Spring 2015

Can We Influence How Students View Physics?

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CAN WE INFLUENCE HOW STUDENTS VIEW PHYSICS?

An Honors Undergraduate Thesis Presented

by

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Submitted to the School of Physics the

University of Portland in partial fulfillment

of the requirements for the degree of

BS IN PHYSICS

April 2015

ACKNOWLEDGMENTS

I want to express the deepest appreciation to my family and my fiancé for their support as I have worked on this project. My fiancé Corey Nelson was instrumental in getting my data analyzed and his assistance with coding was invaluable. I especially want to thank my father Dr. Charles J. Wetterer for his help with writing problems and physics expertise. He is unquestionably the smartest man I know and he was my mentor throughout my entire thesis.

I would like to thank my thesis advisor Tamar More, who both gave me the vision for my project as well as the tools I needed to complete it. Without her endless support and help my senior honors project would not have been possible.

In addition, I would like to thank Allison Lawrence for her assistance with preparing, administering, and scoring the survey. I thank both the physics department and the honors program at the University of Portland for their support. Finally I thank all of the students who dutifully took my surveys and answered my interview questions for they are truly the life blood of my project.

ABSTRACT

Using the Colorado Learning Attitudes about Science Survey assessment and student interviews we examine changes in introductory physics student's beliefs towards physics in general and toward reasoning and consistency checks when problem solving in particular. We present our results in relationship to previously done assessments and both what our results say about influencing student's beliefs on physics and the reasoning behind student responses.

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Directed by: Professor Tamar More

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CHAPTER 1

INTRODUCTION AND BACKGROUND

Introduction

In recent years there have been great strides in understanding students' ideas about physics content in order to improve student learning. Many studies argue that student beliefs about physics – the structure of physics knowledge, the connection between physics and the real world, how to approach problem solving, and how to learn physics – play a substantial role in a student's ability to learn physics and consequently there has been a growing effort to develop assessment tools that target student' perceptions of physics as a discipline.[1-3] Many of these assessment tools target students' development of expert-like thinking such as the Views About Science Survey (VASS),[4] the Maryland Physics Expectation (MPEX),[5] the Epistemological Beliefs Assessment for Physical Science (EBAPS),[6] and the Colorado Learning Attitudes about Science Survey (CLASS).[3] Often these tools probe students' beliefs by asking students to respond to statements on a Likert scale and compare their responses to expert opinions.

Studies using these tools have found that despite the wide range of beliefs held by the population of students taking introductory physics courses, there were clear trends in students' beliefs about physics and learning physics.[3, 5] They discovered many students have quite novice views of physics and that over the course of a semester rather than their beliefs shifting to better reflect the expert views held by their professor, they often become more novice like. At the foundational level, the expert view of physics is that it is a coherent framework of concepts that describes nature. Novices on the other hand feel that physics is isolated pieces of information that has no connection to the real world.

Arguably the most commonly used assessment tool is the CLASS.[7, 8] Researchers from the physics education group at the University of Colorado at Boulder created the CLASS Assessment by extending questions from prior surveys such as the MPEX, interviews, reliability studies, and extensive statistical analyses of responses from over 5000 students. While there are some that will argue against the use of the CLASS claiming that it has poor psychometric, or measuring, properties[7], the CLASS assessment has had substantial validation[1] and, according to Google Scholar on April 5, 2015, the article introducing the CLASS Assessment published in physics education research (PER) has been referenced in 320 articles. The CLASS Assessment has been modified for biology[9], chemistry[10], and laboratory courses[11] and it has been translated for use in several languages. The creators of the CLASS state, "This survey probes students' beliefs about physics and learning physics and distinguishes the beliefs from those of novices. The CLASS was written to make the statements as clear and concise as possible and suitable for use in a wide variety of physics courses"[3]

Further studies using the CLASS assessment have shown that students can hold seemingly contradictory ideas about physics and learning physics. A study done by Gray *et al.* showed that while students may think that they cannot find coherence in their knowledge of physics, they expect scientists to have coherence in their ideas in the subject. They also found that students who have not yet taken physics in college have a surprisingly accurate idea of what physicists believe about physics no matter what their high school background or what physics courses they choose to take in college. Furthermore, these ideas are largely unaffected by their college physics instruction. This would indicate that their beliefs concerning experts in physics are constant. In contrast, students' personal beliefs about physics differ with varying high school physics backgrounds and college physics courses in which they enroll, and these beliefs are measurably and substantially affected by college physics instruction.[8]

It's apparent that introductory physics instruction influences students' beliefs on physics, and that often it negatively affect these beliefs, but there are few substantial accounts of what introductory physics courses can do to improve this trend when restricted to the traditional lecture based classroom.[8, 12, 13] Many Universities are attempting to integrate more active and engaging learning techniques into their classroom. However, not only is introducing smaller class sizes and exploration periods for students is not possible for all Universities, but studies have shown that there are decreases in the percentage of favorable responses over the course of one semester for a calculus-based Physics I (mechanics) course regardless of whether it is a traditional lecture-based course or a course with interactive engagement if the instructor does not attend to students' attitudes and beliefs about physics.[1]

Some studies done with the CLASS that have shown that practices aimed at explicitly addressing student beliefs about physics can have clearly measurable and positive effects[1] but there is room for more research on methods to positively affect students' beliefs in physics within a traditional lecture based classroom. In this project, we look at students' beliefs on physics at the University of Portland through the use of the CLASS assessment and student interviews with a focus towards reasoning and consistency checks while problem solving. A project we conducted in 2014 on the use of conceptual checks when solving physics problems indicated that performing conceptual checks could improve students' real world connections and attitudes towards physics. If this is the case, then this could add the use of conceptual checks in physics problems to the existing techniques for positively impacting students' beliefs in physics, and by extension, their performances in introductory physics courses. This would have practical applications in introductory physics classrooms.

Set Up and Background

The Difference between Attitudes and Beliefs

The terms attitude and belief are sometimes used interchangeably; however, within fields of science education research it is imperative that there is a clear distinction and understanding of the differences between the two. Within the scope of our project we are looking at students' beliefs and will consequentially be using this terms extensively within this paper. For the purposes of our research we are taking beliefs to be defined as cognitive content that a person holds to be true. Using this definition a belief is an acceptance that a statement is true or that something exists. An example of a belief within physics is that a person can believe in the existence of a concept such as gravity or magnetic fields. These beliefs are the ideas that can shape a persons' understanding of physics and by extension the cosmos. While the specific examples of gravity and magnetic fields are grounded in experimental data and logically reasoned, this is not a necessary condition for beliefs. Often beliefs are axiomatic and not necessarily logical or reasoned. Students' hold other beliefs concerning physics such as the role that physics plays in the universe or where physics tools and concepts such as equations and physical relationship come from. Someone might believe that their professor makes up some of the relationships she writes on the board. While experimentally there is little evidence to support this, the idea that a concept comes from some point of authority is a common belief.[13]

An attitude on the other hand is a settled way of thinking or feeling about something. Attitudes are fairly stable, evaluative dispositions that make a person think or feel either positively or negatively towards some concept or issue. Attitudes can either be cognitively based or affectively based. This means that a person's attitude can be based on the evaluation of information available to them which would lead to relatively dispassionate attitudes which would be more open to give and take; or it can be based on emotions rather than objective information and thus difficult to change. A person's attitudes towards physics are therefore fueled both by information and a person's emotions regarding the subject. A person's attitude towards physics may depend on their professor or emotional state while in physics class as much as their beliefs concerning physics.

