one of the important goals of schooling is to foster the development of students’ minds… then educators must concern themselves with motivational questions” (Blumenfield et al. 1991). Given this, it is only logical for me as an aspiring teacher (as well as anyone interested in education) to pursue an understanding of student motivation.

Developing curriculum with the aim of leveraging motivation to address topics of low student motivation was selected as the overarching goal of this thesis. It was selected because it was a common goal that fit both the department’s ongoing reform process as well as my personal interests. This overarching question is broken down into a series of questions:

1.) What topics in PH 211 are particularly low in regards to student motivation?
   More specifically, what is the nature of this motivation?

2.) What specific features of Project Based Learning (PBL) can be leveraged within the constraints of an introductory physics with calculus course at Oregon State University (OSU)?

3.) What dynamics emerge during the implementation of the activities in the classroom setting?

4.) Did the created activities change students’ perception of topics of low student motivation?

List 1.1 Questions Addressed by thesis
Addressing these questions and ultimately creating the desired curriculum is the goal of this thesis.

We begin by considering the first question posed above. This was done by dividing the first term of the Introductory Physics with Calculus series (PH 211) into 11 subtopics based on the department-approved standard content for that course. A series of surveys were then used to refine the initial list of 11 topics down to four. The Chi-Squared Test (Non-parametric Statistics) as well as other methods of analysis were used during this refinement.

Two topics (“Vectors and Vector Mathematics” and “Coordinate System Choices”) were selected as markedly low in regards to student motivation, making them the topics that should be targeted with the curriculum. Two other topics (“Understanding Newton’s Laws” and “Different Forms of Energy”) were high in regards to students’ self-reported motivation. These two topics of high student motivation are models from which to leverage existing student motivation as we attempt to address the topics of low student motivation. More specifically, the low motivation topics were identified to be low with regards to student interest and real-world application, though students generally realized they were useful for coursework. The creation, distribution and analysis of the surveys are discussed in full in the Determining Topics of Low and High Student Motivation section.

Literary reviews of student motivation and PBL are then used to consider current understanding of student motivation and curricular formats. This review process determined that a strong connection to a real-world context, student inquiry and open-endedness were all specific features of PBL to incorporate into our curriculum format,
while still considering the constraints of an introductory physics with calculus course at OSU.

The theme of carbon nanotubes was chosen to tie topics of high-motivation to the low-motivation topics. This provided a mechanism for leveraging the research on student motivation and PBL. Having a common theme promotes two goals: providing benefits of PBL in an environment that makes implementing large projects difficult, while also providing a way to incorporate modern content into the course. A previous survey asked OSU faculty from departments that require their students to take the PH 211 what they would like to see us address in these courses.

The survey revealed a recurring interest in relevant modern topics such as nanotechnology. This input was used to focus the curricular creation process. Fully outlined in the Determining Curriculum Structure section, this process proposes a set of useful features of PBL to be implemented into an introductory physics with calculus course at OSU. The results of this process are presented in the Curriculum Produced section.

The Assessment of Success section then summarizes how the selected features of PBL were indeed leveraged within our course context, but also faced several set-backs. These included time-constraints while the students worked through the activities as well as limits in how open-ended the questions could be designed within the course context. This section also explores the dynamics that emerge during the implementation of the activities in the classroom setting. This was done by interviewing the professor who was doing in-class observations and peer-mentoring during this course (as part of a separate project), and asking targeted questions about these activities’ implementation in the
classroom. Student feedback was elicited by three open-ended questions in the general course evaluation survey given at the end of the term. Students also answered the same set of questions distributed the previous year (called Spring Quizdom Questions 2011).

The Reflection on Learning Process section addresses my personal learning during the thesis process. Here I discuss how the research as well as my understanding developed over time, and make other comments that may be interesting to future instructors going through a similar process, but not relevant to addressing my research questions.

The answers to the questions posed in List 1.1 are reiterated in the Conclusions and Future Work section. This section also discusses the additional feedback and analysis to be done on this specific research project, as well as ideas for other future projects.
Course Overview

Oregon State University operates on a trimester schedule and offers a Calculus Based Introductory Series, which consists of three-courses. The first term of the series is referred to as PH 211, and consists of introductory mechanics. The second term (PH 212) is the combination of rotational motion, fluids, waves, optics, and gravitation. The third term of the series (PH 213) is electricity and magnetism. A traditional student begins the series in spring term of their freshman year, although a “trailer series” is offered, that begins fall term. Using Spring 2011 as an example, the student population (by major) is 90.3% engineering, 2.1% mathematics, 1.5% physics, 2.1% undeclared and 4.1% other.

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*Table 2.1 Traditional student schedule*

There are normally three sections of each course offered during any one term, with approximately 200 students in each section. There is some variation in how each section is taught, as OSU offers a studio section, which consists of two hours of lecture, two hours of lab and two hours of studio a week (see Beichner 2008 for more discussion). The traditional sections have three hours of lecture and three hours of lab each week. All sections follow the same content, text, and assigned readings, which are agreed upon by the lower-division faculty curriculum committee.
**Winter 2011 Survey (WS11)**

In order to make informed choices in regards to curriculum development, we need to determine which topics within PH 211 are particularly low and high in regards to student motivation. The former topics will be the target of the curriculum created while aspects of the latter topics will be incorporated into the curriculum structure. WS11 is the first survey developed to determine these outlier topics.

The Winter 2011 Survey (Appendix A) was administered during the lab portion of the studio section of PH 213 during Winter term, 2011 at Oregon State University. The PH 213 students were thought to be a useful population, as they were just completing the Introductory Physics with Calculus series, and would have a well-rounded perspective of the topics in the series. The survey was distributed in lab because it would have minimal impact on available course time. It was presented as related to research that the instructor of the course, Professor Dedra Demaree, was doing to improve the curriculum in the introductory sequence.

The first step in the development of WS11 was dividing up the PH 211 curriculum into 11 categories:

- Vectors and Vector Mathematics
- Coordinate System Choices
- Diagrammatic Representations of Problems (Motion Diagrams, Free Body Diagrams and Energy Diagrams)
- Position, Velocity and Acceleration
- Types of Motion (Projectile, Relative, Uniform Circular, Free Fall)
- Using Net Force to Analyze Motion
Understanding Newton’s Laws
Momentum and Impulse
Conservation Laws
Different Forms of Energy
Work and Power

**List 2.1** 11 categories of the PH 211 curriculum

To determine these 11 categories, the course text (*Physics for Scientists and Engineers* 2nd Edition by Knight) as well as the course calendar were consulted. I went through several drafts, each of which checked for content validity (defined later in this Chapter) by professor Demaree, as I sought to simplify the term into the most concise and intuitive categories possible.

In the survey, students were prompted to “…check the box for each of the following PH 211 topics corresponding to your level of motivation to learn them.” There was then a list of the 11 topics from above, each with a five-point scale of Very Low Motivation to Very High Motivation (Likert-type rating scale) next to them. This was used to group student’s responses, and later analyze the data for outliers. The use of the word ‘motivation’ was intentional, as it geared the responses to WS11 towards my topic of interest (addressed in the Introduction).

WS11 was presented as voluntary, and was distributed and collected by Teaching Assistants with minimal verbal framing. We received 86 responses from the class of 165. This response rate of approximately 50% is consistent with larger studies of survey-based research (see Baruch), and is not a source of concern.
Validation

To formally validate a survey, one must consider four factors: face validity, content validity, construct validity and criterion-related validity. As defined by Lord et al. 2009, a survey has **face validity** if it looks clear and well-organized. A survey has **content validity** if the questions fall into the area under study. A survey with **criterion-related validity** is directly comparable with other measures of the same student attributes; for example, class grades should correlate with student responses to post-class surveys of content knowledge.

**Construct validity**, the requirement that the survey actually measures what it is intended to measure, is the most important requirement and the hardest to satisfy. The formal definition is that the theoretical concept matches the measuring device. You cannot use a meter stick (poorly suited measuring device) to measure the diameter of a carbon nanotube.

Face and content validity can be checked by considering the opinions of experts in the field. Criterion-related validity requires extensive correlational considerations between comparable measures. Construct validity would require extensive feedback from survey-takers and then more comparisons, and is more time-intensive.

All of the four factors discussed above were addressed to some level in the formation of WS11. However, more drafts and input from other professionals would be needed to achieve formal validation. Some PhD theses consist solely of validating surveys – to do this well requires multiple iterations and considerable work. Therefore, we chose to mimic the validation process but not focus on it since my thesis is instead focused on curriculum development with the theme of improving motivation through the
use of project-based ideas and modern physics topics. Considering this primary goal, spending significantly more time on survey formation would serve as an unnecessary and impractical tangent.

**Non-Parametric Statistics**

By not validating WS11, we have essentially restricted ourselves to general interpretations of the data. Testing for statistical significance makes little to no sense when our measuring device is not painstakingly calibrated. However, there are commonly used methods for quantifying Likert scale data for a coarse analysis which we applied. Although this analysis cannot be used to test for statistical significance in our case, it is needed for ranking the topics. A full discussion of this process can be found in Appendix B.

In order to analyze the data, an appropriate statistical approach is needed. To begin, consider a parametric approach. In order to apply parametric statistics, the data have to satisfy three assumptions: First, the data is assumed to be from a population with a normal distribution. Secondly, the data must be measured on an **interval scale** (e.g. any interval between two measurements is meaningful - such as a person's height in centimeters). Lastly, parametric tests make use of parameters such as the mean and standard deviation. The data from WS11 is not continuous, as it had five discrete possible responses. Furthermore, the intervals between two measurements are not meaningful (discussed below). When we consider these two topics alone, we see that parametric statistics cannot be applied.

Non-parametric statistics would need to be used in a more complete analysis of
WS11. The data from WS11 are non-parametric in nature because students’ responses to each topic are not normally distributed. Furthermore, the relative values of different options are not comparable. The difference between “Low Motivation” and “Somewhat Low Motivation” is not the same as the difference between “Neutral” and “Somewhat Motivated.” While both deal with consecutive options on the 5-point scale, each step is not comparable to any other step.

The data also consists of discrete values (Ex: “Somewhat Low Motivation” for “Vectors and Vector Mathematics”), making even a discussion of a normal distribution nonsensical. This predicament (often encountered by education researchers) is humorously summarized by Jamieson: “[T]he average of ‘fair’ and ‘good’ is not ‘fair-and-a half’; this is true even when one assigns integers to represent ‘fair’ and ‘good’!”

A Chi Square test is needed to analyze our non-parametric data. More specifically, a Single Sample Chi Square Test (also referred to as the One-Way Classification) will be used to determine if a set of observed responses differs from what is expected. In this case, we expect students’ responses to be randomly distributed. Put another way, we want to test the null hypothesis that the students’ responses to WS11 are randomly distributed.

After considering the responses to one topic (Vectors and Vector Mathematics) as an example calculation, I will then consider all the topics.
Table 2.2 Single Sample Chi Square Test example calculation

The expected Number of Rankings was calculated using the following formula:

\[
E = \frac{\text{Row total} \times \text{Column total}}{\text{Total number } N \text{ of table}}
\]

Consider an example using data from Appendix A to find E for Very High Motivation “Vectors and Vector Mathematics”:

\[
E = \frac{87 \times 85}{938} \approx 7.88
\]

To consider the statistical significance of 8.82, we need to consider the degrees of freedom present in our sample. For a Single Sample Chi Square Test, the degrees of freedom are classified as r-1, where r is the number of levels. In the case of WS11, there are 4 degrees of freedom. To be significant at the 0.05 level with 4 degrees of freedom, a result of greater than 9.488 is needed. As such, “Vectors and Vector Mathematics” is not significant at the 0.05 level, although it is significant above the 0.10 level (7.779).
Table 2.3 Chi-Squared Values for all 11 topics addressed in WS11.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Chi-Square Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vectors and Vector Mathematics</td>
<td>8.82*</td>
</tr>
<tr>
<td>Coordinate System Choices</td>
<td>18.69**</td>
</tr>
<tr>
<td>Diagrammatic Representations of Problems (Motion Diagrams, Free Body Diagrams and Energy Diagrams)</td>
<td>1.25</td>
</tr>
<tr>
<td>Position, Velocity and Acceleration</td>
<td>2.89</td>
</tr>
<tr>
<td>Types of Motion (Projectile, Relative, Uniform Circular, Free Fall)</td>
<td>2.06</td>
</tr>
<tr>
<td>Using Net Force to Analyze Motion</td>
<td>3.72</td>
</tr>
<tr>
<td>Understanding Newton’s Laws</td>
<td>6.72</td>
</tr>
<tr>
<td>Momentum and Impulse</td>
<td>3.54</td>
</tr>
<tr>
<td>Conservation Laws</td>
<td>3.10</td>
</tr>
<tr>
<td>Different Forms of Energy</td>
<td>5.49</td>
</tr>
<tr>
<td>Work and Power</td>
<td>1.92</td>
</tr>
</tbody>
</table>

* significant at the 0.10 level    ** significant at the 0.01 level

Table 2.3 shows that the same set of four outlier topics are the most deviant from the expected distribution as were determined by our earlier parametric method. The later method of non-parametric statistics is the appropriate way to treat the data, which is why it was outlined.

