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Physics Education Research into
Reflection and Transmission in the Context of Waves and Physical Optics
University of Washington Physics Education Group
Research Experience for Undergraduates 2010

I. Introduction

Having students remember physics concepts through traditional lecture-based teaching has shown to be less effective over the years. One of the tests called the Force Concept Inventory (FCI), which probes student understanding on introductory physics concepts, helped highlight this fact for many instructors. At first, some professors refused to believe that a test on simple physics concepts could be so difficult; especially for physics undergraduates and graduates alike. One such professor, Dr. Eric Mazur, had his students at Harvard University take the test to prove they would pass without any difficulties. However, "…the test came as a shock: the students fared hardly better on the [FCI] than on their midterm examination. Yet, the [FCI] test is simple, whereas the material covered by the examination (rotational dynamics, movements of inertia) is of far greater difficulty or so [he] thought" (Mazur, 4)[1].

This incidence shows the importance of improving student learning in physics courses through other methods. Physics education research (PER) aims to achieve this goal by identifying and addressing the common problems students have on physics concepts. Thus, PER not only looks into the teaching method of physics, but the students' learning and understanding of it.

II. Background

The University of Washington Physics Education Group (PEG) obtain their goal by using a cycle of instruction, research, and curriculum. Through instruction, PEG administers pretests and post-tests in the classes to analyze student responses. To gain a better understanding of what students do and do not understand, student interviews are conducted as well. Once the data is collected, PEG can analyze it to identify the reasons why students might not understand a concept and develop a curriculum that addresses those issues. PEG has developed two curricula called *Physics by Inquiry*[2], which deals with the professional development of K-12 physical science teachers, and *Tutorials in Introductory Physics*[3], a text designed to supplement standard instruction in introductory university physics courses. These two curricula help students understand physics concepts better by supporting ideas taught through instruction. Then, more tests are re-administered to be gathered for research to identify other issues. Thus, the curricula are constantly being modified for improvement.

[1]Mazur, Eric. Peer Instruction: A User's Manual. Upper Saddle River, New Jersey: Prentice Hall, 1997.
[2]McDermott, L.C. and the Physics Education Group. Physics by Inquiry. New York: John Wiley & Sons Inc., 1996
[3]McDermott, L.C., Peter Shaffer, and the Physics Education Group. Tutorials in Introductory Physics. Upper Saddle River, New Jersey: Prentice Hall, 2002.

The curriculum used primarily in this research paper is *Tutorials in Introductory Physics* (tutorials). It consists of pretests which gauge the level of understanding the students have after relevant standard instruction on a physics concept. These serve many purposes, one of which is for the professors and teaching assistants (TA). The pretests allow them to know what the students do and do not understand in order to help guide students more effectively during laboratory sessions. During those sessions, students work together in groups of three to four, answering questions that address physics conceptual problems. If students have difficulty answering a question, the professor or TA can help answer the problem, but only in the Socratic or Guided Inquiry Teaching Method. This forces students to find the answers on their own. Afterward, they are assigned homework from the tutorial workbook that reinforces the ideas from class and the worksheets.

From the student perspective, the TAs seem all knowing as they walk around each group of students, guiding them flawlessly. This requires careful TA preparation. Before each lab, TAs come together in a meeting and take the same pretests the students did and then go over the worksheet in detail, making sure they understand the answers to the problems. They mark which problems they think students might have difficulties with and confirm this by looking over the student responses on pretests. These meetings allow the TAs to help students more effectively.

Yet, students are not the only ones to benefit from the development of *Tutorials in Introductory Physics* curriculum. During five weeks in the summer, the Summer Institute in Physics and Physical Science helps in-service K-12 teachers understand physics concepts so they in turn can teach their students with greater knowledge. They come in around 9 am and work until 3:45pm Monday through Friday. During the summer of 2010, the teachers worked through a modified version of tutorials entitled *Tutorials for Teachers in Introductory Physics*. In the session, they were aided by TAs of their own. Similar to the TAs in the student labs, they come together in meetings to go over the tutorials, but in greater depth. Unlike the student version oftTutorials, the teachers have periodic "check-outs" where TAs will ask deeper questions about the material covered and give a midterm and final exam during the course instead of post-tests.