Our project uses evaluative tools such as the CLASS Assessment, surveys, and homework problems to probe the attitudes and beliefs of students and how those beliefs affect their attitude towards physics. A persons' beliefs on physics topics changes over the course of the semester as they learn increasing amounts of facts and data. These changes in belief about content are not only expected but desired and are often measured through homework, quizzes and other forms of examination. The goal of my project was to conduct further investigation on whether students' views of physics process and relevance changes through course instruction.

Methodology

During the Fall 2014 semester, we used the Colorado Learning Attitudes about Science Survey (CLASS) to measure students beliefs both at the start (pre) and the end (post) of the semester in the introductory calculus mechanics course (PHY 204) at the University of Portland. See Appendix A for a full list of the CLASS questions. In the first lab period at the beginning of fall semester 2014, 151 students enrolled in introductory calculus based physics took the assessment. It was important that the pre survey be administered as early as possible in the semester so that it could be used as the pre instruction survey. Students answered the 42 questions using a five point Likert scale with the possible responses - strongly disagree, disagree, agree, and strongly agree.

To allow for pre-post comparisons, students provided the last four digits of their student ID numbers. Twenty nine of the students failed to provide this information; therefore those surveys are excluded from the analysis. Using a MATLAB code, the raw data was transferred into Excel format. Once the two survey responses were matched the data was imported into the CLASS analysis excel spreadsheet provided by the physics education group at CU Boulder.

Throughout the semester we conducted student interviews in order to ask more open ended responses. After the data points from the CLASS survey were analyzed we conducted 28 further interviews in order to better understand the results from the CLASS. The interviews were focused on conceptual checks, what students thought about the idea of the checks, and the practice of answering problems that included conceptual checks.

Conceptual Checks

Within physics courses students are encouraged but rarely required to check their work and thus do not typically do so. A conceptual check aims to link the numerical aspect of the problem back to the concept through use of interconnecting problems, limiting cases, and other such methods that apply a general understanding of the concept. An example of a problem with a conceptual check would be a question asking a student to find the electric field from a rod of a finite length. After finding an answer, the student could be asked what would happen if they were to move infinitely far away or infinitely close to the rod. They would see that their expression for the electric field would look like a point charge when they were infinitely far away and like an infinitely long rod when they were infinitely close to the finite rod. Physically this is exactly what we would expect seeing as a rod will look shorter and shorter as we get further and further away, and similarly a rod would look longer and longer the closer we get to it. This type of problem requires students to critically look at the problem they are answering and connect their response to the larger physical picture. This would force them to make real world connections and see the physics problem as a part of a larger field and not as an independent idea and concept.

We hypothesize that if they were to conceptually check their work their general understanding on the topic would increase. The idea behind this is that traditional physics problems lead students to think like an arrow. They learn a concept; apply math, and then get an answer and that is where the learning ends with an answer that is either correct or incorrect. The idea of a conceptual check is that if after a student gets an answer they check that answer conceptually, they return back to the concept completing the circle so to speak. When solving problems, students often get incorrect answers and mistakes that could be avoided if they were to think about what was happening conceptually and see that they have conflicting answers in multistep problems, or answers that are far off in orders of magnitude. Yet they do not use these checks due to a general fixation on the final numerical answer, and a general lack of knowledge of context of the solution. These trends can be seen while grading homework, talking to students, during lab, and on more formal evaluations such as on exams and quizzes.

Types of Conceptual Checks

We break the idea of conceptual checks into four different categories of types of checks: given checks, explicit checks, hinted checks, and problems with no scaffolding. Given checks are problems where the correct answer is given and students are asked why it is true. Explicit checks are problems where the students are told exactly what check to perform and how to perform it although they are left to find the answer and perform the check themselves. Hinted checks are problems where the check the students could perform is hinted but not explicitly given and problems with no scaffolding have no mention of a check. Examples of conceptual checks can be found in Appendix C.

CHAPTER 2

ANALYSIS AND CONCLUSIONS

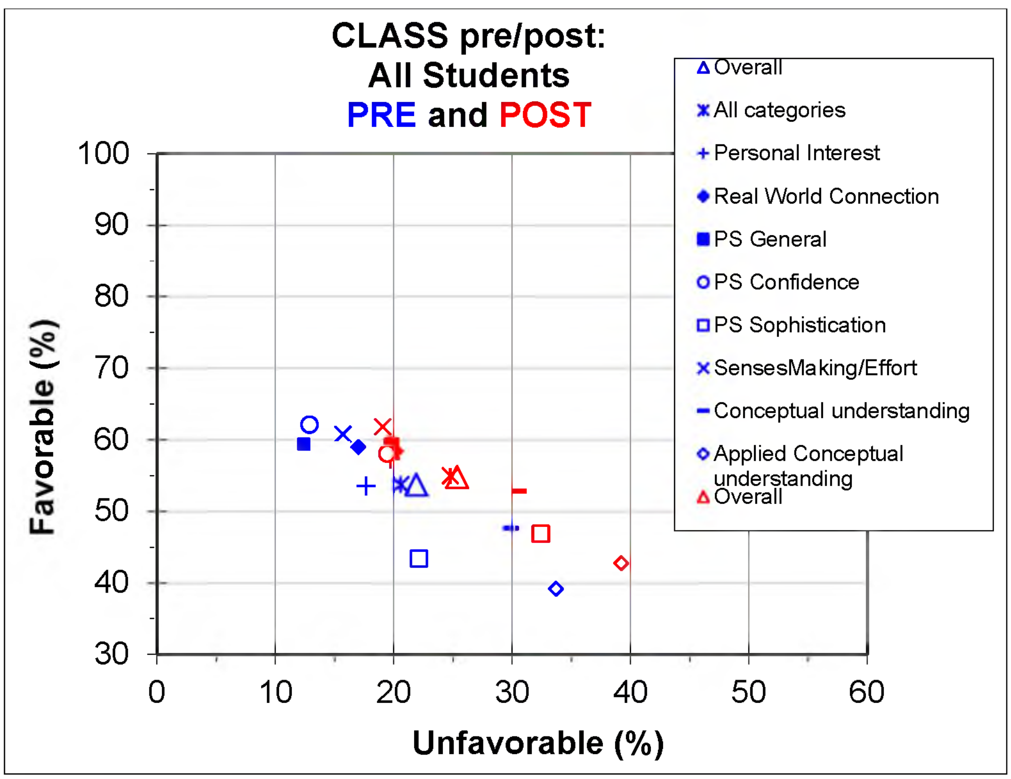
The CLASS data can be analyzed by question and by category. The eight categories are personal interest, real world connection, problem solving general, problem solving confidence, sense-making/effort, conceptual understanding, and applied conceptual understanding. The categories within the CLASS were experimentally determined to be rigorous categories from both factor analysis and interviews.[3]

In order to look at how student beliefs were affected by conceptual checks we specifically look at four of the categories: personal interest, real world connection, conceptual understanding, and applied conceptual understanding. Of the 42 questions (listed in Appendix A) on the CLASS only 36 have unified expert responses. Sixteen of these questions (Table 3) are related to conceptual checks and so special attention was paid to the responses given to those questions.

Complete details of the design, categorization, validation, and scoring of the CLASS are reported by Adams et al[1] but, briefly, the CLASS is scored by comparing student responses to expert responses. We are looking at shifts in belief over the course of the semester so we are looking at the changes between the students' pre and post responses compared to expert responses in two different ways, percent favorable and percent unfavorable shifts. Percent favorable and percent unfavorable shifts are found by determining, for each student, the change in the average percentage of responses for which the student agrees with the experts' view (percent favorable). The shift in average percent unfavorable is determined in a comparable manner, looking at the change in responses that disagree with expert views.