WS11 also posed two open-ended questions:

(1) For a subject you marked as “High Motivation”: Why were you motivated to learn about this topic?

(2) For a subject you marked as “Very Low Motivation”: Why were you not motivated to learn about this topic?

List 2.2 WS11 Qualitative Questions
37 students responded to the first question and 23 responded to the second. These responses were sorted into categories of motivational source (Ex: I am very highly motivated to learn about Newton’s Laws because it is applicable to the courses in my major and future career). Although more background in motivational literature is needed to fully discuss these responses (Chapter 3), they will be presented now in order to keep all WS11 considerations located in one chapter of this thesis. The responses, our interpretations of them, and our sorting of them can be found in Appendix A.

Interest in topic
Applicable to future courses
Useful to solve other problems
Applicable to major
Topic is easily understood
Useful to solve other problems
Concept itself is important to understand
Applicable to real world
Mathematics of problem was easier

List 2.3 Repeated responses to Question #1 in List 2.2

When developing the questions to ask in Spring 2011 Quizdom Questions (see next section), we considered these common responses. This use of students’ responses to format our next survey is an example of “shadowing” the formal validation process. The fact that the questions in Spring 2011 Quizdom Questions are based on common student responses increases its construct validity.
Spring 2011 Quizdom Questions (SpQ11)

Spring 2011 Quizdom Questions (Appendix C) were administered during three sections of lecture at the end of the first term of the Introductory Physics with Calculus Series (PH 211) during Spring term 2011 at Oregon State University. It was presented as related to the ongoing research that the physics department conducted so as to better understand and teach its students. Two of the sections of PH 211 were taught by Mr. Jim Ketter while the other section was taught by Professor Demaree. Both asked their students to answer the four questions via Quizdom Q4 remotes, thus taking minimal class time yet gaining feedback from large numbers of students.

<table>
<thead>
<tr>
<th>Course</th>
<th>Students Enrolled</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demaree</td>
<td>165</td>
<td>107</td>
</tr>
<tr>
<td>Ketter 10 AM</td>
<td>175</td>
<td>92</td>
</tr>
<tr>
<td>Ketter 11 AM</td>
<td>181</td>
<td>78</td>
</tr>
</tbody>
</table>

Table 2.4 Breakdown of student responses to SpQ11 by course

The four questions presented were created by refining List 2.3 down to the four topics:

Question #1: Interest in topic

#2: Applicable to major

#3: Applicable to real world

#4: Applicable to future courses outside of major

List 2.4 Student-Identified Reasons for “High Motivation” used to format SpQ11

As previously mentioned, this application of student’s responses to WS11 gives
SpQ11 increased construct validity. It also addresses the second part of the first question posted in List 1.1, as it determines what aspect of motivation is or is not present for these topics. This question is of interested because it will allow curriculum to be focused towards considering a specific aspect of motivation, rather than motivation as a whole. SpQ11 distinguished between these aspects by asking the students to rank the 6 topics from most to least in terms of one of the four sources of motivation.

SpQ11 was initially analyzed by considering the average ranking of each of the six topics within each question (outlined in Appendix B). As previously discussed with respect to WS11, parametric analysis is not the correct way to analyze Likert-style data. The data was re-analyzed using the correct non-parametric approach. However, this analysis was done after the activities had already been created.

The only topic that the parametric and non-parametric analysis did not interpret the same way was whether “Understanding Newton’s Laws” or “Momentum and Impulse” was greater in regards to student motivation. Due to the timing of the discovery of this discrepancy, “Momentum and Impulse” will not be analyzed in this thesis while “Understanding Newton’s Laws will be part of the curriculum development process.

SpQ11 will additionally be used as a measure of the created activities success. These same 4 questions will be presented to the same student population that interacts with the created curriculum. Analysis of this data will take place in Chapter 6 (Assessment of Success).

Non-Parametric Consideration of Different Question Responses

The responses to each topic were analyzed with regards to each of the four
questions. An example is given below (all data is presented in Appendix C):

Table 2.5 Example analysis of Vectors and Vector Mathematics

*See Appendix C for values assigned to rankings

The P-values that are significant at the 0.05 level are outlined in red in Table 2.5.

The P-Value is based off of the same Chi-Square calculation extensively outlined for WS11.

We learn several important things about student’s perceptions of the six topics:

1. Both “Vectors and Vector Mathematics” and “Coordinate Systems Choices” are significantly low in regards to student interest and applicability to the real-world.

2. “Vectors and Vector Mathematics” is high in regards to perceived applicability to courses in and out of students’ majors. “Coordinate System Choices” is low in regards to the perceived applicability to courses outside students’ major.

3. “Different Forms of Energy” is significantly high in regards to both perceived usefulness to classes outside students’ majors as well as applicability to the real world.
4. “Position, Velocity and Acceleration” is not significantly deviant with respect to any question.

5. “Understanding Newton’s Laws” is significantly high in regards to applicability to the courses outside students’ majors.

6. “Momentum and Impulse” is significantly high in regards to student interest, as well as classes within students’ majors.

List 2.5 Summary of SpQ11 findings.

These findings will be combined with the goals of implementing specific aspects of PBL (outlined in Chapter 3) in determining the general structure for the curriculum. This process will be outlined in Chapter 4 (Curriculum Creation Process).

Summer 2011 Email (SE11)

Summer 2011 Email (Appendix D) was sent out to all of the students in the previous Spring’s PH 211 course. This is the same student group that to SpQ11. This email was written to further enquire into what specifically was so appealing about Understanding Newton’s Laws. Response was voluntary, and student’s responses as well as the exact wording of the email can be found in Appendix D.

The poor timing of the email (the beginning of Summer break) could be a contributing factor to the small number of nine responses. Even so, the responses helped to address our initial question. In general, the responses suggested that the wide applicability and social prestige were positive aspects of Newton’s Laws.
unanticipated other end of the spectrum, there was a large proportion of comments to the effect of “Newton’s Laws don’t really interest me.” These statements are consistent with later non-parametric considerations.

As previously mentioned, the survey validation process was shadowed in the creation of WS11 and SpQ11. Common student responses to the qualitative questions posed in WS11 were used to format the questions in SpQ11. Furthermore, WS11 was used to refine the initial list of 11 topics in PH 211 to 6. The SpQ11 was used to further refine this to 4 topics, while also differentiating between aspects of student motivation.

WS11, SpQ11 and SE11 combined find “Vectors and Vector Mathematics” and “Coordinate System Choices” to be low in regards to student motivation. Due to a delay in non-parametric analysis, the surveys had mixed conclusions about topics of high motivation. While “Different Forms of Energy,” “Understanding Newton’s Laws” and “Momentum and Impulse” all positively deviated with respect to at least one motivational factor, only the former two topics will be used for the remainder of the curriculum creation process.

These three surveys have also helped us to gather a more sophisticated sense of what motivates students in our target population (PH 211). This knowledge will be applied in the next step of the process, in which pedagogical strategies will be studied, with the eventual goal being the development of a set of activities to address the issues of “Vectors and Vector Mathematics” as well as “Coordinate System Choices”, while using the topic of “Understanding Newton’s Laws” and “Different Forms of Energy” as positive models.
<table>
<thead>
<tr>
<th>Survey</th>
<th>Summary</th>
<th>Classes Administered to</th>
<th>Number in Course</th>
<th>Number of responses</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS11  Ap A</td>
<td>Likert Scale of motivation to learn about 11 different topics in PH 211. Free response questions about &quot;Very High Motivation&quot; and &quot;Very Low Motivation&quot; responses.</td>
<td>PH 213 (Prof. Demaree)</td>
<td>165</td>
<td>86</td>
<td>List of 11 topics refined to 6 topics</td>
</tr>
<tr>
<td>SpQ11 Ap C</td>
<td>Four &quot;clicker&quot; questions, asking students to rank each of the 6 topics from PH 211 in regards to personal interest, relevancy to success in major, relevancy to real world and relevancy to success in other 200-300 level courses outside major</td>
<td>PH 211 (Prof. Demaree)</td>
<td>199</td>
<td>107</td>
<td>Selected 2 topics as markedly low student motivation, and also differentiated between the four particular aspects of potential student motivation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PH 211 (10 am) (Mr. Ketter)</td>
<td>175</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>PH 211 (11 am) (Mr. Ketter)</td>
<td>181</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>555</td>
<td>277</td>
<td></td>
</tr>
<tr>
<td>SE11  Ap D</td>
<td>Email that asked more specific questions about &quot;Understanding Newton's Laws&quot;</td>
<td>Same as SpQ11</td>
<td>9 (total)</td>
<td></td>
<td>Further qualitative understanding of student's perception of &quot;Understanding Newton's Laws&quot;</td>
</tr>
</tbody>
</table>

**Table 2.6**: Summary of three distributed surveys.
Student Motivation

Every instructor would hopefully agree that their students’ willingness, need, desire and compulsion to participate in, and be successful in, the learning process (Levy and Campbell 2008) is very important. This concept is referred to as student motivation, and it is very commonly known, at least qualitatively, in society today. However, in order to teach in a way that stimulates this, instructors need to know much more about motivation than its simple definition:

What form of motivation is thought to contribute to better retention and understanding of material?

How can student motivation be modeled?

What factors are thought to affect student motivation?

How should instructors structure activities in their classes to motivate students to learn their underlying topics?

List 3.1 Questions relevant to student motivation that will be partially addressed

I do not claim to completely answer any of these questions. What I will do is elaborate on each question, hopefully providing a framework from which you, the reader, can use to further address the topic of student motivation.

Similar to PBL (see previous section of Background), the current research on student motivation is very dense with different people labeling their slightly different
theory with yet another acronym. I do not have the time or desire to address all of this variety. I will address the general approach employed in the research.

What form of motivation is thought to contribute to better retention and understanding of material?

The overarching label of motivation is often broken into two categories: intrinsic and extrinsic motivation. An extrinsically motivated student learns or performs tasks in order to attain an external reward such as a good grade, social acceptance from peers or scholarship money. A student is said to be intrinsically motivated when they do something for the sake of understanding (Donald 1999).

While not directly influencing academic performance, intrinsic motivation is correlated to independent learning and cognitive strategy use; these variables are directly linked to academic success (Levy and Campbell 2008). From an employer perspective, would you rather hire someone who tries their best to learn more and do better at something they enjoy doing, or someone whose performance is directly related to how big the holiday bonus is?

Intrinsic and Extrinsic motivation also present educators with a conundrum; as external to the student, how do we as teachers cultivate intrinsic motivation? While I think that this would largely be accomplished from general things such as classroom environment and grading practices, I will mainly leave this as an open question for you to consider.

This thinking can be directly applied to our four subtopics of student motivation (discussed in Chapter 2’s consideration of SpQ11). Two of these topics; perceived
relevance to courses inside students’ majors and perceived relevance to courses outside students’ majors, are very external things. A class you are taking and the demand that class has on prerequisite knowledge is an external influence, and is therefore more malleable. Students’ interest in a topic or their perception of how relevant that topic is to the real world is a different consideration. The generation of student interest from external factors provides an apparent paradox when research says that this interest is more powerful if based internally (Intrinsic motivation). Neither the literature nor I have a solution to this dilemma, but it is a relevant consideration to curriculum development.

**How can student motivation be modeled?**

Seifert 2004 provides us with a very nice overview of four theories of student motivation. I will briefly summarize each of these while also commenting on motivation modeling in general.

**Self-Efficacy** is synonymous with personal confidence, but can be formally defined as a person’s belief that they are able (or unable) to perform a task. This is correlated with self-worth, achievement performance and motivation. Students who are efficacious (perceive themselves as capable) are more likely to be self-regulating, strategic and metacognitive than students who do not feel efficacious. **Self-Efficacy Theory** uses a person’s self-efficacy as the central driving force behind their actions and decisions.

An **attribution** is the perceived cause of an outcome. It is a person’s explanation of why they failed a test, won a soccer game or chose not to go to work. Common attributions in an academic setting include effort, skills, knowledge, strategies, ability,
luck, the teacher’s mood or the teacher’s mistakes. Another aspect of attribution is whether the cause is perceived to be stable or controllable. Attribution Theory puts attribution as the central force driving student motivation.