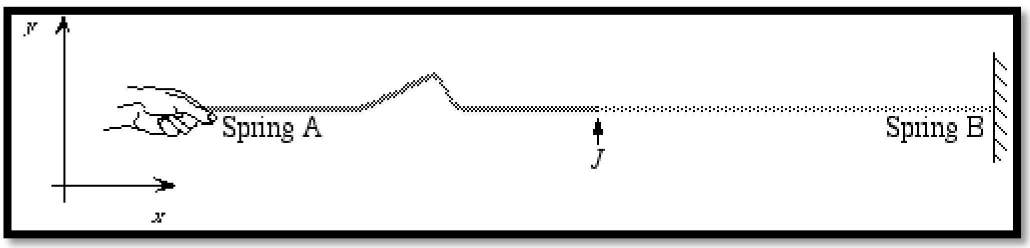
III. Overview of the Research

In this research project, the tutorial on reflection and transmission is examined to identify any areas students and teachers might be struggling with. Pretests for this tutorial are analyzed to establish where they are in their understanding of the concept. Thus, we can target possible problems that should be addressed in the curricula. One of the reasons for following both the teachers and students during the Summer Institute and Student Laboratory Sessions, respectively, allows us to understand their thought process when going through the tutorials. We learn how they interrupt and learn from the material, so modifying the curricula will be done more efficiently. Also, learning about the concept itself more deeply enables us to analyze the data with more understanding. However, if a misconception is not properly addressed in the curricula, a student may still possess it and is revealed on the post-test. We do this by comparing the pretests and post-tests results. When doing so, we can find interesting trends and expand the research into other areas we might not have known students were having difficulties in. One such important trend was examining thin film interference as well, discovering students making similar mistakes in this tutorial as those in reflection and transmission.

IV. Reflection and Transmission

Knowing where the students are in their knowledge of physics is important before delving further into research. The first pretest examined for this projected asked the following question:

A. The pretest on reflection and transmission



All images on this research paper are from *Tutorials in Introductory Physics* pretest, post-test, worksheet, and homework.

A student performs an experiment with two different springs, A and B, attached end-to-end at point J as shown below. The student creates an asymmetric pulse by quickly moving spring A quickly side to side. The student notes that pulses travel twice as fast in spring A than in spring B.

a. Is the tension in spring B greater than, less than, or equal to the tension in spring A? Explain. If it is not possible to make this comparison, explain why not.

b. Is the mass per unit length of spring B greater than, less than or equal to the mass per unit length of spring A? Explain. If it is not possible to make this comparison, explain why not.

i. Correct Student Responses to Pretest Questions

Before analyzing the results, the answers to the question should be known. The tension is equal in both springs while the linear mass density of spring B is greater than spring A. Yet, knowing the answer isn't enough. Students can have the correct answer for the wrong reasons. Thus, establishing what would be considered to be a completely correct answer is needed. Below are student responses that illustrate a correct answer to the question.

The answer to part a is equal to, because "Neither Spring A nor B are <u>moving</u> (save for wave pulses) so the <u>net force</u> on each of them is <u>zero</u>. The tension force on the right end of A is, by Newton's laws, the same as the tension force on the left end of B. Therefore, the tension force in each spring is the same."

As for part b, "There are two ways to increase pulse speed - increase tension or decrease mass/length. Since the pulse was slower on spring b, it must have more mass per unit length than spring a, because the tension in both is the same."

The underline portions of the responses show key points in explaining the questions correctly.

ii. Student Answers on Pretest

The table below shows the percentage of students who answered the pretest questions. The rows are the responses to the linear mass density and the columns are the responses to tension. There are a total of 2676 students who took the pretest online. They came from various classes and instructors.