Figure 1 presents percent favorable on the *y* axis and percent unfavorable on the *x* axis where the blue symbols refer to the pre survey data and the red symbols refer to the post survey data. The different symbols refer to the eight different categories. This is a visual method for looking at the shifts in the data. The shifts we would like to see are shifts moving up and to the left. So ideally, all of the red symbols would be in the upper left corner. Occasionally within our data we see such shifts; however, most of the shifts within our data go to the right indicating an increase in unfavorable responses and little to no change in the favorable responses.

Figure 1: A comparison of pre and post CLASS data



For a more quantitative look, Tables 1 and Table 2 show the CLASS results for the introductory mechanics courses offered at the University of Portland in the fall 2014. These results for a first semester of a traditional lecture-based course are in line with the typical results seen from all other universities.[1] Table 1 outlines the favorable shifts and Table 2 shows the unfavorable shifts with the standard error, a measure akin to the standard deviation of the mean. It is typical for the post survey responses to have a larger standard deviation (and subsequent standard error) than the pre data. This is generally because students' responses become more polarized over the course of the semester because their experiences within the course are not identical.

The data shows some small shifts within the favorable responses both in the positive and the negative direction. None of the shifts are large shifts, and no shifts were larger than the standard error in the measurement thus none of the favorable shifts are statistically significant. While it would have been nice to see stronger increases in favorable responses, having the responses remain constant is not discouraging within the context of national trends, as stated in the introduction.[1] Additionally, in both the Conceptual Understanding and the Applied Conceptual Understanding categories there was an increase in favorable responses.

TABLE 1. Typical CLASS percent favorable results

Category	Pre	St Error	Post	St Error
Overall	54%	1.6%	55%	2.1%
Real World Connections	59%	3.1%	58%	3.6%
Personal Interest	54%	2.5%	57%	3.0%
Sense Making/Effort	61%	2.6%	62%	2.8%
Conceptual Understanding	48%	2.3%	53%	2.5%
Applied Conceptual Understanding	39%	2.0%	43%	2.4%
Problem Solving General	59%	2.5%	59%	2.8%
Problem Solving Confidence	62%	2.9%	58%	3.4%
Problem Solving Sophistication	43%	2.5%	47%	2.7%

Figure 2 displays the change in percentage of statements for which students agrees with expert responses through binning students by their shift in beliefs; for example thirty students agreed with expert responses on ten percent more of statement in the post survey.

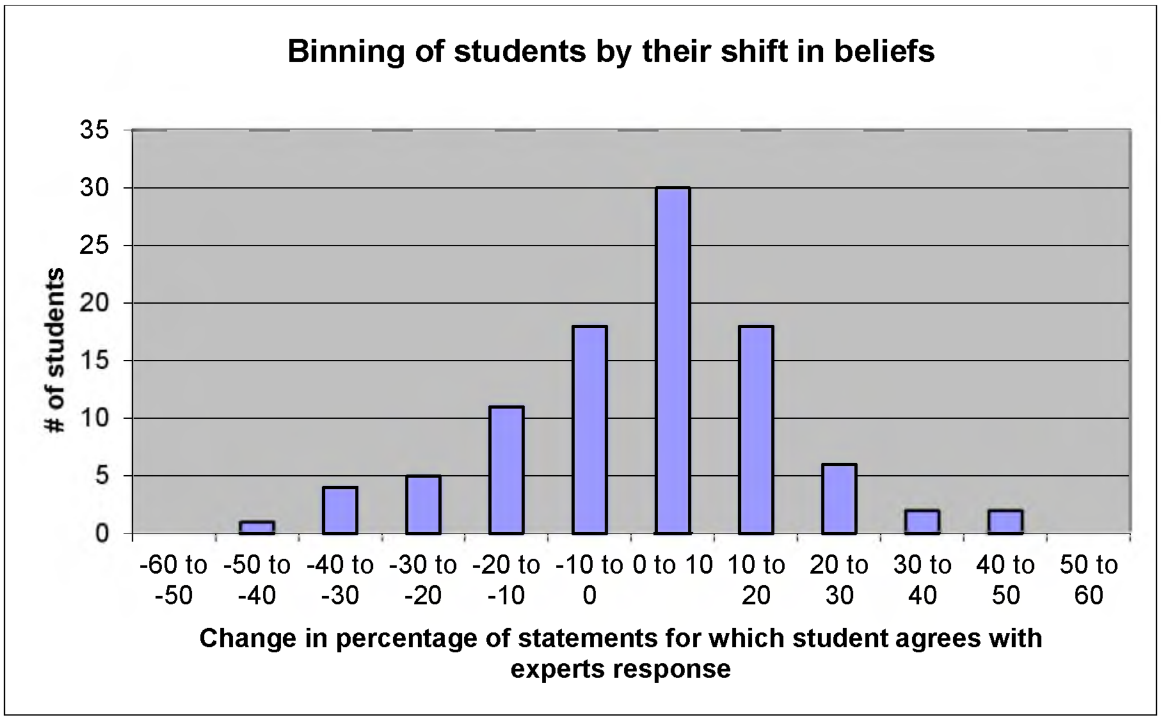


Figure 2: Binning of students by their shift in beliefs

The unfavorable responses increased in every category over the course of the semester which can be seen in Table 2. Six shifts were large, meaning that the increase in unfavorable responses was more than double the standard error. There was a large shift in unfavorable responses overall, and in problem solving general, problem solving confidence, problem solving sophistication, and applied conceptual understanding. The largest shift was in problem solving sophistication with increase in unfavorable responses of 10.3%.

TABLE 2. Typical CLASS percent unfavorable results

Category	Pre	St Error	Post	St Error
Overall	22%	1.3	25%	1.7
Real World Connections	17%	2.2	20%	2.8
Personal Interest	18%	2.0	20%	2.4
Sense Making/Effort	16%	2.3	19%	2.3
Conceptual Understanding	30%	1.9	31%	2.4
Applied Conceptual Understanding	34%	1.8	40%	2.4
Problem Solving General	12%	1.5	20%	2.2
Problem Solving Confidence	13%	1.9	19%	2.7
Problem Solving Sophistication	22%	2.0	32%	2.6

As shown in Table 3 for the 16 conceptual check related questions the majority of shifts were in the negative, or novice direction, whether that was an decrease in percent favorable or an increase in percent unfavorable. However, the shifts in the positive or expert direction, whether due to an increase in favorable responses or a decrease in unfavorable responses, were in general much larger than the majority of the negative shifts. The favorable responses within the data fluctuated and in many cases increased from the pre to post surveys, unlike the unfavorable responses which had a clear negative trend. Even when grouping the percent favorable and percent unfavorable responses together into positive, increases in percent favorable and decreases in percent unfavorable, and negative, decreases in percent favorable and increases in percent unfavorable, shifts conceptual check questions still show some improvement over the course of the semester.

Table 3: Conceptual Check Questions

Net Shift	Statement
15% EXPERT	3. I think about the physics I experience in everyday life.
15% NOVICE	35. The subject of physics has little relation to what I experience in the real world.
14% EXPERT	21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.
13% EXPERT	18. There could be two different correct values for the answer to a physics problem if I use two different approaches.
13% NOVICE	36. There are times I solve a physics problem more than one way to help my understanding.
12% EXPERT	6. Knowledge in physics consists of many disconnected topics.
12% EXPERT	38. It is possible to explain physics ideas without mathematical formulas.
9% NOVICE	17. Understanding physics basically means being able to recall something you've read or been shown.
9% NOVICE	30. Reasoning skills used to understand physics can be helpful to me in my everyday life.
8% NOVICE	10. There is usually only one correct approach to solving a physics problem.
8% EXPERT	37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.
7% NOVICE	13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.
6% NOVICE	2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.