**Self-worth** refers to the perception an individual has about their own sense of worth and dignity as a person. A person who has a sense self-worth knows that they are loved and respected as a person. This sense is created as a byproduct of a person’s success as well as ability. **Self-worth theory** proposes that success comes from ability and perceived effort. It goes into depth on the ramifications of high effort and failure (implying low ability, leading to shame and humiliation) as well as low effort or high ability successes (feelings of pride and self-esteem).

**Achievement goal theory** posits that students ultimately structure their actions around attempting to reach goals. These goals are primarily divided into two categories: **mastery** (or learning) and **ego-oriented** (or performance). Students who pursue mastery goals are often described as self-regulating and self-determined. These students are more likely to take responsibility for success as well as failure. Ego-oriented goal seekers tend to be more concerned with their performance relative to others, and are more likely to believe that ability is needed to be successful.

**What factors are thought to affect student motivation?**

Student motivation does not operate in a vacuum. Given adequate time and patience, we could spend the next week generating a list of all the things that could affect a student’s motivation to learn about any given topic. Instead, we will focus on several
key concepts: learning style, epistemological beliefs, course curriculum, and classroom environment.

**Epistemological beliefs** are the views that students have in regards to what it means to learn and understand physics (Elby 2001). Some students view physics as consisting of loosely connected pieces of information to be separately learned. Others see physics as a coherent web of ideas to be tied together. Another aspect to consider is what constitutes learning physics? Is memorizing formulas sufficient?

The final two factors that I will discuss are the classroom environment and curriculum. I present these two topics together due to the fact that it is very hard to separate where one ends and the other begins. These two areas are also where Physics Education Research attempts to make its largest changes. While I cannot propose an ideal version of either of these, I can briefly summarize what I currently consider to be ideal: curriculum needs to be structured in a non-trivial, as close to real world context as possible. Students need to directly interact with the material, and constantly generate questions and enquire into their solutions.

All of this background information leads to the consideration of a final question: **How should instructors structure activities in their classes to motivate students to learn their underlying topics?** Based off of everything I have read and know, there is no concrete answer (nor will there ever be). The amazing diversity of instructors, students, and cultures will never allow the creation of a one-size-fits-all template for education. Instead, instructors are left to develop activities to the best of their abilities.
In order to do this, epistemological beliefs, abilities, motivational styles, personal teaching style and much much more all need to be considered. Furthermore, all of this needs to happen at the same time. This generally bleak and overwhelming synthesis is not meant to doom educators into an unproductive depression. Rather, it is meant to point out that all of the factors that we have discussed do not operate in isolation. Rather, they are all pieces of a larger puzzle that is the educational process.

**Project-Based Learning**

Time or rather the lack thereof, is truly the bane of any educator’s existence. Teaching all the material that she or he wants in the time period given is never an easy task. Due to this dilemma, people often question whether there is sufficient time to incorporate new activities (or add additional ones) to their course. They are concerned that reformed-based strategies will lead to a lack of time to ‘cover’ traditional content. Although there is literature addressing this issue, it still remains a common concern. It is with this in mind that I would like to consider the worth of Project-Based Learning (PBL).

Our overview of PBL will begin with a background discussion and related terms definitions. We will then consider multiple cases of relevant curricular reform from various educational settings, and reflect on the perceived outcomes, benefits and disadvantages. I will then us these group findings to consider what is needed to implement PBL, and what the perceived benefits and disadvantages will be.

**What is Project-Based Learning?**
A thorough understanding of PBL is important for meaningful conversation about its implementation. I will synthesize and discuss several different definitions on my way to an operational definition. I will then consider several other terms that are similar to, but distinct from, PBL. Once PBL has been defined, I will consider five characteristics that must be present in order to merit the label.

It makes intuitive sense that the most common word in the five definitions of PBL that I am considering is “project.” But what exactly constitutes a project? Blumenfeld et al. 1991 chose to simply define a project as a relatively long-term, problem-focused unit instruction that integrates many disciplines. Holubova 2008 is more general in calling a project something that deals with “real world” physics, modern physics, or everyday problems. Still others choose to define the term ‘project’ more exuberantly than PBL, specifying that the complex task should involve students in design, problem solving, decision-making or investigative activities (Thomas 2000). Thomas further specified that a project engage students in autonomous work for extended periods of time and culminate in a realistic presentation or product. Combining these three definitions, I will define a project as a long-term activity that puts students in an autonomous, “real world” context to address a complex (often interdisciplinary) problem.

Now that we have an operational definition for ‘project’, we can move on to considering PBL. As with the term “project”, the term “PBL” has a wide range of meaning. It basically comes down to having the bulk of the definition being carried by a “project” or PBL. One is often extensively defined while the other only needs to be concisely linked. This is nowhere more apparent than with Thomas, whose extensive definition of “project” we have already considered. He can simply define PBL as a model
that structures learning around projects. Waters and Luste-Teasley 2011 go for brevity in
the extreme in saying that PBL assigns student teams to discuss, research and solve “real-
world” problems. He does not even introduce the term “project.” I will simply define

**PBL** as a model that organizes learning around projects.

Now that we have an understanding of what PBL and projects are, let us go more
in depth as to what characteristics must be present in order to constitute PBL. Thomas
outlines five characteristics: centrality, driving question, constructive investigations,
autonomy and realism. Working in order, **centrality** is merely the requirement that the
curriculum is projects. Projects are the central teaching strategy, but can occasionally be
complemented with traditional instruction.

A **driving question** is one that “drives” students to encounter central concepts
and principles of the discipline. This specification requires that questions not be trivial or
highly idealized. The core idea is that the questions asked in PBL are grounded in the real
world and the concepts of the course.

Furthermore, projects need to involve students in **constructive investigation**.
Investigation is a goal directed process that involves knowledge building, resolution and
inquiry. While investigation can be present in many different settings (design, decision-
making, *etc.*), it mainly acts to raise the quality of work being done by students. A non-
example of investigation would be a project that can be addressed with already-known
information or skills. This is actually defined as an exercise, and does not have the same
educational benefits.

**PBL** also includes a large amount of student **autonomy**. This requires that
projects are largely student paced and motivated. A non-example of this would be an
instructional booklet. While it may have a driving question and be central to the curriculum, they have a predetermined path, which is not present in PBL.

The final required aspect of PBL is that the projects are realistic. Realism can be present in the topic, task, student roles, context, collaborators that work with the students, results produced, audience, or the criteria for assessment. The projects use their realism or authenticity to motivate students to acquire skills relevant to “real life.”

We now have an operational definition for both PBL and project, as well as a set of requirements for what an activity must contain in order to fit in our category of interest. This in-depth understanding needs further assistance, as Education Research is fraught with terms that are remarkably similar to PBL. I will briefly address two big examples.

**Expeditionary Learning (EL)** is a learning model that grew out of **Outward Bound (OB)**, which is an adventure and service-based educational program that is known for its wilderness expeditions. While an expedition appears similar to a project, they are structurally very different. EL is a method for total school improvement, and requires a flexible schedule as well as school-wide reorganization. While PBL is arguably present in EL, PBL does not necessarily mean EL. PBL can be implemented in an educational environment with a traditional schedule and format, while EL cannot.

The second and final example of a term that is very close to PBL is Problem-Based Learning. Friedman and Deek 2002 define **Problem-Based Learning** as an active, problem-centered, student centered, collaborative and interdisciplinary model that utilizes small groups and operates in a clinical context. Problem-Based Learning was developed to give medical interns practice diagnosing and processing patients in a hypothetical
setting. As with EL, Problem-Based Learning has more structural requirements than PBL, while having the same general approach to how the lessons should be addressed.

PBL and projects have been extensively defined. We know that centrality, driving question(s), constructive investigation, autonomy and realism must be present in curriculum for it to fit into the category of PBL. We also know that Expeditionary Learning and Problem-Based Learning are different than PBL. Now that we have an in-depth understanding of PBL, we can move on to consider several cases of implementation in various educational settings.

Cases of Relevant Curriculum Reform:

Ramsier 2001, Holubova 2008 and Dym et al. 2005 all present the findings of their own personal implementation of PBL (or something very similar). It is a very powerful tool to review the current literature on the reform you are considering. I will summarize the findings of each group, and summarize an overall reaction to PBL.

Ramsier discusses the introduction of “active learning strategies” into the first semester of a university-level introductory physics course. He begins by outlining the main goals of the course. Some of the relevant goals are a focus on a team-working strategy, challenging students to use realistic problem solving, and introducing students to other transferable skills. Once the setting for the course reform had been set, Ramsier outlined the course design and structure.

The novel aspect of the course design is a team lab project, involving the main topics of the course. The requirements for this project seem very broad, as the students get to define a set of design criteria for a device of their choosing. Once approved by the
instructor, the students can then go about creating their final product, which is due at the end of the term. The course also emphasized group meetings outside of the three hours a week devoted to in-class time.

At the end of the course, students anonymously completed a survey that posed free-response questions and also asked the students to grade various aspects of the course on a 4.0 scale. Ramsier has a large amount of data from this. With regards to the project, students felt that the project helped them learn more physics than in the standard laboratory sequence (3.2), and also helped them to further develop organizational and writing skills (3.2). The goals of the project were clear and reasonable (3.4), but also required significant effort (3.8). This feeling may be responsible for the responses to whether the project should be included in future versions of the course (3.1).

Much of the feedback from the instructor’s perspective was focused on one particular student team that built a submarine. This group went on to receive attention from the local media, as well as the US Navy and the University of Akron Board of Trustees. They currently have a website available about their project, and their success has obviously motivated the administration to continue with this type of instruction.

As the course moves forward, they intend to address the possibility of student frustration surrounding less-than-full cooperation of team members. They hope to address this potential issue with log books, which would be used to document and reflecting on past successes and failure during the design process. They are also looking to move a previously optional “physics in everyday life” component to the actual graded work.
Holubova similarly looks at a college-level physics classroom. The introduction of PBL (which is explicitly referenced in this article) into the curriculum was motivated by the growing gap between how students live and what/how they learn. She also discusses the work that the university did with teachers in an attempt to prepare them to incorporate PBL.

The bulk of Holubova’s paper is dedicated to outlining different possible topics for projects. These include the photoelectric effect, the energy of the sun, water, and “wind around us.” While there is little discussion of how each specific project was implemented, the general formatting of each project is outlined. She also proposes an eight-step outline for how to prepare and realize project work.

Holubova then neatly summarizes the advantages and disadvantages of PBL. The student activity and opportunity to solve interdisciplinary problems was found to be one advantage. The opportunity for students to work as researchers as well as the use of various tools and technologies were also reported as being positive. The main disadvantage found was in regards to teachers having the time or interest in preparing interdisciplinary projects and collaborating with others. They also had difficulty finding a satisfactory way to evaluate the work of an individual member of a student team.

Dym et al. considered what variety of pedagogy would best cater to the needs of the engineering field. The fact that real-world engineering projects are completed while working in teams that focus on real problems make it is hardly surprising that modeling such experiences in the classroom would be beneficial. This connection transitions them
into their definition and discussion of PBL and how it satisfies the needs of the engineering community.

PBL is proposed to be the solution to the desire for engineers who are not only experts in their domain, but also adept communicators, team members and life-long learners. It is also said to address transfer, which is a key issue in the cognitive sciences. Transfer is defined as the ability to extend what has been learned in one context to other, new contexts. This skill is obviously of interest in the field of engineering, as well as education in general.

Dym et al. go on to explain multiple other aspects of PBL. They discuss how retention rates, design thinking, interest, learning motivation and performance in capstone design courses and experiences are all positively impacted by PBL. They largely consider PBL in the context of a first-year cornerstone course or capstone design course, but their general analysis is applicable to PBL in general.

The discussion then turns to how PBL can be made better. How authentic should PBL experiences be compared to industry design experiences? Can a pedagogical framework be developed for globally distributed communities? Lastly, how can students be evaluated and graded when much of the course work is done in a group?

The four different groups discussed above had different experiences with and observations about PBL. However, I find several common themes mentioned throughout.

1. PBL has helped to introduce group work, multidisciplinary knowledge, as well as designing skills.
2. PBL’s close relationship to the actual work environment is repeatedly mentioned.

3. PBL was adopted to develop a new skill set or stimulate motivation in students.

4. Two common difficulties with PBL appear to be authentic student evaluation as well as instructor and student time requirements.