	Equal To	**Greater Than**	Less Than	Unable to Tell	Grand Total
Equal To	5%	**15%**	5%	0%	**20%**
Greater Than	0%	5%	5%	5%	10%
Less Than	5%	**30%**	10%	15%	**55%**
Unable to Tell	0%	1%	0%	10%	10%
Grand Total	10%	**50%**	20%	25%	100%

iii. Trends on Student Answers

The percentage of students answering both parts correctly (15%) is very low. Individually, students didn't fare any better with only 20% of them answering part a right, but on part b 50% of them responded correctly. This seems odd since in order to answer the linear mass density completely correct, a student had to realize the tension was the same on both springs. So, "Why did so many students answer the question on linear mass density right (50%) compared to tension (20%)?" Several student explanations responded along the lines of "More mass means more energy is required to move the spring in a wave motion, thus in spring B with more mass, the wave would travel slower due to more energy needing to be exerted." This demonstrates they drew from their personal experiences on how lifting or moving something heavy takes more time and energy than something lighter. We want students to think this way, making observation from the real world and applying to physics problems they face. Too many students believe that physics is impractical and does not work in the real world.

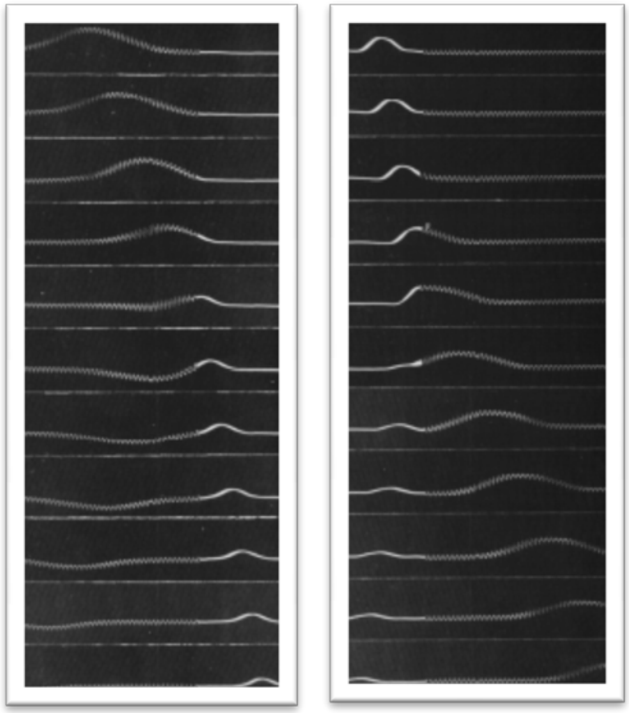
However, this does not explain why students didn't answer tension correctly. Thus, another question that arose from the table helps answer the previous one is "Why is 'Less Than' the most popular answer for tension (55%)?" A student who answered in this fashion explained, "It was demonstrated last week that a pulse will move faster in a spring that is stretched out more. Because the pulse moves faster in spring A, spring A has more tension." In the tutorial before reflection and transmission, students learn that increasing the tension increases the wave pulse speed. This is true for a single spring system, but the pretest that pertains to the question had a two spring system instead. Although students are making connections from physics to the real world through their observations, but they are over generalizing them.

Though, another interesting trend appeared when looking over the explanations more closely. It seemed that students who answered tension correctly had more complete explanations for the answer and thus tend to get the linear mass density right compared to those who had missed tension. The responses of "correct a and b" (393 students who answered equal to for tension and greater than for linear mass density) and "correct a and incorrect b" (207 students who answered equal to for tension and everything except greater than for linear mass density) were categorized separately. Afterward, there wasn't anything conclusive to prove the assumption stated before true. However, one interesting result from the analysis did arise. There were 29% of students in the "correct a and incorrect b" group who restated the answer, didn't know, or had no explanation compared to the 8% who answered in a similar way in the "correct a and b."

B. Overview of Reflection and Transmission Concepts

Before proceeding further, it's important to understand what the students covered in the tutorial for reflection and transmission. Students starting the tutorial build off of their understanding on superposition and reflection of pulses (covered in a prior tutorial). In the latter tutorial, students learn about "fixed-end" and "free-end" situations; where sending a pulse down a spring attached to a wall will result in an inverted reflected pulse and when sending a pulse down a spring attached freely on a rod will result in a reflected pulse on the same side as the incident pulse. They apply this idea to a two spring system by making a prediction of the springs' shapes and comparing their prediction to photographic evidence.

When an incident pulse travels from a lighter to heavier spring, the transmitted pulse is smaller and slower on the same side as the incident pulse with an inverted reflected pulse, becoming a "fixed-end" situation. Alternatively, when the incident pulse travels from a heavier to lighter spring instead, the transmitted pulse is larger on the same side as the incident pulse, but the reflected pulse is also on the same side, more like a "free-end" situation. Students should take out from the tutorial the idea of "fixed-end" and "free-end" instances and recognize that a pulse traveling between two different media will always have a transmitted and reflected pulse at the boundary of those two media.