In Figure 3 the percent favorable and percent unfavorable responses are displayed next to each other for simple and direct visual comparison. It is easy to see the increase of unfavorable responses in every category, yet it is also clear that the percent favorable responses dwarf the unfavorable responses. So while there are definite negative treads within the responses, overall, the beliefs' of the students surveyed are in line with the expert beliefs.

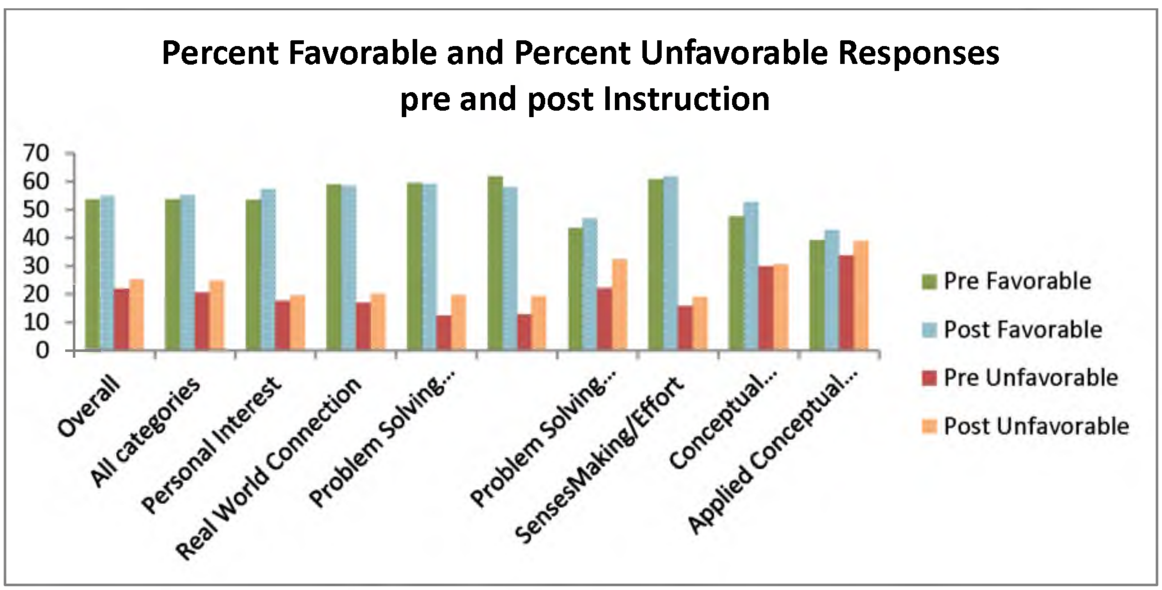


Figure 3: Percent Favorable and Percent Unfavorable Responses pre and post Instruction

The shifts present within the analyzed data indicate that students' beliefs were indeed affected through one semester of introductory physics instruction. While not all of the shifts present within the data were positive shifts – either an increase in favorable responses or a decrease in unfavorable responses – there were substantial positive trends within the data in three of the four conceptual categories with one remaining constant. Additionally, the largest shifts in the questions pertaining to conceptual checks were in the positive direction.

Adams et al. argue that the dominant reason for increased interest are belief related and that the dominant reason for decreased interest are related to specific aspects of instruction.[13] Adding to their argument, surveys such as the CLASS attempt to measure student beliefs and thus while there are negative shifts present in the data, these negative shifts can often be attributed to outside factors such as the professor of the course, class size, workload etc. Student interviews support this claim. When the students who took the CLASS were later told that the trend seen in physics education research is for students' beliefs about physics to become more novice-like over the course of the semester, many responded that as the semester progressed they cared less about learning the material and more about getting through and passing the class. One student said, "As the semester goes on you realize it's difficult so you go into survival mode and just want to get through." The overwhelming consensus from the student interviews was that they were aware that the goal should be to make real world connections, but throughout the course they found themselves just trying to make it through and pass the class.

When students were asked what they thought was the goal of solving a physics problem there was a similar trend. Students seemed to be aware of what the "correct" or rather expert belief was, even though this was generally not their own belief. This is in line with what Grey et al. found in their 2008 study[8] using their modified CLASS assessment, where they asked students to respond to the 42 questions both with what they themselves believe and with what they think an expert would say. Students said that in practice their goal when solving a physics problem is to get the answer. That being said, they recognize that the goal could, and perhaps should, be to learn more about the world. A handful of students also said that the goal of solving physics problems is to learn skills that they will use later in future engineering courses and in their engineering career. Given that the majority of the population taking the calculus based mechanics course were engineering majors this goal also makes sense.

Students' were also asked about what they thought of conceptual checks. When asked merely if they checked their work, and what they thought a check was, most responded that they did not check their work, and they believed that checking their work referred to checking if they got the correct answer. When pressed further and asked about conceptual checks, and given a definition for what a conceptual check is there were more uniform responses. Students unanimously did not like the idea of additional work being added to their homework, but almost all of the students interviewed mentioned that linking the math done in physics problems to the concepts helped them understand. When asked about particular problems with conceptual checks, students commented that while they like the idea of mastering the concept, conceptual checks make the problems harder.

In summary, while the percent unfavorable responses increase in all categories, with four categories having large statistically significant shifts, there were increases in percent favorable responses as well. The increases in unfavorable responses could be largely due to outside factors such as workload, instruction, or understanding course material. The shifts in favorable responses are generally more belief related and consequentially, our preliminary research indicates that it is possible to influence students' beliefs, which is in clear alignment with what past studies have shown.[1, 3, 12, 14] The unspoken goal of teaching physics is to impress more expert-like views upon the students taking physics courses so the positive shifts present with in the data on both a category and a question scale are encouraging. Conceptual checks are aimed to address beliefs so the increase in favorable responses in the relevant categories as well as large shifts in questions pertaining to conceptual checks shows that the use of conceptual checks to positively influence students has potential. The supportive evidence from student interviews in response to the CLASS data is also encouraging and while further evidence is needed, it affirms the notion that conceptual checks can improve student understanding and positively affect students' beliefs in physics.

CHAPTER 3

ADDITIONAL RESEARCH

In addition to the CLASS and interview there were a number of other efforts at probing conceptual checks and student attitudes. These were not as complete and are therefore not included in our analysis in chapter two.

Homework

Starting in the spring semester 2014 I have worked with the University of Portland physics faculty to craft homework problems that contain the four different types of conceptual checks. I then looked at the responses to the problems so see if the presence of the conceptual check affected the score of the problem. This is very preliminary and limited data but the responses received appear to support our conclusions outlined in chapter 2. Presentation and analysis of these questions and results can be found in Appendix C.

Conceptual Checks Within Lecture

In the Fall 2014 semester, I sat in on different introductory mechanics lectures and took notes of the times that professors utilized conceptual checks within their teaching. Using a rubric (found in Appendix D) I gave the class a score on its use of conceptual checks. The goal was to correlate this score with the CLASS responses for the relevant conceptual check related categories. Due to small class size it is not practical or statistically relevant to disaggregate the data by classes. It is, however, interesting to note that all professors used multiple types of conceptual checks extensively within the limited number of lectures observed despite differences in topic.