List 3.2 Themes found in PBL literature

Conclusions:

Project Based Learning is an educational model that organizes learning around projects, which are long-term activities that put students in an autonomous, “real world” context to address complex (often interdisciplinary) problems. There are many terms that are closely related to PBL, including Problem-Based Learning and Expeditionary Learning. If an instructor or institution is willing to put in the time and effort to implement PBL, it is thought to give students an educational experience closer to the “real-world.” It also facilitates students having a more integrated, multidisciplinary knowledge base, which is thought to help with transfer. It also provides students with experience in teamwork, design and experimentation.

Unfortunately, PBL not will work in our given context. The entire syllabus and course structure would have to be re-written to accommodate the time-demands of true PBL. What we will instead do is focus on incorporating several specific aspects of PBL that we think will be particularly relevant to our attempts to stimulate student motivation. These aspects are:

1. Strong connection to a real-world context

2. Based around student inquiry
3. Open ended (as possible)

**List 3.3 Aspects of PBL to be incorporated into curriculum**

In addition to focusing on specific aspects of PBL, we know from the very beginning that there are some aspects of PBL that will have to be explicitly omitted from the curriculum. Theses aspects are:

1. Direct experience in an industry environment
2. Large time-commitments

**List 3.4 Aspects of PBL to not be incorporated into curriculum**

The real-world context, student inquiry and openness are all aspects of PBL that we believe can be implemented to some degree within an introductory physics with calculus course at OSU. At the same time, we suspect that direct industry experience and large time-commitments are not feasible.
A combination of the finding of the surveys conducted as well as the pursuit of specific aspects of PBL was used to create the specific wording of the curricular materials. SpQ11’s found that students were dis-interested with “Vectors and Vector Mathematics” and “Coordinate System Choices.”

The delay in non-parametric analysis resulted in a variation in the findings with respect to topics of high student motivation. Initial parametric tests found that students were particularly interested in “Different Forms of Energy” and saw particular real-world relevance in “Understanding Newton’s Laws.” These findings meant that I was looking to increase student interest in the two topics of low student motivation while looking to utilize their interest in “Different Forms of Energy” and real-world appreciation of “Understanding Newton’s Laws.” Reconsideration of the data with non-parametric methods suggests that other topics should have been leveraged. This realization was achieved after the curriculum process was already complete. I will fully address this discrepancy in Chapter 8.

The results of a previous survey distributed to instructors in departments that required their students to take PH 211 were also considered. One message from this survey was that instructors were interested in the incorporation of modern research into the course curriculum. This finding is very much in line with PBL’s emphasis on the need for a real-world context to stimulate student thinking and motivation. All previous knowledge was incorporated into striving to create a set of activities that utilized an interesting real-world context that is accessible to PH 211 students in order to address the two topics of low student motivation.
Determining this real world context was a very lengthy and open-ended process. Although the previously mentioned faculty survey did suggest Nanotechnology as a potential field of interest, there were still a very large number of potential areas off of which to base the activities. A variety of topic platforms were considered, including photo-luminescent molecules and the field of Materials Science in general. I eventually met with Professor Ethan Minot to discuss the basics of his area of research: carbon nanotubes. We then began to consider how they could be used in the PH 211 course. I also read a review article that addressed the characterization of nanotubes (Belin and Epron 2005).

Carbon nanotubes were selected as the real-world context for the activities for a variety of reasons:

- Prevalence in current research
- Accessibility to students
- Wide breadth of application
- Availability of information (Thanks again to Dr. Minot)

List 4.1 Reasons for selecting carbon nanotubes as real-world context for activities

Once drafted, the curriculum was modified several times. Feedback from many sources was collected, and many modifications were made before they were implemented. Although modifications varied greatly from activity to activity, common examples of modifications and/or suggestion that were made include:

- Reformatting to address what was to be spoken, written or noted
• Documentation and consideration of what students work would look like
• Increased structure to help students arrive at the activity goal within time constraints
• Changes in understanding of underlying physics of problem
• Clarification of carbon nanotube information

**List 4.2** Common Modifications made in drafts of Curriculum
The rest of this section is made up of the final product that was presented to the students, as well as reflections on each question. A closely-tied sequence of activities was presented during the 1st, 2nd and 3rd week of Spring Term 2012 to all three sections of PH211 studio. These specifically addressed vectors and coordinate systems. Additional activities that utilized carbon nanotubes were also implemented in the 6th and 9th weeks. During week 4, an activity inspired by the students work with vectors along the hexagonal shape of graphene was used to motivate the direction and magnitude of uniform circular motion but is not directly related to nanotubes so will not be considered further in this thesis.

All collected student work can be found in Appendix E

Comments not presented to students will be given in a text box that looks like this.

Each section will contain examples of student work for that week. Additional examples can be found in Appendix F.

WEEK 1

Activity 1

This activity looks to address students’ previous understanding of coordinate systems and vectors to an inquiry and real-world oriented context. By having students initially address the situation as they would like to and later transition to introduce a new way of solving
the problem (See next activity), I hope to engage the students in inquiry. This inquiry will hopefully invest the students more in the learning process and possibly increase personal interest in the topics.

**Time:** 20 minutes

**Purpose:** Define vectors for arrangements of atoms using different coordinate systems.

**Workspace:** All groups use the large group whiteboards.

**Task:** You have seen an example of how to draw a vector between two specific points and how to express a vector in terms of unit vectors defined by a choice of coordinate system. You have a piece of paper that shows how carbon atoms are arranged in graphene.

1. Choose two different coordinate systems (using different colors) that you can use to draw vectors on the graphene. For example, one coordinate system could consist of a standard horizontal x-axis and another axis which is rotated by some angle counterclockwise from the x-axis. The vector components will not be written the same way in the two different coordinate systems.

Coordinate System selection varied greatly depending on the student group. The coordinate system they select here will later be contrasted with coordinate systems conventionally used with graphene. This comparison hopes to emphasize how coordinate systems are a tool that can be selected in whichever way make the problem easier to solve.
2. Using each of these coordinate systems, determine the position of any two carbon atoms. The end result will be two vectors, one vector for each atom. Each vector will be labeled two different ways.

This is another group-dependent calculation that will be referenced later. The general goal of this is for student to see how messy the two components of their vectors are with a traditional-looking coordinate system that we expected most (if not all) students would try to use.

3. Compare your groups coordinate systems with those of the other groups at the table. Did any particular choice make the vectors easier to write down? What were the similarities and differences between the choices made by different groups, and what was similar and different for how the coordinate choice impacted the way the vector was labeled? Be prepared to tell the whole class which similarities and differences you found.

This question prompts students to explicitly compare and contrast coordinate systems that they generated and consider which one(s) worked best.

Activity 2

This activity transitions from students’ previous knowledge of the material to a new situation. Ideally, students would come to find one of the two proposed coordinate systems in their own group work. However, due to previously discussed time constraints, the process is sped up by providing the students with the new coordinate system and asking them to contrast it with their previous ones. This comparison will still allow the
student to select whichever coordinate system they feel is best, but is hopefully getting at the idea that some will make the problem a whole lot easier to solve. This idea of being able to select coordinate systems in an inquiry-based environment within a real-world context is present with the hope of bolstering student interest and perceived real-world relevance.

**Time:** 20 minutes

**Purpose:** Understand different coordinate choices used by researchers who work with graphene.

**Workspace:** All groups use the large group whiteboards.

**Task:** The instructor will show you the two coordinate system choices that are used conventionally by researchers in the field of graphene.

1. Using the atoms you picked in the previous activity, write a mathematical expression for the location of the two atoms in terms of each of these two new coordinate systems.

Having explored a situation given their own coordinate systems, students go back and recalculate using these two coordinate systems:
Students are also asked to contrast these two coordinate systems with the ones they selected in the previous activity.

2. Check your work with the whole table to make sure everyone has consistent results. Be prepared to discuss similarities and differences between these two coordinate choices with the whole class.

Groups are asked to cooperate and help each other get to the same result as well as prepare each other for a larger class discussion.

3. In the last few minutes of this activity, go online and find two places where graphene occurs in nature, and be prepared to say something about why it is useful in current research.

For week 1, students solely worked with graphene. In the following weeks, they will transition from graphene to a carbon nanotube. This final prompt is given to get them thinking about applications of graphene. We will build from this when they return next week.
This activity transitions from the 2-D graphene to the 3-D carbon nanotube. This transition is extending students’ work with coordinate systems and vectors towards large areas of research on carbon nanotubes. They are not directly working in this research, but they are addressing a topic that will hopefully spark their interest and motivate their participation in the activity. This is where the real-world context aspect of PBL is increasing its presence within our context.

**Time:** 20 minutes

**Purpose:** Continue analyzing graphene.

**Workspace:** All groups use the laptops and large group whiteboards.

**Tasks:**

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*Figure 5.2 Example of student work from Week 1 Activities*
• Find at least three uses for graphene by searching online.

Many students did not complete this at the end of last week, so it was posed here once again.

• Watch this video:
  http://www.youtube.com/watch?v=l3lRDG1HAmA&feature=related

• There is something very important that we've already studied which is missing from a scene in the first part of the video. What is missing?

See Bibliography for full video citation. An instructor noticed the omission of units in the video and added the second part of the question.

• Express the given vectors in terms of one of the coordinate systems from last week.

Figure 5.3 Example of the “given vectors” provided for students

Students had difficult with this previously, so a second practice with more structure was given. It will also be used to transition to carbon nanotubes.
• Use each vector (one at a time) from the previous activity and roll the graphene sheet so that the tip and tail of the vector touch. You have created a scale model of a carbon nanotube! In this application, the vectors are called the *chiral* vectors, and they are one way of characterizing a nanotube.

This is the transition from 2-D graphene to a 3-D nanotube. This is also the first encounter with the chiral vector, which will be used in later activities.

• What are the magnitudes of the chiral vectors in terms of the length, diameter, area, volume, and/or circumference of the cylinder?

This question is trying to prompt students to look at the geometry of the situation and realize that the magnitude of the chiral vector is equal to the circumference of the cylinder.

No student work was collected for Week 2

**WEEK 3:**

This activity directly mimics the process a scientist goes through in categorizing a carbon nanotube. Much more structure is present (due to time constraints), but this activity directly incorporates the real-world platform present in PBL. It does this while still being inquiry based as well as open ended as possible within our time constraints.

**Time:** 30 minutes
**Purpose:** Determine the magnitudes of carbon nanotube chiral vectors, consider the relationship between experimental measurements and chiral vectors, and determine how the chiral vector relates to properties of carbon nanotubes.

**Workspace:** All groups use the large group whiteboards.

**Tasks:** Follow the instructions below and check your answers with the other two groups at your table. Before you begin, review the attached pdf (See below) for information about the coordinate systems, angles, and distances relevant to graphene.
\[ c^2 = a^2 + b^2 - 2ab \cos C \]

Two conventional coordinate system choices are shown above

Examples of location of atoms in terms of basis vectors in 60° coordinate system shown above

\[ a_{cc} = 1.4 \text{ Å} = \text{distance between adjacent carbon atoms on graphene (Å = Angstrom = 10^{-10} m)} \]

\[ \sin(30) = \frac{1}{2} \quad \tan(30) = \frac{1}{\sqrt{3}} \]

**Figure 5.4** Graphene reference sheet given to students during Week 3 activity
1. How does the magnitude of a vector on the graphene sheet relate to the diameter of a carbon nanotube made from rolling the sheet along that vector? To help answer this question, roll the piece of paper to make a scale model of a nanotube such that the tip and the tail of the vector touch. The magnitude of the vector does not have to be equal to the width or height of the piece of paper. For example, the vector could go only half way across the piece of paper.

This is very similar to the last question from last week. The sole difference is that this question required another step (calculating diameter from circumference).

2. **The vector on the graphene sheet is called the chiral vector.** Determine the relationship between the magnitude of a chiral vector and the location of the tip of the vector in the 60 degree coordinate system, which is diagrammed in the pdf. The law of cosines is included in the pdf. You may find it useful.

See Appendix D for the full pdf reference sheet given to students. his question is asking the students to relate the components of the chiral vector to its magnitude. The hope is for them to get a general relationship that they can use in later parts of this activity.

3. Use the fact that, as diagrammed in the pdf, the nearest atoms of graphene are 1.4 Å apart to write the relationship in units of Å.

This step guides the students to refine their previous relationship to meaningful units.
4. Given the three sample vectors drawn in the handout, find their magnitudes using the relationship from step 3.

**Figure 5.5** Three sample vectors provided to students

The students then use their general relationship to calculate the magnitudes of several specific examples of chiral vectors.

5. Atomic Force Microscope (AFM) images and Raman Spectroscopy data indicate the existence of nanotubes with diameters given in the handout. Which chiral vectors correspond to which diameters?
*Three different versions were distributed, each with a different set of diameter measurements that corresponded to two different chiral vectors.