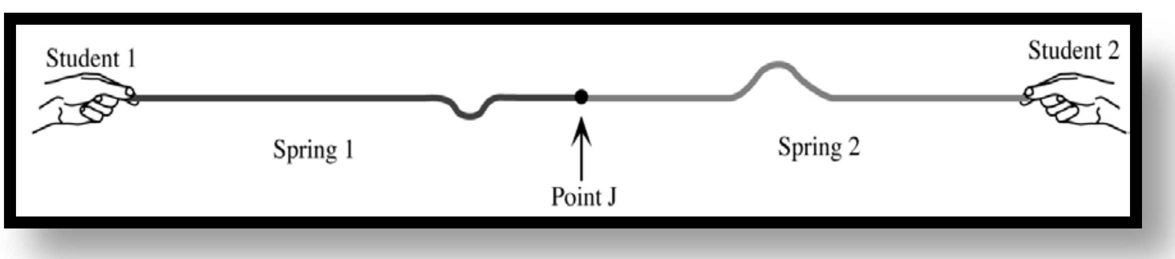


Fixed-end on the left, free-end on the right.

C. Investigating Post-Tests on Reflection and Transmission

The concept of comparing single spring instances to a two spring system is difficult and poses many problems as seen on the pretest results. After going through the worksheet and homework, we hope students have a better understanding of reflection and transmission. To be sure, we compare the results from the post-test to the pretest.

i. First Post-Test Analysis on Reflection and Transmission



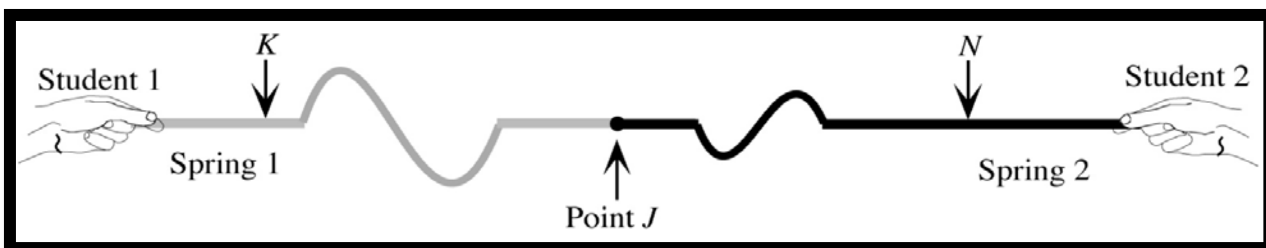
A particular post-test asked the same problem again as in the pretest except students had to infer from the picture which spring had a faster wave pulse rather than given it, making the problem harder than the pretest. Tension would remain constant, but the linear mass density depends on which spring has a higher wave pulse speed. Students would have to analyze the picture and note how the pulse on spring 2 is wider and traveled farther from junction J. Therefore, spring 2 had a faster wave pulse speed. This led to answering that spring 1 had a greater linear mass density.

The results are given below in the table for a class of 102 students.

Question	Pretest	Post-test
1a)	20%	90%
1b)	50%	80%
Both	15%	75%

The percentage correct for each part and both parts of the problem have increased dramatically. This shows that the tutorial is working in helping students understand the relation of wave pulse speed to tension and linear mass density. Yet, a question emerges from the results. Does asking about tension help the student answer the question correct on which spring is has more linear mass density? In order to answer the linear mass density completely correct, the student has to realize that tension is equal on both springs. So, another post-test was analyzed that only asked about the linear mass density.

ii. Second Post-Test Analysis on Reflection and Transmission



Again, the post-test didn't state which spring had the faster wave pulse speed, but it can be inferred from the size of the pulses. Since the pulse on spring 1 is wider and traveled farther than the pulse on spring 2, spring 1 has a faster wave pulse speed. Therefore, with tension constant, the linear mass density of spring 1 is less than spring two. Oddly enough, 95% of students (in a class of 202) answered the question correctly. That is 15% more than the class that had been prompted a question on tension.