CHAPTER 4

FURTHER STUDY

Future Plans

While my initial study yielded interesting results, it is merely looking at one semester of instruction which is akin to a snapshot in time. If introductory mechanics students were to take the CLASS assessment over the span of a few years there would be far more data points and it would better place the results in context. I would also like to look at the long term impact of conceptual checks on students. Within my data this year I saw signs that conceptual checks positively influenced students' beliefs despite the fact that in student interviews many claimed that they did not like doing conceptual checks because it was added work.

After a period of rest, beliefs that are influenced by fundamental changes in understanding related to physics are likely to remain constant but beliefs that are affected by course instruction and other outside factors might not be as lasting. Students who felt overwhelmed by the workload of the course were likely to rank their beliefs lower, but if given a chance to decompress; their emotions might not be as strong of an influence in their responses. Comparing CLASS responses from the beginning of two consecutive courses might reflect this and thus in the future it would be interesting to look for shifts of this nature.

I briefly looked into how conceptual checks influenced class grades but there is much more that can be done to investigate the relationship between beliefs grades. Appendix D shows a plot of the grade distribution for the students surveyed. Without further analysis there are few conclusions that can be drawn. However, additional grades and survey results for future classes would allow us to look for correlation between belief and performance. Studies have shown that belief plays a large role in determining who becomes a physics major and whether or not those students keep physics as their major.[15] It would be interesting to see how beliefs concerning physics affect the performance and retention of major for students going into other fields of study such as engineering or heath related fields.

Finally, I would like to continue to ask students what they are thinking and try to understand why they feel the way they do. Every response I received set off a chain of new questions and I feel that even at the close of my project I have many more questions that I would like to have answered. I think that continuing in person the student interviews (as opposed to written surveys) would continue to yield insight into how student beliefs are affected through course instruction while continuing to probe that question of why.

APPENDIX A

CLASS QUESTIONS

These are the questions in the CLASS. These questions in this form were given to the students at the beginning and the end of the semester. For more explanation on the survey's creation and the question selection process see the 2004 and 2006 papers by Adams et al[1, 3].

1. A significant problem in learning physics is being able to memorize all the information I need to know.
2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.
3. I think about the physics I experience in everyday life.
4. It is useful for me to do lots and lots of problems when learning physics.
5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.
6. Knowledge in physics consists of many disconnected topics.
7. As physicists learn more, most physics ideas we use today are likely to be proven wrong.
8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values.
9. I find that reading the text in detail is a good way for me to learn physics.
10. There is usually only one correct approach to solving a physics problem.
11. I am not satisfied until I understand why something works the way it does.

12. I cannot learn physics if the teacher does not explain things well in class.
13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.
14. I study physics to learn knowledge that will be useful in my life outside of school.
15. If I get stuck on a physics problem my first try, I usually try to figure out a different way that works.
16. Nearly everyone is capable of understanding physics if they work at it.
17. Understanding physics basically means being able to recall something you've read or been shown.
18. There could be two different correct values to a physics problem if I use two different approaches.
19. To understand physics I discuss it with friends and other students.
20. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else.
21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.
22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.
23. In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.
24. In physics, it is important for me to make sense out of formulas before I can use them correctly.
25. I enjoy solving physics problems.

26. In physics, mathematical formulas express meaningful relationships among measurable quantities.
27. It is important for the government to approve new scientific ideas before they can be widely accepted.
28. Learning physics changes my ideas about how the world works.
29. To learn physics, I only need to memorize solutions to sample problems.
30. Reasoning skills used to understand physics can be helpful to me in my everyday life.
31. We use this statement to discard the survey of people who are not reading the questions. Please select agree-option 4 (not strongly agree) for this question to preserve your answers.
32. Spending a lot of time understanding where formulas come from is a waste of time.
33. I find carefully analyzing only a few problems in detail is a good way for me to learn physics.
34. I can usually figure out a way to solve physics problems.
35. The subject of physics has little relation to what I experience in the real world.
36. There are times I solve a physics problem more than one way to help my understanding.
37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.
38. It is possible to explain physics ideas without mathematical formulas.
39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.
40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.
41. It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.

42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.

APPENDIX B

SELECTED INTERVIEW RESPONSES

Throughout the course of the 2014-2015 academic year I conducted interviews with students enrolled in introductory physics courses at the University of Portland and the Air Force Academy in order to gain insight into their beliefs and attitudes concerning physics. Below are a selection of student responses to a few of the key questions asked in the interview sessions.

Why are you taking physics?

- To prepare for my future as an engineer
- To learn concepts I will use in future classes
- I am required to take at least one semester
- It’s required for my major
- It is a requirement to take the MCAT
- I need it for my major
- To make the link – apply to the real world different situations and make connections
- Because it’s pretty awesome
- I wish I wasn’t taking it –but its required
- I want to go into engineering which is basically applied physics

What would you say is the goal of solving a physics problem?

- It depends on the problem and the context
- To get an answer
- It’s really just to get the right answer
- Understand how things work and behave
- To help critical thinking skills and get a more conceptual understanding

- As engineers we will use the answers and apply them to the real world later so the goal is to prepare to solve future problems
- Get a passing grade and a degree
- Learn concept
- Make predictions
- To model how something works
- Gain knowledge for future
- Understanding tools
- Understand how world works
- To understand concept
- Find answer
- Solve problem
- The goal depends on the setting. Experimentally the goal is to probe a hypothesis. In the classroom the goal is to get an understanding of laws and equations
- Get a grade
- Get a passing grade
- For fun
- Torture kids
- Do it for the grade
- Practice applying equations
- To get the right answer
- To answer questions about how things in the real world work
- To get it right and to get an A
- Getting an A – appease teacher
- To figure out interactions between different equations and how they get you to an answer
- Come up with right answers
- To answer questions presented to you

Studies have shown that student's beliefs about physics shift over the course of a semester and tend to get more novice like, what do you think about that?

- Fair enough
- Workload
- Before taking the course they think they have a clear understanding of the world, while they're taking the class the see that it doesn't make sense and so their interest goes down
- As the semester goes on it becomes more about the grade and less about the concept
- Physics courses teach lots of information fast and there is often not enough time to digest and understand the concepts. If you fall behind and don't understand one thing then it can affect the whole rest of the semester. If you want it to be more focused on the learning it has to be slower.
- Student's focus was more on learning about the way the world works at beginning but as the semester goes on you just wanna get through with it
- Concepts used in statics and such
- Opinion on class changes
- As the semester goes on you realize it's difficult so you go into survival mode and just want to get through
- As you learn more and more concepts it can become overwhelming
- Towards the beginning of the semester it is mostly review, but as the semester goes on you learn more and more new material
- I feel like I have learned quite a bit and remember a lot of what I've learned.
- Makes sense – I hate physics now. *Why?* Because it doesn't make sense. The teacher doesn't teach so I have to learn the concepts myself. I just memorize the equations and it seems pointless.
- When you have a teacher that can't teach the material it makes the class, and learning impossible.
- At first I felt like "this is my subject" but the teacher doesn't make sense to I don't get it
- It depends on the teacher. A smart teacher uses more equations and concepts
- Don't think people fully understood what they were getting into at the beginning of the semester and once it started happening they were shocked
- Didn't know what to expect and then just wanted to get the credit

- Learned out much we don't know which is both exciting and terrifying. Probably influenced people both positively and negatively
- Come in excited and didn't really know what to expect. Depending on your experience it would affect how you feel about it.
- If students take the end of semester survey during school they are probably tired out with school. If they were to take it months after they might be more positive about it
- Generally people start out with a more positive attitude and then as their workload increases throughout the semester their attitude will get worse
- I only have to take the one semester and so I don't really understand the concepts or want to understand the concepts.
- I just need to pass

What do you think about conceptually checking your answer?