Figure 5.6 Handout given to students for Week 3 activity
This question is when we relate what we are doing in class to the real world. Scientists normally measure the diameter of their nanotubes and then have to work backwards. So do we! In summary, the worksheet asks students to decide which of the given chiral vectors are present in their sample (given by nanotube diameter).

6. Search online to determine how chiral vectors relate to the properties of carbon nanotubes.

Students are then free to explore how the concept we have investigated applies to their lives.

Figure 5.7 Example student response to Week 3 activity
WEEK 6:

This activity is an example of how structure and open-endedness are difficult to balance within our course context. While a real-world context was directly addressed during the entirety of the activity, a large amount of scaffolding was needed to make this activity fit. I think this is a case where the questions turned out to be less open-ended than initially desired as a result of time constraint.

**Time:** 40 minutes

**Purpose:** Apply Newton’s laws, solve a model problem and compare the solution to the proposed structure.

**Workspace:** All groups use the large group whiteboards.

**Task:** Solve a problem using a very simple model for a space elevator.
A space elevator would be a cable which would extend from the surface of the Earth into low-Earth orbit and be used to launch satellites by moving them up the cable and
releasing them. To function properly, the cable would have to remain at the same position with respect to the Earth at all times. This is related to Geosynchronous orbits. Look at the image at the top right of this webpage:

A space elevator would be quite complicated mechanically. Briefly look at this webpage:

In order to construct a very simple model, we will first consider a rope with two balls attached to it. A person's hand spins the rope such that the balls rotate in uniform circular motion in the horizontal plane. See Figure 1 in the attached pdf.

• Draw a force diagram for each ball.
• Find the ratio of the tension in the left half of the rope to the tension in the right half. Use the fact that the radial acceleration is equal to the product of the angular speed squared and the distance from the axis of rotation. Notice that the balls have the same angular speed.
• For a space elevator, why would the part of the cable at the center-of-mass position feel forces in both directions? Why would the cable need to be thickest at the center-of-mass position?

A figure (not to scale) of a space elevator is included in Figure 2 of the attached pdf. The figure indicates that the cable is thicker in the middle.
• Compare the force diagram included in Figure 2 with the force diagram for the ball in the middle of the rope. What is the same? What is different?

We want to determine how much tension the cable must provide at its thickest point. The pressure on a cross-section of the cable at the center-of-mass position is \( P = \frac{(F_u - F_L)}{A} \), where \( F_u \) and \( F_L \) are defined in the diagram on the pdf, and \( A \) is the cross-sectional area of the cable.

• Write an equation for the net force on the thin red slab at the center-of-mass position. Note that you can't simply use \( mg \) for the force of gravity. If you don't know the equation yet for the gravitational force far from the surface of the earth, then it is given in the pdf.

• Write this equation in terms of the pressure \( P \) defined above and solve for \( P \) on the left side.

Tensile strength \( T \) (roughly speaking) is the maximum pressure the thin slab can withstand before breaking. Replace the symbol \( P \) with the symbol \( T \). Replace mass with the product of density and volume. Replace volume with the product of cross-sectional area and height. Since we're looking at an infinitesimally thin slab, replace height with \( dr \), an infinitesimal amount of distance in the radial direction, and the tensile strength with \( dT \), an infinitesimal amount of tensile strength.

• Now look at the equation located near the bottom of the pdf. This is the correct equation for the tensile strength of the cable's center-of-mass. Verify that the equation you derived is correct.
The generation of a mathematical model that was simple enough for PH 211 students to consider while also not being trivial was very difficult to generate. This activity directly addresses one of the major issues with introducing real-world phenomenon in an introductory course: the students do not have the knowledge to address the situation (yet). This activity strove to address a real-world context and address it at an introductory course level. Although I was the principle creator of an earlier draft, my proposed model yielded imaginary lengths. As such, Professor Demaree reconstructed the activity over a short period of time.

- The solution to this equation is given directly below in the pdf. Using the numbers given, red groups determine the required tensile strength if the cable is made of carbon nanotubes and compare it to the value given in the pdf, green groups do the same for steel, and purple groups do the same for Kevlar.
- Compare the values you get with the others at your table. How does the required tensile strength compare to the maximal tensile strength that material can provide without breaking?
- Why would the space elevator cable be impossible to build without carbon nanotubes?
- For more information about the space elevator, try:
  http://www.newworldencyclopedia.org/entry/Space_elevator
  For results see:
  http://www.mill-creek-systems.com/HighLift/chapter2.html
Having established a model, the activity then prompts students to utilize the model in considering possible materials to construct the space elevator with. This second section is more open-ended and inquiry-based than the earlier section, as more extensive scaffolding was needed to help students through mathematics in a timely fashion.

**Figure 5.9** Example of student work for Week 6 Activity

**WEEK 9:**

This activity continues to be open-ended as possible and inquiry-based while also considering time constraints. This activity also addresses a new aspect of carbon nanotube application in an attempt to address a real-world context that is accessible to PH 211 students.
Time: 45 minutes. Note: The instructor will check everyone's work after they've completed Parts 1 and 2.

Purpose: Consider the energy-storing capabilities of azobenzene with an attached carbon nanotube structure and utilize understanding of stable and unstable equilibrium points from previous activities.

Workspace: Green groups write the answers to Parts 2 and 3 on the StarBoards and all other answers on the large group whiteboards. All other groups use the large group whiteboards.

Task: Figures 1 and 2 are in the attached pdf.
Figure 1:

![Diagram of a molecular cycle involving sunlight absorption and energy transfer.](image)

Figure 2:

![Graph illustrating energy levels and reaction energy changes.](image)

**Figure 5.10** Handout given to students for Week 9 Activity
Part 1:

Azobenzene is a photoactive molecule which means it changes its shape in response to light, allowing it to store energy. Two researchers at MIT (Kolpak and Grossman) designed a molecule that contains both azobenzene as well as carbon nanotubes (CNTs). This material, called Azobenzene-Functionalized Carbon Nanotubes, absorbs sunlight and stores the energy from the sunlight in its chemical bonds. This process is depicted in Figure 1 in the attached pdf.

1. The quantity $h\nu$ is the amount of light energy absorbed by the molecule. Explain how the absorption process is depicted in Figure 1.

2. What are the units of $h\nu$, $E_a$, and $\Delta H$?

3. Where on the graph is the stable state for stored energy?

4. According to Figure 1, what must happen in order for this energy to be released and the molecule to return to its initial shape?

5. Based on the answers to the above questions, determine appropriate explanatory names for $h\nu$, $E_a$, and $\Delta H$.

This series of questions is guiding students through analyzing Figure 1, which can be found in Appendix H. This diagram provides lots of good information, but would take students a very long time to analyze if not given structure.

Part 2:

Think of the energy stored in a Azobenzene-Functionalized Carbon Nanotube molecule as the gravitational potential energy of a marble rolling on a track with the same shape as the graph of energy shown in Figure 2.
1. Where is the lowest stable equilibrium point? This point is called the ground state.
   Assume the energy of the ground state is zero.

2. What energy corresponds to the local maximum?

3. If a marble starts at the lowest stable equilibrium point, but gains more energy
   than the local maximum, then how would it move?

4. In Figure 1, for the processes labeled with red arrows pointing up, is the molecule
   gaining or losing energy? How do you know?

5. Identify the portion of the graph that represents the stored energy.

6. According to the diagram, what causes the molecule to settle into this region of
   the graph so that energy can be stored?

7. The values of $E_a$ and $\Delta H$ are very important to potential applications. If $E_a$ is too
   small, then explain why the molecule won't stay in the photo-excited state.

8. Why is it best for $\Delta H$ to be as large as possible?

While continuing to provide an outline of how to go about analyzing the diagram, this
section also connects situations that the students have previously worked with to the new
situation provided.

Part 3:

Azobenzene-Functionalized Carbon Nanotubes strike a balance between storing a lot of
energy (large $\Delta H$) while continuing to store the energy until triggered (large $E_a$). A
solution of azobenzene, without carbon nanotubes, can also store light energy, but is
relatively unstable and cannot store as much energy.

1. What does "relatively unstable" mean in terms of the potential energy graph?
2. What does "cannot store as much energy" mean in terms of \( hv \), \( E_a \) and/or \( \Delta H \)?

3. Construct a possible energy graph that would depict the characteristics of azobenzene without carbon nanotubes.

After discussing the physical interpretations of several values, students are asked to apply what they know to explain general wording about the situation. They are also asked to create a new energy curve that fits the given descriptions.

Part 4:

1. Azobenzene-Functionalized Carbon Nanotubes release energy in the form of heat. What advantages and disadvantages does this have?

2. Read articles about Azobenzene-Functionalized Carbon Nanotubes and fulvalene diruthenium online using a search engine. What are some other materials that are being considered for this same purpose? What are their advantages and disadvantages?

The activity ends with an open-ended consideration of research being conducted in this field. This open-ended ending is an attempt to incorporate a little bit of PBL’s open-ended exploration of topics.
Figure 5.11 Example of student work for Week 9 activity
Observation of the activities implementation in the classroom as well as student feedback will be used to gauge the success of the activities. Due to time constraints, only part of the student feedback can be included in this iteration of research, as a set of open-ended questions will be distributed in conjunction with an end-of-term course evaluation. I will first discuss the observation of the activity implementation, then present student feedback.

Observation of Activity Implementation

This section is written based off of interviews with Professor Dedra Demaree, who observed many of the activities being implemented in conjunction with other work for the physics department. I also consider feedback given by Mr. Dave Bannon and Mr. George DeBeck. Both were instructors who implemented the activities.

My comments will separately address each week

Week 1 (Final Two Activities of Day):

The overall purpose of these two activities was to have students see how to write the location of atoms within a graphene lattice. This activity also hoped to demonstrate that some coordinate systems that weren’t the standard horizontal and vertical choices made this task much easier. It was observed that students selected “easy atoms” (atoms very close to their coordinate system’s origin) for analysis. As a result, students had a hard time noticing any difference in difficulty between the different coordinate systems.
Explicit instructor encouragement to look at atoms farther away from the origin was needed.

George transitioned from the students’ own coordinate systems to considering the two coordinate systems convenient for graphene by writing them on the white board and asking students if “they were ok with them.” When met by minimal response, he asked students to pick harder atoms and use one of these two coordinate systems.

All sections of the course ran out of time. Many of the groups were unable to address the final part of the activity, which involved looking for applications of graphene online. This last part was therefore added to the following week’s activity.

**Week 2 (Final Activity of Day)**

The overall purpose of this activity was to introduce the concept of vectors as they apply to graphene. Students also began to transition from 2-D graphene to 3-D carbon nanotubes. Students were very enthusiastic to call out applications of graphene that they found in their research online. It resulted in several conversations outside of class about a variety of these applications. This outside engagement suggests increased student interest in the related topic. However, doing this small sub-part took over 10 minutes of class time.

Once again, time was an issue, and very few students seem to have gotten to the final part of the activity in which they related the magnitude of the chiral vector to a dimension of the corresponding carbon nanotube. Students only had 6 minutes of class left after watching the carbon nanotube video. Once again, parts of the activity were carried over to the next week.
Week 3 (Not the Final Activity of Day)

The overall purpose of this activity was to assist students through a theoretical classification of carbon nanotubes. After a group discussion with the instructors it was determined that students never appeared to be comfortable with basis vectors. Additionally, the instructor himself wrote out the vectors in another non-traditional way. This was problematic, as one way of labeling atoms in graphene was by simply considering writing down coefficients of basis vectors. Instructors suggested that a square lattice be used as an intermediate step to help students think in terms of basis vectors in the future.

Despite this confusion, most student groups successfully identified the correct carbon nanotubes as present in their theoretical sample. This suggests that at least some of the desired connections (coordinate system use, vector mathematics, etc.) were made.

The activity was not the last one this week. This was based on a suggestion made by Dave Bannon to ensure that the students have enough time to complete this activity sequence. As a result, everyone was able to finish it in its entirety.

Week 6 (Not Final Activity of Day)

The overall purpose of this activity was to have students apply Newtonian mechanics to the novel situation of a space elevator in a way that highlighted carbon nanotubes’ importance in this research area. This week’s activity faced several technical issues in the first section of class. In that section, one of the teaching assistants provided students with information that was inconsistent with the model outlined in the activity. As
a result, students were unable to solve the model with the extraneous force that had been provided to them. In addition, one of the instructors did not seem to be as aware of the goals of the activity, and did not clearly lead discussion at the end of the activity. The activity took ~50 minutes which was far longer than anticipated.