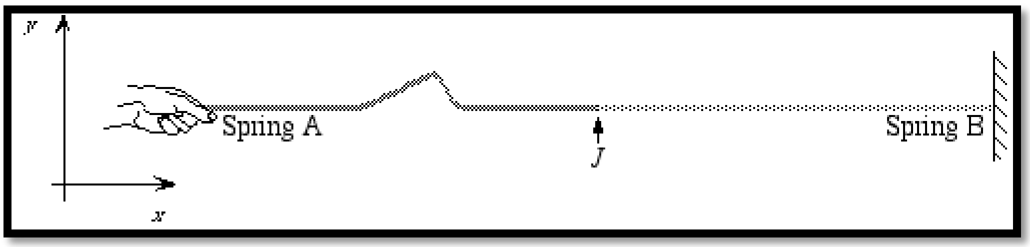
We then wondered, "How many students who answered the linear mass density correctly used tension in their response?" The responses were categorized and sorted by students who used tension and those who did not. The results are seen below on the table.

Student response	Post-test with Tension Question N = 83	Post-test without Tension Question N = 192
Used tension	30%	70%
No tension	30%	70%

With these results, we find that students will answer the question about linear mass density the same regardless if they are prompted about tension or not.

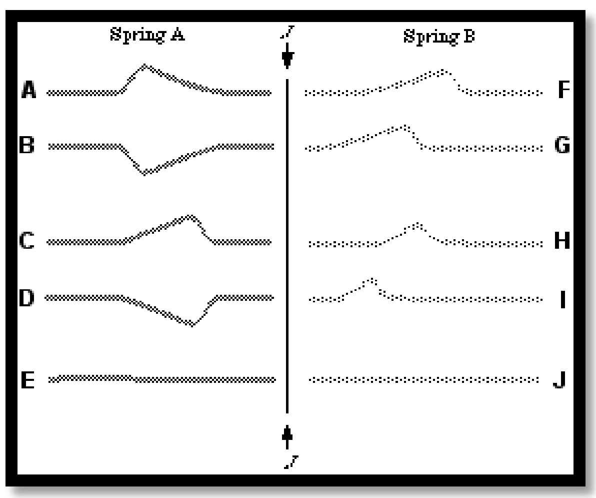
D. Second Question on Pretest for Reflection and Transmission

Since the results of the post-test as well as the student responses showed a large improvement about tension and linear mass density, the second question was looked into as well. The situation is the same as the previous pretest used earlier in the paper:



A student performs an experiment with two different springs, A and B, attached end-to-end at point J as shown below. The student creates an asymmetric pulse by quickly moving spring A quickly side to side. The student notes that pulses travel twice as fast in spring A than in spring B.

2. After the pulse has traveled past junction J, what shape(s) do the springs take out of the following options?



According to the tutorials, a transmitted pulse will always be on the same side as the incident pulse. The size and distance the transmitted pulse travels depends on the linear mass density difference between spring A and B. Since spring B has a greater linear mass density than spring A, the transmitted pulse will be smaller and travel a short distance. With spring A being lighter than spring B the reflected pulse will resemble a fixed-end situation and be inverted. Therefore, C and I are the correct answers.

The result of the pretest was startling as less than 5% answered the problem correctly. 90% of students picked an answer that involved a transmitted pulse, so students realize that an incident pulse will create a transmitted pulse in the new medium. However, 60% of students had no reflection on spring A.

E. Post-Test 2 on Reflection and Transmission

The results of the pretest over the second problem on reflection and transmission caused us to analyze the post-test specifically to see how many students understood reflection with so many before missing it. The post-test asked students to sketch out the incident pulse after it passed the boundary from light to heavy and heavy to light.