- I like the idea of linking the math to the concept but I don't like doing the checks
- They add a lot of work to the problem but were useful for understanding what was happening
- The concepts make more sense when they are linked to the math
- Conceptual checks help me to learn but they are too much work
- I think they could be helpful but instead they make it harder
- I might have liked the checks if I understood the concepts.
- I don't get the conceptual aspect so the checks don't make sense
- Don't like them because they're tedious
- They just add more work to the problem
- Don't like checks because I don't know the concept
- Checks don't help
- No I don't like checks
- Checks can be really useful for making sure that I used the right equation and that I have all of the variables in the right place. Using a conceptual check and make it so you catch a mistake with the variable or something
- Checks help to understand the concept

- I think that checks help to find the answer
- When you solve the problem a check validate your answer
- Using a conceptual check can help you find the answer and understand the concept
- Conceptual checks help me to link concepts and answer and makes me feel better with my answer. When I see that it is consistent with the theory I'm happy that it behaves the way it should
- I caught a mistake with a check. Using a conceptual check I was able to see that my answer was not consistent with what I should have expected.

What would you consider checking your work to look like?

- Doing the problem?
- Conceptual to think over answer the real world and going over the math
- Going through the solutions manual
- Going back over problems and answers with inputs
- Covering up work and reworking problem
- See if friend got the same answer
- Showing that all the units work out and rewriting neatly

Are you satisfied getting the correct numerical answer even if your math seems a little shady?

- 71% claim that they are satisfied

APPENDIX C

HOMEWORK PROBLEMS, SOLUTIONS, AND ANALYSIS

In the Spring 2014 semester, homework problems were used as a way to study the effect of conceptual checks to student grades and understanding. The problems below present both examples of homework questions including conceptual checks and the results that were found doing this study.

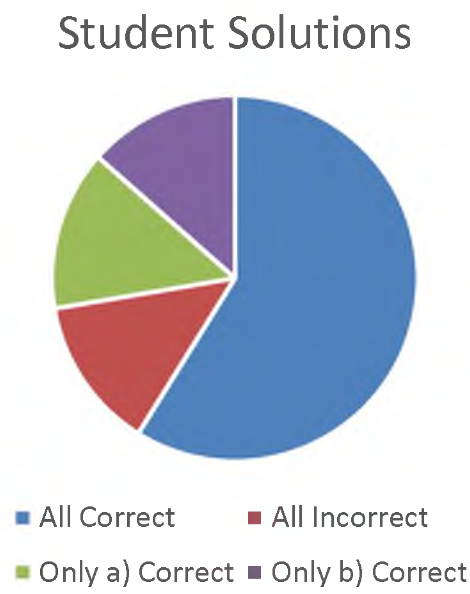
Results to Homework Problem Containing conceptual check

Unbeknown to Spaceman Spiff, his spacecraft (m = 1324 kg) has a residual negative 1.2 Coulomb charge on it from his encounter with the Zorg. The region of space Spiff has just entered has a magnetic field that bends the trajectory of his craft into a circular path (r = 1500 m).

- *(a) Indicate the direction of the magnetic field.*
- *(b) How would Our Hero's trajectory differ if his ship had a positive charge and the direction of the magnetic field was flipped?*

Conceptual check

- Use the right hand rule to correctly identify the direction of the field
- The answer to part b) "conceptually checks" the answer to part a)
- Because a) and b) are asking the same sort of question, the answers should be consistent with one another



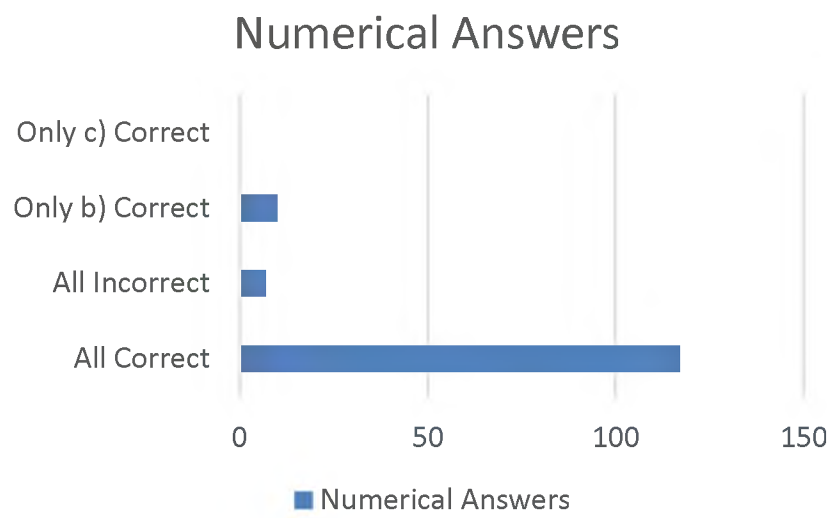
- Part b) is a conceptual check to part a) so I want to know how many people either got either both write, one of them correct, or neither
- 58% got the entire problem correct!
- Most who missed only part a) forgot or didn't know how to account for a negative charge
- Most who missed only part b) thought the trajectory would go the opposite direction
    - Took into account one but not both of the switches (charge and B direction)
- Most who missed both combined those two errors

Picture as a Check

(a) Starting from the equations for magnetic force (F~B = q~v × B~), Newton's 2nd Law, centripetal acceleration, and assuming that ~v is perpendicular to B~, show how the radius of the circular path of a charged particle in a magnetic field relates to the object's mass, charge, velocity and the magnetic field strength.

(b) Use this formula to calculate the magnetic field strength on Spiff's spacecraft in Problem 1.

(c) Calculate the force on Spiff's ship and ***indicate the direction of the force*** *in the graph above.*

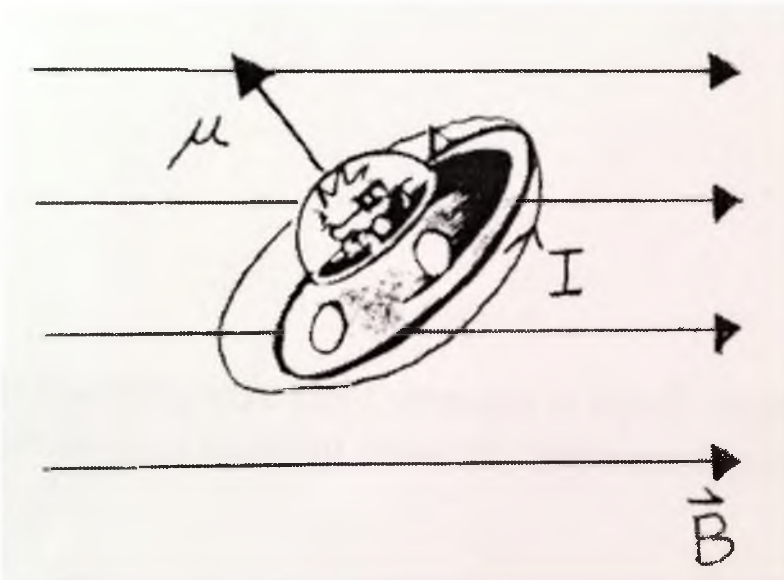


Skewed data

- Part c) is providing a graphical check to part b) so I would like to see if there is a correlation between getting parts b) and c) correct. Part a) is need to solve for b) so I'm assuming if they get b) they will have gotten a)
- Everyone calculated the force but **almost no one** drew it
- This alludes to the fact that almost **no one performs checks even when explicitly asked**

Problem with a Consistency Check

Spiff is able to bleed off the excess charge on his ship and regains control, although he's not out of danger. The FREEM drive of Our Hero's craft uses a 10-turn coil of wire carrying a current around the circumference of the ship (r = 2.4 m) with a current of 98.7 A. Spiff's craft is oriented with respect to the magnetic field as shown. Our Hero is still stuck in in the magnetic field, which has now reached 200 T!