The second instructor was contacted and informed of the difficulties. Once again, he addressed this issue by providing students with more guidance at the start of the activity. As part of this guidance, he provided students with the Free Body Diagram of the situation. Despite this, the activity still took approximately the same amount of time. On later investigations, it was found that the toy model suggested by Dave Bannon using uniform circular motion was outside the range of topics addressed in the course, and students had never connected radial acceleration to net force prior to that part of the activity. Had this information been known ahead of time, further scaffolding would have been provided.

For both instructors, the activity ended with a qualitative consideration of why steel and Kevlar would be way too heavy and not strong enough for a space elevator cable, while nanotubes provide the only known material that might solve this design issue in the future, though the students were not able to complete that calculation for themselves.

**Week 9 (Final Activity of Day)**

The overall purpose of this activity was to have students analyze an energy-curve that was relevant to an alternative sustainable fuel sources (that utilized carbon nanotubes). Instructors thought that the activity nicely built on the previous two problems
that dealt with a metal ball on a track and a pdf worksheet and used potential energy graphs to relate to motion of a particle. The common topics that mentioned were critical points and turning points, as relevant to potential energy diagrams.

The largest student issue was considering what the units of the horizontal axis were in the figure given to them for this activity. There were also some issues interpreting the diagram in general, and it was suggested that the instructor just explain the diagram in the future. I think this would undermine the desire to incorporate student enquiry into the activity, and would instead consider reformatting the figure to make the steps of energy storage in Azobenzene-Functionalized Carbon Nanotubes clearer.

The activity nicely addressed the common student issue of assuming that both axis correspond to a position (as is true with the commonly used case of a roller coaster), but could benefit from being lead up to.

The activity’s length was intimidating (as it also was in Week 6). It is suggested that it be intentionally formatted into three separate sequential activities so as to not deter students.

There was minor confusion over the use of “v” in hv present in Figure 1 (Appendix H), and it is suggested that f be used in the future.

In all, the activity went “at least moderately well” in the sense that students were able to solve the activity with well-formulated solutions and seemed to inspire a considerable amount of out-of-class thought in both students and instructors (as reported by Dave Bannon).

Dynamics That Arose During Activity Implementation
There are a variety of dynamics or patterns that emerged during the implementation of the activities. This list is generated based off of the interviews with the class observer and two instructors:

- Ran out of time
- Additional information desired (by both instructors and students)
  - Ex: Clarification on Units on the Horizontal Axis of Week 9, Figure 1 (See Chapter 5)
- Instructors and teaching assistants needed to better understand the activities before implementing them in the classroom
- Enthusiasm around qualitative discussions of topics
- Desire for activity to be broken into smaller pieces

**List 6.1** Dynamics present in classroom during activity implementation

This list will be useful during the future consideration of curriculum improvement. For a full discussion of this, see Chapter 9.
Student feedback will be collected by redistributing the SpQ11 questions to both a control population (PH 211 course that did not complete the created activities) and the students who completed the activities as well as through three open-ended questions included in the overall course evaluation. The data from the redistributed questions, which I will refer to as Spring 2012 Quizdom Questions (SpQ12), are fully analyzed in this section. Due to the timing of course evaluations and the completion of this thesis, a discussion and explanation of the three open-ended questions will be included, but the responses will not.

Spring 2012 Quizdom Questions (SpQ12)

The same four questions from SpQ11 (Appendix C) were presented to two different PH 211 classes at OSU. One class was a traditional PH 211 course (Control Group) while the other was the Studio-Style course who implemented the activities created. These questions were presented in the same manner and approximate timing as SpQ11.

The same Chi-Square Test with one alteration was utilized to analyze SpQ12 data. Instead of using the same calculation method for expected values (as outlined in Chapter 2), I used scaled values from SpQ11. The data was scaled so that the total number of observations was equal, while not affecting the distribution of the data. Consider this single case:
### Table 7.1 Example Calculation of Scaled Expectation Value of SpQ11 Responses

* Scaled is SqQ11 Response x Ratio of total Responses

Using this computational method, the deviation from the SpQ11 results of the two classes responses were calculated. I will present one example of this data (see Appendix I for all results) and verbally summarize the findings:

### Table 7.2 Example of comparing SpQ11 and SpQ12 responses

As explained in Chapter 2, the weighted rank was used to determine how the topic varied compared to SpQ11

**Findings:**

There were very few variations of statistical significance between SpQ11 and SpQ12. The only significant variations that did not occur in both the Control group and the Studio group were changes with respect to the two topics that were not explicitly addressed by the developed activities (“Position, Velocity and Acceleration” and
“Momentum and Impulse”). While “Vectors and Vector Mathematics” did deviate significantly in a positive way, it was in respect to perceived relevance to courses outside students’ majors. Furthermore, this change occurred in both the Control group and the Studio group.

While the results of SpQ12 very strongly suggest that the implementation of the created activities did not impact student’s interest in or perceived relevance to real life of “Vectors and Vector Mathematics” or “Coordinate System Choices.” While there are a variety of other factors that could have contributed to this apparent lack of change, such as variation of instructor’s teaching techniques, students not reaching the desired points of the activities, fluctuations in student population, etc., there are no grounds to conclude that the created activities affected student motivation with respect to the two topics of low motivation.

This non-result can be attributed to a variety of factors. As discussed in Chapter 2, the surveys created in conjunction with this thesis were created in a way that “shadowed” complete validation. As such, specific change is very difficult to conclusively measure. Furthermore, the activities’ implementations were heavily impacted by student and learning curves experienced throughout. One example of this can be found in Week 1’s activities in which students chose atoms in graphene that were very close to their selected origin, making the different coordinate systems to have essentially no effect on the ease of calculation.

Many of these factors are things that can be addressed over time. While not formally changing anything, these activities were observed to inspire student and instructor interest both in and out of the classroom.
Qualitative Feedback

Three open-ended questions were added to the end of term evaluation of the PH 211 course. These will be voluntarily filled out at the end of the trimester.

1.) What parts of the carbon nanotube activities (completed in studio) did you find most useful and/or interesting?

2.) What parts of the carbon nanotube activities (completed in studio) did you find confusing or irrelevant?

3.) Do you think that the carbon nanotube activities were different than other studio activities? Please explain.

List 7.1 Open-ended questions posed to students on post-course survey

The first and second questions are hoping to gauge students’ interest in the activities and the underlying topics. We also hope to get explicit student recommendations as to how we could improve the activities. The last question is geared towards seeing if the aspects of PBL that we strove to incorporate into the activities’ structure were noticed. We were also interested in the way that students perceived this format to be different (if at all) from regular activities.

Due to the timing of when students fill out end-of-course evaluations, responses to these three questions will have to be included in a later write-up of this research.
There are several aspects to this thesis. One major step in its formulation was me learning how to differentiate from what I had learned, what I had explicitly proven with data, and what I had gleaned from others. This section discusses my perceived educational development over the course of my thesis creation. I have loosely structured my response by considering: What went well? What didn’t work/was different from expectations? General Comments.

What went well?

As I will note in the next section, written communication made clear communication difficult. It was sometimes difficult for instructors to decipher what the actual question I was proposing to give students was. One way of addressing this issue was to write out solutions to each of the questions. This often clarified what questions were asking. This also made thinking from the student’s perspective simpler while also being very helpful in determining if enough information was given by the question.

Explaining my goals and ideas to others was also very helpful. A large amount of understanding is required to be able to verbalize plans in a way that made sense to others. This is especially true when explaining something to another instructor who must understand the material enough to present it to students. This was largely possible due to the general atmosphere of collaboration within the PER group as well as the OSU Physics department in general.

Using others as a resource in determining topics for the activities was also very useful. Once “Coordinate System Choices” and “Vectors and Vector Mathematics”
were selected as the topics to address, the issue then became how to address them.

Talking with instructors gave structure to this very open-ended process. This was done through informal meetings with research faculty. I would first explain the general context of interest (PH 211 activities to address vectors and coordinate systems). I would then ask if there were any topics within their area of research that could be tailored to this setting.

**What didn’t work/was different from expectations?**

*Written communication*, while being very convenient, also contributed to a great deal of confusion during the curriculum drafting process. In the earlier drafts of the activities, I had a *coding system to differentiate between what was spoken to students, provided as a resource to instructors and anticipated student questions or issues*. This coding system only made sense to me, but was the primary documents that I was sending to others to describe the activities. Direct conversation would clarify our issues, but solely written communication made addressing this issue very.

*Open-ended problems or problems with less scaffolding came in direct conflict with time as well as knowledge constraints*. It is very difficult to approximate PBL in a student population that is just beginning to adjust to a physics class.

Expectations around critical thinking and problem solving are still being established, and the reservoir of physics knowledge available to students in just beginning to take shape. As a result of this, the final lessons are much more structured than I originally intended.

Once “Coordinate System Choices” and “Vectors and Vector Mathematics” were chosen as the topics of interest, a topic through which these topics would be addressed had to be chosen. Once this was determined to be Nanotechnology, another round of
refinement was needed to end up with Carbon Nanotube Characterization. Both of these transitions or narrowing of topic considerations were very time-consuming. A repeatable process or outline for this has yet to be created. The previously mentioned practice of meeting with Professors was the one method that addressed this issue.

**General Comments:**

Many of the modifications made to the curriculum were related to feasibility due to knowledge and time constraints. Conferring with instructors on this was invaluable, as they have extended experience working with PH 211 students, and could evaluate accordingly. As someone who did not interact with these students on a weekly basis, I had an extra step to go through in designing curriculum for them. This leads me to suggest that curricular reform and design is easier if you were doing it for a student population that you already interacted with extensively. I know this sounds very intuitive, but this whole experience reiterated it so strongly that I feel the need to note it.

Communicating the goals of the various activities was an additional barrier that I attempted to address during this process. It was their understanding of the activity, not mine, that ultimately impacted how the activities were implemented. While this provided a very unique learning process, I do look forward to entering the education field myself, so that I can directly design and implement my own curriculum.

Another unanticipated twist occurred in the data analysis of SpQ11. Part of my thesis work was learning the proper statistical method to analyze my data. I did not know how to do this analysis after the distribution of SpQ11, and initially used parametric analysis.
As discussed in Chapter 2, this is not a valid method, but it was to serve as a place holder before I learned the correct way to go about analyzing. However, the curriculum process quickly progressed while my statistics knowledge did not. When I did learn of the appropriate non-parametric test to apply, the curriculum had already been created. When I returned to analyze the data with the Chi-Square test, I received the somewhat different result that momentum and impulse would have been a stronger choice for a high motivation topic than Newton’s laws. Due to this time-delay of statistical capabilities, I have two aspects to my consideration of topics of low and high student motivation. The first is the original parametric analysis that I acted upon in the curriculum development process, and the second is the non-parametric results that I can compare before and after the activities were distributed (See Chapter 7).

I will end with an outline of the entire curriculum-creation process:

1.) Determine topic for thesis: curriculum geared to foster motivation in areas that were currently low in this area.

2.) Determine which areas in PH 211 curriculum are particularly low and particularly high in regards to student motivation

3.) Determine specific topic around which to structure activities

4.) Create exact wording of activity through an iterative drafting process with collaborators.

**List 8.1 Outline of curriculum creation process**

An initial goal of my thesis was to create an outline for curricular development that targets student motivation. List 7.1 is as specific of an outline that I can suggest based on
my experience throughout this thesis project. As with many things in education, there is certainly no single correct way to develop a new set of curriculum. Additional experiences in curriculum development as well as teaching in general will help me add to and refine this process. As is common in research, this goal became a secondary one as my work progressed, and I look forward to spending more time addressing it in the future.
CONCLUSIONS AND FUTURE WORK

1.) What topics in PH 211 are particularly low in regards to student motivation? More specifically, what is the nature of this motivation?

“Vectors and Vector Mathematics” and “Coordinate System Choices” were determined to be topics of particularly low student motivation. More specifically, they were both found to be low in regards to student interest as well as perceived relevance to the real-world. This finding helped to guide the large and qualitative goal of curriculum creation towards addressing these two topics. These two topics were more specifically found to be low in regards to student interest and perceived relevance to real-life. These shortcomings alight very closely with the aspects of PBL that was incorporated into the curriculum.

It was also found that “Different Forms of Energy,” “Understanding Newton’s Laws” and “Momentum and Impulse” were high in regards to student motivation. The former two of these topics were used in conjunction with specific aspects of PBL to form the general structure of the activities.

2.) What specific features of Project Based Learning (PBL) can be leveraged within the constraints of an introductory physics with calculus course at Oregon State University (OSU)?