	Heavy to Light	Light to Heavy	Pretest Light to Heavy
Percent of Total Students	15%	15%	60%

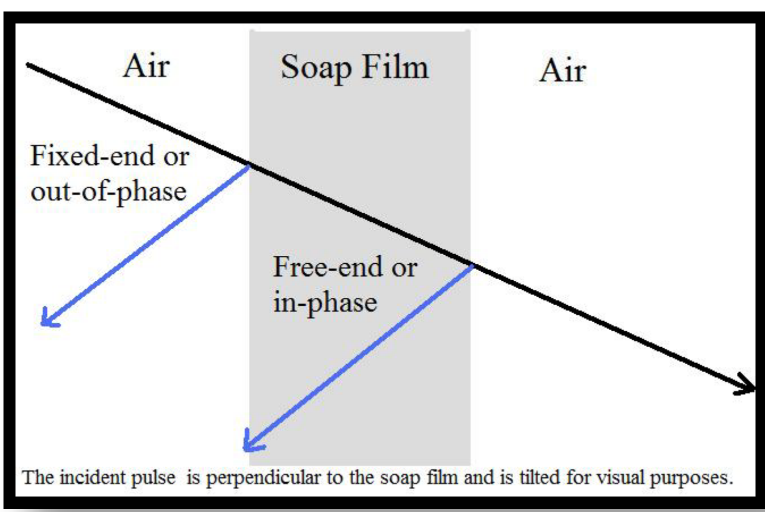
The percentage of students on the post-test that had no reflected pulse improved. Only 15% had drawn a straight line instead of 60%. Yet, there are still 15% of students who believed to be no reflected pulse on the first spring.

V. Thin Film Interference

The physics cumulative development of concepts is very linear. If a student doesn't understand a concept early on, then the student will most likely not understand future subjects that involve that concept. With 15% of the students missing that there is a reflection at the boundary between two springs might affect how they comprehend a future subject such as thin film interference that relies on that previous knowledge.

A. Overview on Thin Film Interference Concept

For example: In order to tell if a distant observer will see maximum brightness, minimum brightness, or neither on a thin film, students must understand what occurs at each of the boundaries. In the tutorials, they are told to compare the boundaries to springs acting as a fixed-end or free-end. For instance: a thin film of soap surrounded by air. When a light wave travels incident to the first boundary, the reflected pulse will act like a fixed-end or out-of-phase since the soap film is more optically dense than air. At the second boundary, the light wave reflects off like a free-end

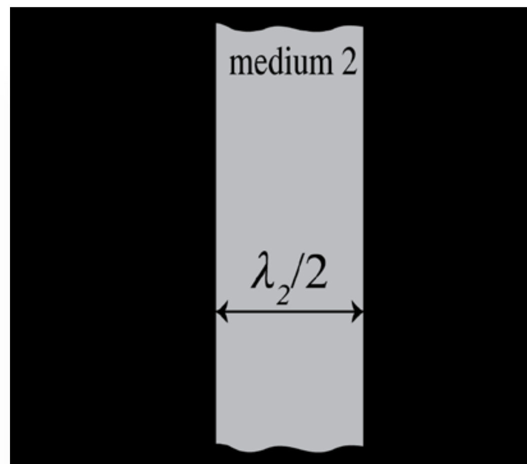


or in-phase since air is less optically dense than the soap film. Finally, knowing the distance the wave travels within the film will affect what the distant observer sees. If the distance is a whole wavelength multiple, then the second boundary reflection will remain in-phase. Thus, out-of-phase plus in-phase will result in deconstructive interference or minimum brightness. If the distance is a half wavelength multiple, then the second boundary reflection will changed to being out-of-phase. Thus, out-of-phase plus out-of-phase will result in constructive interference or maximum brightness. If the distance is neither a whole wavelength or half-wavelength multiple, then the second boundary reflection will changed to being neither in-phase nor out-of-phase. Thus, the observer will see neither maximum nor minimum brightness.

B. Pretest and Post-test on Thin Film Interference

As was the case in the example given on the previous section, students were asked on the pretest and post-test whether or not a distant observer will see minimum brightness, maximum brightness, or neither. Mediums 1 and 3 were more optically dense than medium 2, and the thickness of medium 2 was half the wavelength that traveled within it.

At the first boundary, the reflected pulse will be in-phase since medium 2 is less optically dense. At the second boundary, the reflected pulse will be out-of-phase since medium 3 is more optically dense. The distance traveled total is a full wavelength, so the second boundary will remain out-of-phase. Thus, the observer will see minimum brightness.



The results of the pretest are seen below on the table with N representing the number of students in the class.