(a) What is the net magnetic force on Spiff's ship caused by the magnetic field?

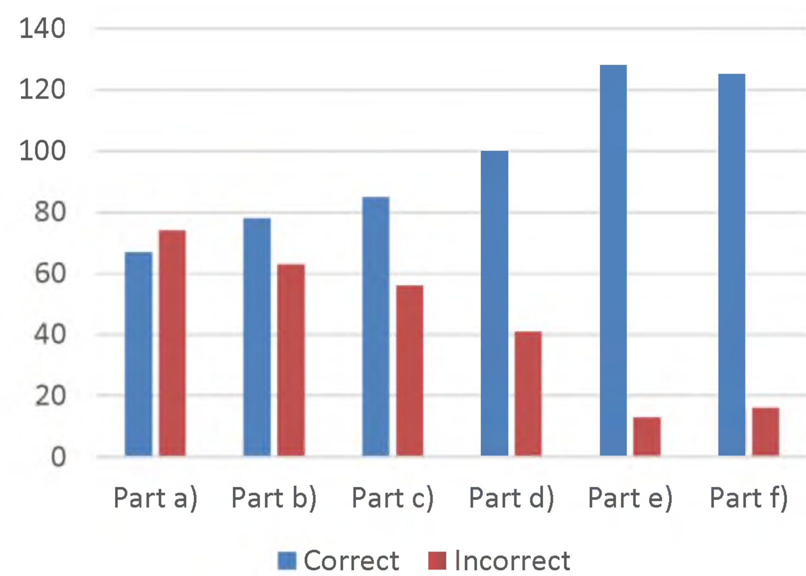
(b) Draw the direction of the forces on the current loop and describe what will happen to the orientation of his ship.

(c) If the axis of the loop makes an angle of 30° with the magnetic field, what is the magnitude of the torque on the ship?

(d) What would the torque on his ship be if the angle was 0°? 90°? 180°?

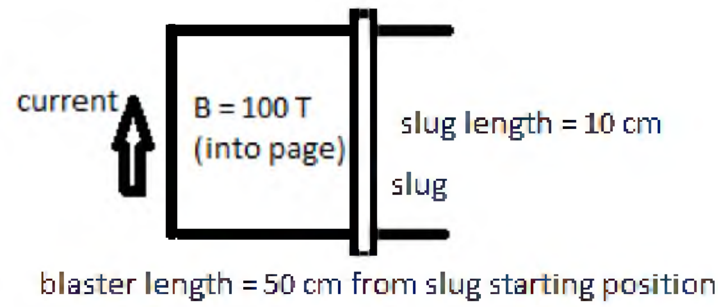
(e) In what orientation does the magnetic torque have a maximum amplitude?

(f) In what orientation does the magnetic torque have a minimum amplitude?



- Parts e) and f) were asking about the same concepts as c) and d)
- Part b) was a check to a) and c)
- Lack of connection between numerical and conceptual questions

Problem Where Student is asked to Recall Prior Knowledge as a Check

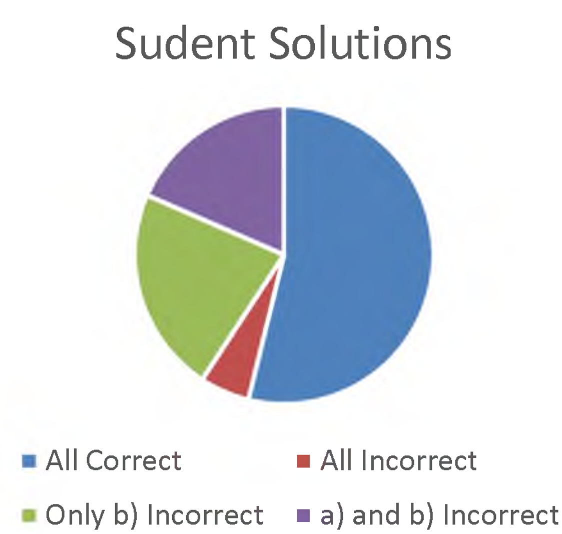


(a) What is the magnitude of the force on the slug?

(b) How fast is the slug traveling when it exits the blaster?

(c) What if Our Hero had the current accidently going the wrong (opposite) direction? (Of course he didn't!)

(d) If the current was going in the wrong direction, what could be changed about the Blaster to enable it to still function correctly?



- 53% got all parts of the problem correct
- 5% got the entire problem incorrect
- 20% got all parts except b) correct
    - Part b) drew heavily upon 204 knowledge
- 22% got a) and b) incorrect but c) and d) correct

- Numerical components incorrect, conceptual checks correct

Applying Conceptual ideas to a Purely Numerical Problem

After successfully deterring one of the Zorg with his slugs, Our Hero's spacecraft reaches the outer edges of the magnetic field, which is now uniformly vertical with a magnitude of 1.2 T. Just when Spiff thought it would be smooth sailing out of this region of space, his ship begins shedding its charge in the form of Li ions (charge +e and mass 1.0 × 10–26 kg)! The ions are accelerated by a potential difference of 10 kV and sent horizontal to the direction of the field. The last thing he needs is for the ions to deflect and hit the many rocky asteroids around him. Acting quickly, he begins to set up an electric field over the same region. Calculate the strength of the smallest electric field Our Hero would need to set up for the Li ions to pass through without being deflected.

The thought process we would like them to go through is

- Identify what the problem is asking
    - Want the ions to not be deflected because of the field
    - In order to not deflect, the magnetic force must be canceled out so that it's zero
- So if the total force $\mathbf{F} = e(\mathbf{E} + \mathbf{v} \times \mathbf{B})$ vanishes, it must be canceled out by a force from the electric field
- Thus the electric field E must be perpendicular to the velocity
- So $v \times \mathbf{B}$ has magnitude vB and $E = vB$.
- To get v, we can use conservation of energy where the potential energy is eV while the kinetic energy is $\frac{1}{2} m v^2$
- We can then solve for v and substitute into $E = vB$

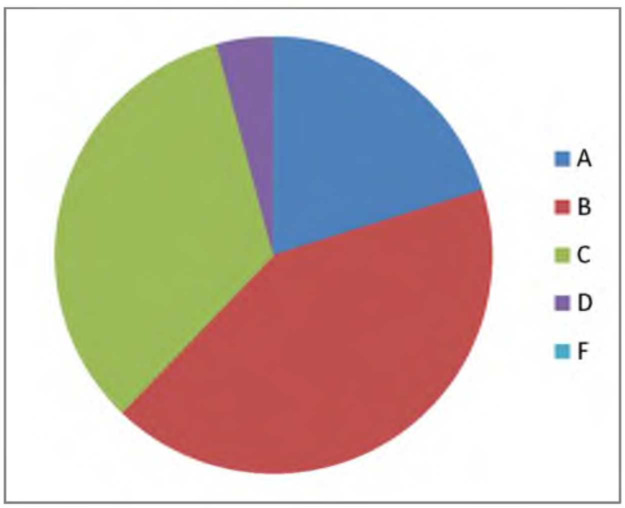
Results

- Only 49% of students got this problem correct
- All students, and some lab TA's, struggled with this one
- Connection with older material
- Conceptual understanding of what the question was asking

APPENDIX D

ADDITIONAL FIGURES

There has been preliminary work done to look at how students' beliefs affect their grade in the course. We have looked at the grade distribution, and there appears to be some correlation, but further investigation is needed to see if there is a true relationship between student beliefs and student grades within the data set collected in the Fall 2014 semester.