The strong connections to a real-world context and basis around student inquiry were successfully incorporated to some degree within the constraints an introductory physics with calculus course OSU. Students’ interest did indeed seem to be sparked by
several qualitative discussion aspects of the activities. However, the open-endedness of the activities as a whole was much less than originally desired.

3.) What dynamics emerge during the implementation of the activities in the classroom setting?

While the dynamics in the classroom are heavily dependent on external factors, a few dynamics did seem to emerge during the implementation of the activities. Administrative dynamics included running out of time as well as the desire for more information and smaller pieces of questions. Communicating with instructors also posed a barrier to implementing the activities in the desired way. Students and instructors were also enthusiasm towards qualitative exploration of the topics.

4.) Did the created activities change students’ perception of topics of low student motivation?

According to SpQ12, the created activities did not alter students’ perception of topics of low student motivation. When the previous student population was compared to the Control group Studio group, no statistical deviation occurred in just the studio group. There was some variation between all the populations, but none with respect to the two topics that were targeted by the curriculum. Qualitative student responses have yet to be collected and considered.

All of this serves as both a case study as well as a consolidated resource to those in the educational community. Not only is this an example of an attempt to specifically
alter the motivation of students to learn about specific topics, but it also provides the beginnings of a qualitative map of how to go about doing it. Aside from my own personal learning and experiences, the best thing this thesis can accomplish is to assist or inspire other educators to better motivating their students to learn.

I will end with a consideration of future considerations and extensions of this research:

- Incorporate student feedback into the consideration of the success of the activities implementation.
- Acquire more extensive instructor feedback be able to better format and communicate about curriculum development in the future.
- Revise activities based on this feedback
- Extend this concept of revision to other topics?
- Develop an in-depth repeatable procedure for curricular development focused on inspiring student motivation and using aspects of PBL

**List 9.1 Future Considerations**


Please check the box for each of the following Ph211 topics corresponding to your level of motivation to learn them (you do NOT need to include your name on this paper):

<table>
<thead>
<tr>
<th>Ph211 Topic</th>
<th>Very Low Motivation</th>
<th>Somewhat Low Motivation</th>
<th>Average Motivation</th>
<th>Somewhat High Motivation</th>
<th>Very High Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vectors and Vector Mathematics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coordinate System Choices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagrammatic Representations of Problems (Motion Diagrams, Free Body Diagrams and Energy Diagrams)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position, Velocity and Acceleration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Types of Motion (Projectile, Relative, Uniform Circular, Free Fall)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using Net Force to Analyze Motion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understanding Newton’s Laws</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Momentum and Impulse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conservation Laws</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Different Forms of Energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work and Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTHER? Name it here:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For a subject you marked as “Very High Motivation”: Why were you motivated to learn about this topic?

For a subject you marked as “Very Low Motivation”: Why were you not motivated to learn about this topic?
### Students Responses to Winter Survey 2011 (Quantitative Ranking)

<table>
<thead>
<tr>
<th>Ph211 Topic</th>
<th>Very Low Motivation (-2)</th>
<th>Somewhat Low Motivation (-1)</th>
<th>Average Motivation (0)</th>
<th>Somewhat High Motivation (1)</th>
<th>Very High Motivation (2)</th>
<th>Weighted Average Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vectors and Vector Mathematics</td>
<td>11</td>
<td>13</td>
<td>36</td>
<td>21</td>
<td>4</td>
<td>-0.07</td>
</tr>
<tr>
<td>Coordinate System Choices</td>
<td>10</td>
<td>24</td>
<td>33</td>
<td>15</td>
<td>4</td>
<td>-0.24</td>
</tr>
<tr>
<td>Diagrammatic Representations of Problems (Motion Diagrams, Free Body Diagrams and Energy Diagrams)</td>
<td>5</td>
<td>15</td>
<td>32</td>
<td>27</td>
<td>6</td>
<td>0.16</td>
</tr>
<tr>
<td>Position, Velocity and Acceleration</td>
<td>3</td>
<td>12</td>
<td>32</td>
<td>28</td>
<td>11</td>
<td>0.37</td>
</tr>
<tr>
<td>Types of Motion (Projectile, Relative, Uniform Circular, Free Fall)</td>
<td>6</td>
<td>11</td>
<td>38</td>
<td>20</td>
<td>9</td>
<td>0.18</td>
</tr>
<tr>
<td>Using Net Force to Analyze Motion</td>
<td>5</td>
<td>9</td>
<td>33</td>
<td>32</td>
<td>7</td>
<td>0.31</td>
</tr>
<tr>
<td>Understanding Newton’s Laws</td>
<td>2</td>
<td>8</td>
<td>35</td>
<td>32</td>
<td>9</td>
<td>0.44</td>
</tr>
<tr>
<td>Momentum and Impulse</td>
<td>6</td>
<td>16</td>
<td>39</td>
<td>18</td>
<td>7</td>
<td>0.05</td>
</tr>
<tr>
<td>Conservation Laws</td>
<td>2</td>
<td>12</td>
<td>35</td>
<td>25</td>
<td>10</td>
<td>0.35</td>
</tr>
<tr>
<td>Different Forms of Energy</td>
<td>4</td>
<td>11</td>
<td>28</td>
<td>29</td>
<td>13</td>
<td>0.42</td>
</tr>
<tr>
<td>Work and Power</td>
<td>3</td>
<td>13</td>
<td>34</td>
<td>28</td>
<td>7</td>
<td>0.27</td>
</tr>
<tr>
<td>Total</td>
<td>57</td>
<td>144</td>
<td>375</td>
<td>275</td>
<td>87</td>
<td></td>
</tr>
</tbody>
</table>

**Table A.1:** Numbers indicate the number of students who marked that particular option (Ex: 25 said they were ‘Somewhat Highly Motivated’ to learn about Conservation Laws). The values assigned to each category for the calculation of the weighted average is denoted in the top row [(-2), (-1), etc.].
Students Responses to Winter Survey 2011 (Open-ended Questions)

For a subject you marked as “Very High Motivation”: Why were you motivated to learn about this topic?

Format: (37 Total Responses)
Student response
(Interpretation)

The higher motivation items I find more interesting to learn about. Things more applicable to my major (Interested in topic, Applicable to major)

Because I’m interested in studying sustainable energy so I wanted to learn more about different types. (Interested in topic)

These areas allow you to solve a lot of really cool problems that are really complex. These skills are also necessary for my field of study; M.E. (Helps solve problems, Applicable to major)

Energy conservation is a great universal concept. (Concept itself is important to understand)

They will help with other classes in my major (Applicable to major)

If I can accurately represent a problem, then I can figure out the concepts to apply correctly. (Useful to solve other problems)

I enjoy how they are often applicable to every day life (Applicable to every day life)
I enjoy kinematics much more than electricity and magnets, it is more applicable to the job I desire (Applicable to future career)

N/A, but if I were too it would be because it dealt with something experienced earlier (Had already covered material)

Because I could get a good picture of it in my head. I could visualize (Topic easy to visualize)

Work and Power were interesting to learn about because it might be useful to me someday (Useful later on)
Conservation makes every thing easier (Useful to solve other problems)

Basics (Useful to solve other problems)

Basis for all physics, important to know (Useful to solve other problems)

It seems more applicable and something that would need to be calculated for real life problems, same with some of the somewhat high motivation topics (Applicable to real world)

The conservation laws are applicable to my planned field of study. (Applicable to major)

Understanding Newton’s Laws, critical to a lot of problem solving, to real world applications. (Applicable to real world, Useful to solve other problems)

The models were much simpler than others (Easier)

Because it was fairly easy to mathematically assess the position, velocity and acceleration (Mathematics of problem was easier)

Seems like a very interesting and fundamental concept (Interest in topic, Fundamental concept)

Not sure, sounds cool! (Interest in topic)

Energy and momentum are relevant to some of my other classes (Applicable to future courses)

It comes into use in higher levels, and it is better to have a grasp of those concepts (Applicable to future courses)

I really like analyzing forces (Interest in topic)

It’s important and a good intro to other stuff (including ENGR 212, Dynamics) (Applicable to future courses)
Energy was very interesting throughout the entire course. It always made sense.  
(Interest in topic, Topic is easily understood)

They came up in subsequent courses and seemed absolutely fundamental in the whole sequence  
(Applicable to future courses, Useful to solve other problems)

I leaned these topics but want to know more  
(Wanted to learn more about topic)

Most interesting and useful, apply in a lot of areas  
(Interest in topic, Fundamental concept)

Always have been interested in electricity.  
Because it is easy mathematically!  
(Mathematics of problem is easy)

I’m taking essentially 2 physics classes now and how you choose coordinate systems determines if you can solve a problem or not.  
(Useful to solve other problems, Applicable to other courses)

Students will be “motivated” to learn whatever it is that helps them the most to pass the class. That the important topic.  
(To get good grade in class)

Necessary for many types of problems the right set up is necessary for modeling real-life problems.  
(Fundamental concept, Useful to solve other problems)

Visualization of pictures and applying it to mathematics is how I roll  
(Interest in topic)

It was easy to diagram and pictures made it easier to learn  
(Topic was easy to understand, Topic made learning easier)

I enjoy being able to physically see an outcome for something I learned/calculated. I want to use the knowledge for future experiments to keep them safe.  
(Applicable to future experiments (courses?), Can see results of work (products of labor))

Common Responses Found (Occurring at least 4 times)

<table>
<thead>
<tr>
<th>Interest in topic</th>
<th>Topic is easily understood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicable to future courses</td>
<td>Useful to solve other problems</td>
</tr>
<tr>
<td>Useful to solve other problems</td>
<td>Concept itself is important to understand</td>
</tr>
<tr>
<td>Applicable to major</td>
<td></td>
</tr>
</tbody>
</table>

Appendix A
For a subject you marked as “Very Low Motivation”: Why were you not motivated to learn about this topic?

(24 Total Responses)

Because I took Vector Calc and did not enjoy the class
(Do not remember material fondly from previous course)

They are boring topics, I have learned them in the past, and I don’t care to go over them again.
(Topics are boring, Learned material before, do not want to repeat it)

Because I had learned them in other classes (“somewhat low”)
(Learned material before and do not want to repeat it)

Because they’re tedious and/or boring
(Topics are tedious, Topics are boring)

I dislike vector calculation more than any other math. Coordinates confuse me
(Do not remember material fondly from previous course, Topic is confusing)

I have a very hard time understating electrical problems. With projectiles etc. I can see the problems in real life, electronics on the other hand, you just have to assume there is a flowing current b/c a voltmeter/ampmeter says so. Magnets aren’t as bad but still have a hard time understating why thins works he way it does.
Position, Velocity and Acceleration: I understand this very well from high school. I already knew the topics and had no desire to re-learn it
(Learned material before, do not want to repeat it)

Average Motivation-Mostly want to know these to understand how the world works and get good grades
(Interesting that this one was listed under one of the low-motivation ones…)

Because it has no relativeness to my life or what is going on in other classes
(Does not see connection to real-life, Does not see relevance to other courses)

Vectors made messes on my paper.
(Dislikes mathematics involved)

The instructor has a lot to do with student motivation
(Instructor Influence)

I don’t see a use to learn it in my field of study
(Does not see relevance to field of study)

1 and 2 (Vectors and Coordinate Systems) were math heavy and seemed we just had to get through it, no enjoyment
(Did not enjoy topic, Mathematics heavy topics)
Moment/Impulse = saw no direct relationship/need for it
(Did not see relevance of topic)

Uninteresting to me
(Was not interested in topic)

I had seen them already
(Learned material before, do not want to repeat it)

Not in my subject choice/don’t care
(Does not see relevance to field of study, Don’t care)

Because I felt that uniform circular motion was explained fairly poorly by the instructor and the book.
(Felt that topic was poorly addressed by instructor, as well as book)

PH 211 ruined them for me (Types of motion)
It’s really arbitrary and irrelevant in the actual PHYSICS of the problem (Coordinate Systems)
(Does not see relevance to other problems)

Work was a concept I never understood and it’s hard to get to this day.
(Does not understand topic)

I have already learned these topics.
(Learned material before, do not want to repeat it)

Didn’t really use it in this course
(Does not see relevance to future material)

Didn’t think I would need vector math
(Does not see usefulness of topic)

Common Responses Synthesized (More Variable than “Very High Motivation” Question)

Lack of relevance to real world, future career, future classes and major
Lack of interest, enjoyment or understanding of topic
Previously covered material, and do not want to repeat
Topic was math-heavy
Using Parametric Analysis to Determine Ranking of Data

Despite being irrelevant to a valid calculation of statistical significance for our data, parametric analysis is useful in determining the ranking of the topics determined as statistically significant by our non-parametric analysis.