Response	Pretest N = 79	Idea of Reflection	Post-test N = 149	Used Reflection
Minimum	40%	65%	50%	80%
Maximum	45%	40%	50%	45%

For the pretest, we could not ask students to explain their answers since it was a multiple choice problem. Also, they have not covered the relevant tutorial, but had instruction from class. However, we were able to ask the students if out of the following options could change what the distance observer would see.

A. Medium 1 being less optically dense than medium 2.
B. Medium 3 being less optically dense than medium 2.
C. Both A and B.
D. Neither
E. Not enough information provided.

If students answered C, they had an idea of reflection. We determined this based on the other possibilities students had. No students had chosen E, so the probability for guessing reduced down to 25% for each answer. A student picking D, saying neither changing medium 1 nor 3, shows the student was not thinking about how the medium's densities affect the phase change on reflected pulses. Now the probability for guessing has reduced down to 33.3%. The options A and B show an "idea of reflection" since individually they are correct. However, without explicitly asking the students their reasons for picking those answers, we cannot say for sure if they were guessing or thought of reflection at all. We know that C is the correct answer in the problem, but, yet again, a third of the students who answered this could be purely guessing. Although, since C incorporates both A and B, we can state that the students were more likely to have had an "idea of reflection." Of course, the percentage of students who answered C could be those who did have an idea of reflection, purely guessed with no reason, or thought C to be correct but not using reflection in their thought process. So, leaving the percentage as is without considering these factors allows us to compare to the post-test unbiased. This is so, because the students on the post-test were expected to explain their answers. If their explanation involved reflection, it was defined as being "used reflection." Thus, we are restricting to only those who truly did use reflection on their responses. While the "used reflection" percent is greater than the pretest "idea of reflection," the percentages are still very close. More interestingly, on the pretest a third of the students believed that changing medium 3 would not affect what the observer sees. However, less than half the students on the post-test continued with this logic. So, there is some improvements occurring between pretest and post-test, but not enough that illustrates a large number of students understanding the concept.

VI. Conclusion

While reflection and transmission is a difficult subject to comprehend, students who had problems with identifying the difference in the tension and linear mass densities between two springs were far less after going through the relevant tutorial. However, the concept that an incident pulse always producing a transmitted and reflected pulse traveling from one medium to another that is different seems to elude some students. They understand that a transmitted pulse will appear in the new medium, but not a reflected in the old. Even though only 15% of students believed this, it was enough to affect the results in the thin film interference pretest and post-tests. Half of the students missed a typical thin film interference problem on the post-test with many still not understanding the connection to reflection.

VII. Future Research

There are many improvements and further research that can be expanded upon this one. In thin film interference, many students had missed the reflection portion on the problem. Therefore, modifying the worksheet and homework would be the next step in clearing any confusion students might have. Though, it is not surprising that so many students did not retain the concept of reflection from the tutorial on reflection and transmission to thin film interference. There are 13 tutorials between the two subjects. Tracking the students' retention of reflection on each tutorial might target where students forget the most. This would require looking into each pretest, tutorial, and post-test. Depending on the results, modifying the worksheet and homework might not be required for the thin film interference, but in other tutorials.

While not discussed about in this paper, another aspect of the research into reflection and transmission was looked into. The Summer Institute in Physics and Physical Science was running from June 28th till July 30th in the summer of 2010. In the mornings from 9am to 12pm, a group of high school physics teachers covered physical optics and waves. They went through the same material as the students who were taking classes for the summer, but more in depth. Comparing the teachers and students responses would hopefully produce some interesting results, especially in how each one would explain their ideas for the answer. The data collected so far has shown teachers making the same mistakes as students in their responses. However, with only 16 teacher response collected, it wasn't enough to make an accurate comparison between the two.

Even though reflection and transmission is important, there are many other topics in physical optics and waves that could be changed and benefit students as well. Reflection and transmission is not the only aspect of physics that students have problems in. Physics education research will forever be ongoing in trying to improve students' understanding.

VIII. Acknowledgements

The author would like to thank the support and collaboration of the Physics Education Group. More specifically: special thanks to Dr. Peter Shaffer, who has dedicated much of his time and energy in guiding this research; the Physics Education Group graduate students and staff, who have given their knowledge and experience. This investigation was made possible by the Nation Science Foundation and the University of Washington Research Experience for Undergraduate Program.