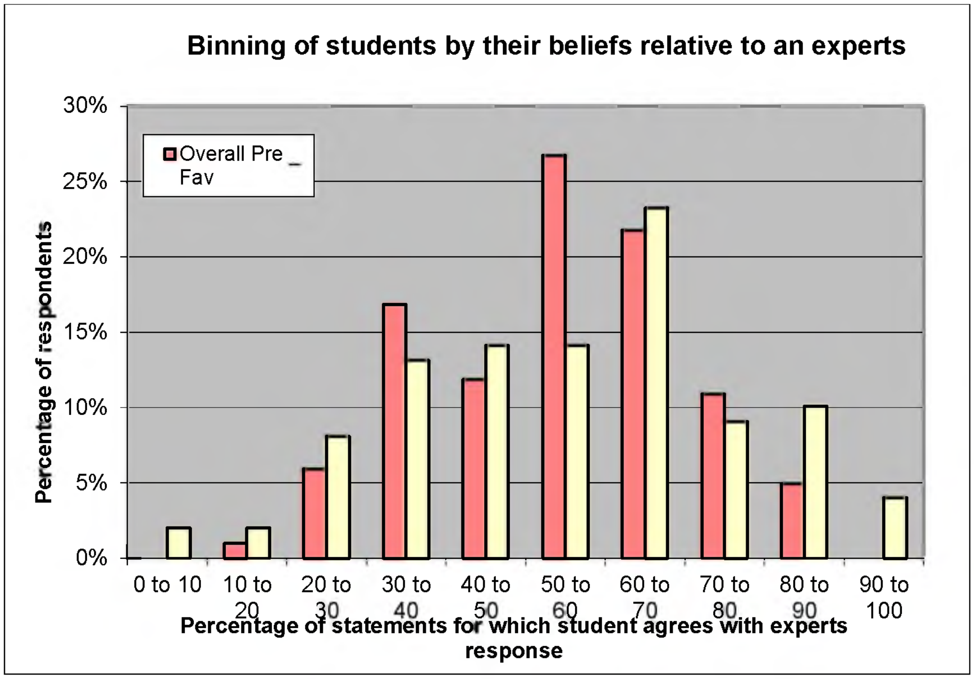


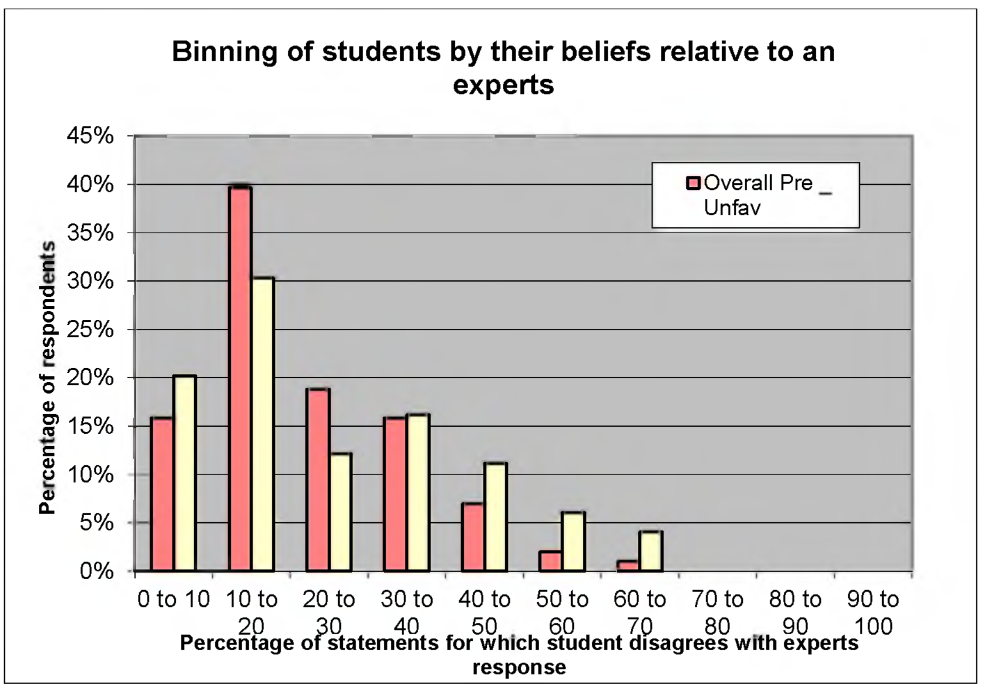
Use of Conceptual Checks in Lecture

CATEGORY	4	3	2	1
Given Checks	Consistently presented situations where a conceptual check could be performed and walked the students through the conceptual check	Periodically presented situations where a conceptual check could be done and gave the students the conceptual check	Used an example where a conceptual check was used and gave the students the conceptual check to be performed	Did not have situations where a conceptual check was given to the students
Explicit Checks	Consistently presented situations where a conceptual check could be performed and explicitly told the students which check could be done	Periodically presented situations where a conceptual check could be done and explicily told the students the check to be performed	Used an example where a conceptual check was used and explicitly told the students what conceptual check could be performed	Did not have situations where a conceptual check was explicitly told to the students
Hinted Checks	Consistently presented situations where a conceptual check was hinted at or implied within the problem	Periodically presented situations where a conceptual check was hinted at or implied within the problem	Used an example where a conceptual check was hinted at or implied within the problem	Did not have situations where a conceptual check was hinted at or implied
No Scaffolding (Reverse order)	Did not have situations without conceptual checks	Used an example without conceptual checks	Periodically presented problems without conceptual checks	Consistently presented problems without conceptual checks

Definitions	Clearly stated the physical meaning and relevance of a physics term in addition to the standard or mathematical definition	Defined physics terms within their mathematical context and compared to other relevent terms	Defined terms purely mathematically or within the context of the problems they are used in	Did not define terms
Comparisons	Consistently used to comparisons to give physics concepts physical meaning or clarity with respect to other physics concepts or conditions	Periodically used to comparisons to give physics concepts physical meaning or clarity with respect to other physics concepts or conditions	Used comparisons to give physics concepts clarity with respect to other physics concepts or conditions	Did not use comparisons within the lecture
Limiting Cases	Consistently presented limiting cases as conceptual checks for physics concepts	Periodically presented limiting cases as conceptual checks for physics concepts	Hinted at using limiting cases as conceptual checks for physics concepts	Did not present limiting cases as conceptual checks for physics concepts
Boundary Conditions	Consistently presented boundary conditions as conceptual checks for physics concepts	Periodically presented boundary conditions as conceptual checks for physics concepts	Hinted at using boundary conditions as conceptual checks for physics concepts	Did not present boundary conditions as conceptual checks for physics concepts
Special Cases	Consistently presented special cases as conceptual checks for physics concepts	Periodically presented special cases as conceptual checks for physics concepts	Hinted at using special cases as conceptual checks for physics concepts	Did not present special cases as conceptual checks for physics concepts
Units	Consistently presented units as conceptual checks for physics concepts	Periodically presented units as conceptual checks for physics concepts	Hinted at using units as conceptual checks for physics concepts	Did not present units as conceptual checks for physics concepts

Additional plots to display the CLASS data.





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