Non-parametric analysis just tells us whether a topic is an outlier. It does not indicate whether this deviation is in the positive direction (the topic is significantly larger than the expected value) or negative direction (the topic is significantly smaller than the expected value). The average values given in Table 3.3 can be used to give us this qualitative information.

Parametric Statistical Analysis of Likert Scale (WS11)

Numerical values were assigned as shown in Table 2.2, and an average for each of the 11 topics was calculated by adding all of the numerical representations of the responses together and dividing by the total number of responses.

<table>
<thead>
<tr>
<th>Response</th>
<th>Assigned Numeric Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Very High Motivation&quot;</td>
<td>2</td>
</tr>
<tr>
<td>&quot;Somewhat High Motivation&quot;</td>
<td>1</td>
</tr>
<tr>
<td>&quot;Neutral Motivation&quot;</td>
<td>0</td>
</tr>
<tr>
<td>&quot;Somewhat Low Motivation&quot;</td>
<td>-1</td>
</tr>
<tr>
<td>&quot;Very Low Motivation&quot;</td>
<td>-2</td>
</tr>
</tbody>
</table>

Table A.1 Numerical values assigned to responses on WS11

The reason ‘0’ is used for ‘neutral’ (instead of starting the scale at 1 and going to 5) is that neutral is not a simple response to interpret. Neutral could mean that students find
the topic average on the motivation scale, that they are indifferent to the topic, that they
don’t recall an opinion about the topic, or other interpretations. These values were then
compared and used to refine the initial list of 11 topics down to 6 topics we found to have
particularly high or low values. For a full account of results, see Appendix A.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Average Response Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding Newton’s Laws</td>
<td>0.44</td>
</tr>
<tr>
<td>Different Forms of Energy</td>
<td>0.42</td>
</tr>
<tr>
<td>Position, Velocity and Acceleration</td>
<td>0.37</td>
</tr>
<tr>
<td>Momentum and Impulse</td>
<td>0.05</td>
</tr>
<tr>
<td>Vectors and Vector Mathematics</td>
<td>-0.07</td>
</tr>
<tr>
<td>Coordinate System Choices</td>
<td>-0.24</td>
</tr>
</tbody>
</table>

**Table A.2 Outlying Responses to Topics in WS11**

We use the results from Table 3.3 to say that “Understanding Newton’s Laws” and
“Different Forms of Energy” deviate in a positive way, if proven to indeed be
significantly significant by non-parametric analysis. Similarly, “Vectors and Vector
Mathematics” and “Coordinate System Choices” deviate in a negative way.

**Parametric Statistical Analysis of Likert Scale (SpQ11)**

A similar weighing scheme as WS11 was used to calculate an overall average for
each topic.
<table>
<thead>
<tr>
<th>Number in List</th>
<th>Assigned Numeric Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
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**Table A.3** Numerical values assigned to responses on SpQ11

For a full list of values corresponding to each topics average ranking for each of the four questions, see Appendix C.
APPENDIX C
Spring 2011 Quizdom Questions

Presented via PowerPoint Presentation to two sections of PH 211 students. Results were collected via the Qwizdom Q4 remotes. Each of the questions were presented as a separate slide on the slideshow.

Rank ALL 6 of the following topics FROM HIGHEST TO LOWEST based on your personal interest to learn about the listed topic (your first entered letter should be the MOST personal interest)

A. Vectors and Vector Mathematics
B. Coordinate System Choices
C. Position, Velocity and Acceleration
D. Understanding Newton’s Laws
E. Momentum and Impulse
F. Different Forms of Energy

Rank ALL 6 of the following topics FROM HIGHEST TO LOWEST based on how useful you think learning the listed topic is for success in your major (your first entered letter should be the MOST useful)

A. Vectors and Vector Mathematics
B. Coordinate System Choices
C. Position, Velocity and Acceleration
D. Understanding Newton’s Laws
E. Momentum and Impulse
F. Different Forms of Energy

Rank ALL 6 of the following topics FROM HIGHEST TO LOWEST based on how applicable you think the listed topic are for understanding real world phenomenon (your first entered letter should be the MOST applicable)

A. Vectors and Vector Mathematics
B. Coordinate System Choices
C. Position, Velocity and Acceleration
D. Understanding Newton’s Laws
E. Momentum and Impulse
F. Different Forms of Energy

Rank ALL 6 of the following topics FROM HIGHEST TO LOWEST based on how useful you think learning the listed topic is for success in other 200–300 level courses outside your major (your first entered letter should be the MOST useful)

A. Vectors and Vector Mathematics
B. Coordinate System Choices
C. Position, Velocity and Acceleration
D. Understanding Newton’s Laws
E. Momentum and Impulse
F. Different Forms of Energy
# Students Responses to Spring 2011 Quizdom Questions

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P-Values in red cells are significant at the 0.05 level
*See Appendix B for weighting scheme used
Appendix D 101

Summer 2011 Email to Students

This email was sent to students who had been in one of the two Ph 211 courses of the previous Spring 2011. Student Feedback, with names removed is included as well.

OSU Student,

Your instructor asked you some voting questions during the last week of your Physics 211 course this past spring. These questions were intended to help us understand how you felt about different aspects of the course. For my honors undergraduate research project I will be working on developing new activities for the content you chose via the voting. This email is following up so we can gain a better understanding of an unexpected response. Your quick response to this email would be greatly appreciated.

We know Newton’s laws are useful for success, but we were surprised they ranked highly as being interesting to most students. To build our new activities we would like to understand what is interesting to you about them and what you are curious about, so we can incorporate that in our changes.

What do you find interesting about Newton’s Laws?

Is there something you are curious about pertaining to Newton’s laws that you would like to see addressed in Physics 211?

Thank you very much. Your response will help us to better understand how students think about the topics we are teaching. Thank you for your time and have a great summer!

Sincerely,

Sam Settelmeyer
Student Response to Summer 2011 Email to Students

*Student 1*

Newton's laws were interesting in the fact that they are so universal in their application--or, at least how they were presented in PH211. I liked being able to condense relatively complicated problems into manageable issues and not a colossal headache.

*Student 2*

Hi Sam,

I think that newtons laws were already emphasized in the curriculum. The class struggled to get through all of the energy laws and later units because it took lots of time for F=ma to settle in correctly. If the class time were to be redistributed, I would chop 2 weeks out of the beginning lessons of the class and utilize them during the end. The beginning of the class moved too slowly and bored most of the students--they tuned out before the real material hit them. Newtons laws were the transitory period between the real material and the fluff at the beginning. Most people had to start paying attention during those lessons, so it was a wise teaching decision on [Instructor A] 's part to linger there a little longer than normal. It took kids awhile to realize that they needed to come to class.

Personally, I still have plenty of questions about the energy laws--I would have liked to explore them in more detail. You could solve problems in several ways and get several wrong answers that seemed plausible on the conceptual level. I understood the material well enough to do well in the class, but would have liked to have another week or so to pester [Instructor A] about specific problems.

I don't believe that everybody in that room could have passed the class. The physics people are very motivated and always searching for better ways to teach, which is fabulous, but some people fundamentally don't see how the physical world works. A lot of these kids are going to repeatedly fail physics or have to memorize problem solving strategies, which should be an indicator to them that they need
to find a new field of study. Not everybody is cut out to be an engineer or physicist—you just want to be sure that you are only discouraging the kids who would genuinely thrive somewhere else.

Hope this feedback helps,

Student 2

Student 3

Being a fourth year ME transfer student taking PH 211 to get into Pre-School, I find Newton's laws interesting because pretty much every equation we use in 211 can be derived from them in basic form. I would like to see these explicit derivations, like the conservation of energy equation or the equations of motion for constant acceleration. To me, this would give a concrete connection to Newton's laws and provide a basis for why certain equations work in some scenarios and not in others. This was an issue I saw come up frequently when fellow classmates would consult me when they needed help with a particular problem.

Student 4

Sam,

In response to your questions about Newton's Laws, I would agree that they are fun to learn about and show up again in many classes outside of physics. The one thing I would change about how those laws are taught would be the things that are said to be negligible. In almost all of the physics problems we did in PH211, we were neglected to add in stuff like air resistance and other factors that definitely will affect Newton's Law calculations. Our professor would then always say that "that of course is not the way the world works, as there is air resistance and all of these other factors." If all of those "other factors" exist, why don't we just do problems with them anyway. In other engineering classes, we have to account for friction and air resistance so why don't we learn how to do it in physics. PH 211 taught us how to solve problems without all the real world factors.

My suggestion would be to teach physics exactly how the real world acts. Don't teach us to ignore friction or air resistance
because those things do exist. It seems like my professor would go to
great lengths to make a very simple problem as hard as he could
without all those factors, but if we were to do real life problems, the
complexity of the problem would be there already and extra steps to
make the problem harder would not have to be taken. PH 211 was a
good class and I learned a lot but I think it could be taught differently
and still teach the same things.

Student 4

Student 5

Hello Sam Settelmeyer,

Thank you for following up on the surveys you conducted in class last
term; I hope the results have been interesting so far.

To answer your question, I believe I am actually a minority on this
one. I did not find Newton's Laws interesting at all, even though I
thought they were very relevant the material (especially earlier) in the
course. The second and third laws (in short, F=ma and equal/opposite
actions/reactions respectively) were used most in the course,
especially in dynamics and statics problems. I'm taking PH213 at
PCC, now, and I still use F=ma every once in a while.

Anyway, I did not find Newton's Laws to be interesting at all--and I
felt this way precisely because they were taken for granted,
oversimplified, and overused. They became part of the arsenal of
equations, and no more time was spent on them. Whether there was
actually enough material to learn regarding Newton's Laws to make
them more interesting is another question--but had we spent more
time studying the history of these laws and had spent more time
specifically referencing and working with them, I might have ranked
them as much more interesting.

I hope this answers your question. Good luck on your studies!

Best Regards,

Student 5
Student 6

Sam Settelmeyer,

I do not know that the voting process accurately reflected student views, as we were asked 4 remarkably similar questions - always with the same answers. My class also had to repeat the exercise (all four questions twice through), as the first voting attempt did not end up working. While I believe that most students attempted to answer accurately, many students grew frustrated and picked some or all of their answers at random.

If there is a large margin that says Newton's laws were interesting, then this could certainly be because students truly believed it to be interesting. I personally did not find Newton's laws to be the most exciting part of the course. Rather, I found velocity and momentum calculations (which obviously involves Newton's laws, but also requires mathematical computation) to be the most interesting because I felt that they were the most applicable outside of the classroom.

As far as suggestions go, I believe that the physics 211 survey should be revised a little bit so that there would be less likelihood of students to press random buttons on their qwizdoms - perhaps providing questions that are less similar or using an online quiz instead?

Hopefully you find my input is helpful,

Student 6

Student 7

They are fun because there are good demonstrations that go with them. They are also something that is easily observed and understood.

Student 8
For me, the interest was pretty simple. Finally I was actually taught the laws that had been referenced (correctly and incorrectly) so many times in front of me. A lot of social weight is put on Newton's mysterious laws. The laws also provide a base for many concepts in my career, mechanical engineering.

Student 8

*Student 9*

I do not believe I personally would have ranked Newton's Laws very high on an interest scale, however I suppose the most interesting thing about them to me is how elegantly, concisely and cleanly they model the world around us.

I hope that's somewhat useful, good luck with the project.

Student 9
APPENDIX E
Student Work from Created Activities

Week 1:

- **Origin:** location of atom
- **Origin:** center of hex
- **Origin:** midpoint between two adjacent atoms

- **Angle:** 90°
- **Angle:** 60°
- **Angle:** 120°

- **Angle between axis:**
  - 90°
  - 120°
  - 60°
  - 150°
  - Multiples of 30°
Week 2:

No student work collected

Week 3:
Appendix E 110

Week 6:
Week 9:

Appendix E
PART 1:

1. The graph shows the potential energy in the molecules. The light is absorbed and stored as P.E. which changes the molecule. When the "trigger" is introduced, the molecules release the P.E. i.e. in the molecules need back to their original state.

2. $h\nu$ is measured in $J$
   $E_a$ is measured in $J$
   $\Delta H$ is measured in $J$.

3. The most stable points are @ $E_a$.

4. A trigger (catalyst) must be introduced.

5. $h\nu$ = absorption energy

6. $E_a$ = reaction energy
   $\Delta H$ = heat energy

1. $E_a$ is smaller, so it might release energy. (less stable)

2. $\Delta H$ is smaller.

3. 

\[ \text{W/ out CNTs} \quad \text{W/ CNTs} \]
# Students Responses to Spring 2012 Quizdom Questions

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Studio Class (Dave’s Class):

P-Values in red cells are significant at the 0.05 level
*See Appendix B for weighting scheme u