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CREATING ACADEMIC COMMUNITY FOR
FIRST-GENERATION COLLEGE STUDENTS
A Graduate Student Instructor Guidebook

Developing Critical Thinking Skills in an Introductory Calculus-Based Physics Class with the Aid of Peer Review

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College coursework requires students to use their critical thinking skills in order to succeed in classes. Current culture in higher education assumes that students arrive to college with a well developed set of critical thinking skills or that they are able to develop the necessary skills on their own. This assumption is especially evident in science coursework, where the students are asked to use their critical thinking on everyday basis (doing lab work, solving the problems), but are rarely taught how. The lack of these skills puts students at a great disadvantage. First generation students are especially at a disadvantage because they usually arrive to college less prepared than their peers from families where parents have had some college education. We propose that the absence of critical thinking manifests itself in low test scores. We investigate this connection by observing the relationship between student test scores before and after the set of exercises developed to develop critical thinking and scientific expression in the introductory physics class environment.

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Developing Critical Thinking Skills in Introductory Calculus-Based Physics Class with the Aid of Peer Review

By Korana Burke

A common phenomenon in introductory physics classes is student difficulty with distinguishing between the right and the wrong solution to an assigned problem. In part, students need to further cultivate scientific critical thinking skills, fundamental to ongoing success in their discipline. A majority of students blindly trust the solutions provided by the figures of authority (professors, teaching assistants, textbooks) and are unable to elucidate why their solution does or does not agree with the provided one. They are inclined to believe that there is only one way to correctly solve a problem, and they frequently do not understand the physical relevance of different steps in the offered solution. Furthermore, if their answer does not agree with the provided one, a majority of the students resort to "formula mining" techniques, trying many different combinations of the formulas found in the textbook and their notes, until they get the answer that matches the offered solution. Commonly the formulas used as a result of this "formula mining" process are not even relevant for a given problem because in the course of trying to match the provided solution, the students forget that the same symbol can refer to two otherwise unrelated variables. Consequently, this approach does not help students learn the material. Instead it hampers their understanding of physical concepts, and as a result, their performance on an exam suffers. A successful science or engineering student is not only capable of providing the correct answer to the problem, but is also able to explain the approach to the solution.

My research project focuses on developing critical thinking skills through the use of peer review and self reflection. The students participating in the project are enrolled in the second semester of a calculus-based introductory physics class. The class is composed of a mixture of majors ranging from biological sciences, chemistry, physics, mathematics and various engineering majors. As such, the participants are a good representation of a general student body.

Previous research in writing and social science instruction has shown that peer review is a valuable tool in developing critical thinking skills. (Some recent work can be found in references [1-2]). As a result, peer review exercises have become common practice in writing and social science classes. However, there is very little indication that a peer review process is being employed in physics or math classes, even though it has been recognized that reading and writing are important in science classes (references (3-4]). This paper presents how peer review can be used as a valuable tool in developing deeper understanding of physical concepts in an introductory physics class, with broader applications to college-level science instruction.

The goal of this study is to show that practicing critical thinking skills enhances students' performance on exams. The class we have chosen is an introductory physics class, with seven discussion/lab sections (n=148). We have chosen two sections to participate in peer review exercises and the remaining five sections were used as a control group. (In the remainder of the paper, I will refer to the two participating sections as groups A and B.) Attendance was not mandatory, and on average we had twelve students participating (n=20). Scores from the first midterm served as a baseline for the whole class. The students from the participating sections were asked on weekly basis to anonymously solve a physics problem. The solutions were collected and randomly redistributed to students for grading. In the process of grading their peers, the students were asked to critically evaluate the physics solution and provide a verbal description backing up the grade they assigned to their peers.

An initial survey helped to determine students' prior experience with peer review (n=12). The closing survey aided in determining students' opinions about the peer review (n=14). Completed survey results can be found in Appendices 1 and 2. The purpose of the initial survey was to understand the level of students' prior experience and their comfort level with the peer review process. All but two students reported earlier participation in peer review with a majority of the experiences being in traditional freshman composition courses. One student did report participating in peer review in a first semester calculus class. However, since the surveys were anonymous, we could not further investigate the nature of the peer review exercises in which this student participated. The assumption is that the student confused group work with peer review because to the best of my knowledge, peer review has not been used in any of the calculus classes on campus. The initial survey also revealed that a majority of the students (almost 60%) feel comfortable with both providing and receiving the feedback from their peers. The students that have reported participating in peer review most frequently in other classes also reported to be more comfortable with both giving and receiving feedback. Finally, initial survey revealed that 75% of the students feel that reviewing peer review feedback helps them understand physics concepts, and almost all (83%) agreed that describing the problem in words helped to guide them to the solution.

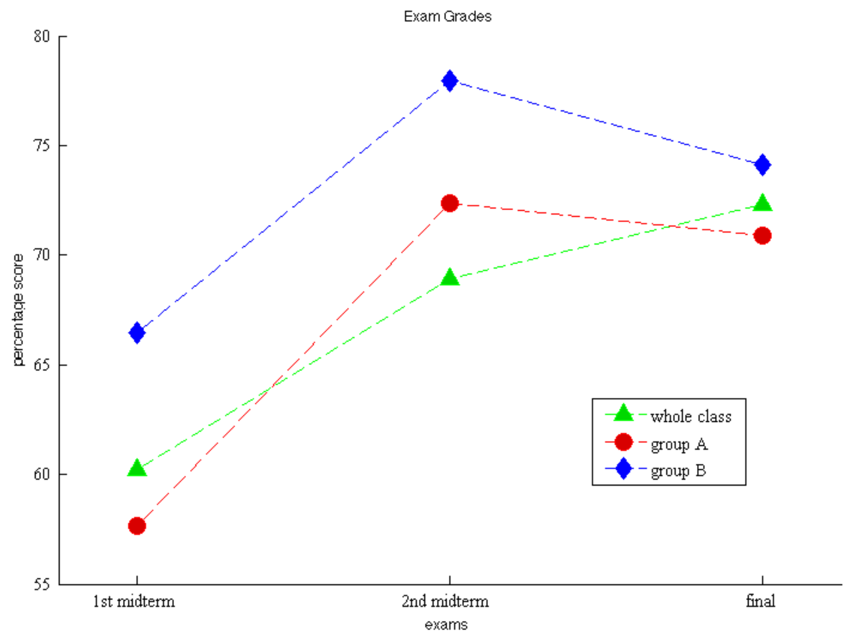
Students participating in the exercise have shown great strides in developing their critical thinking skills. In the beginning, students had harder time distinguishing between the correct and incorrect solutions to the problem. Similarly, the first time the students were asked to provide the explanation of the grade they assigned to their peer, they were mostly providing the answers of the form: “It seems correct/wrong because it agrees/does not agree with the formula.” or “It is correct/wrong because they do/don’t know what they are doing.” (For grading rubric, see Appendix 3.) As students gained more practice using the peer review in a physics class, the explanations became more detail oriented. They started to include more conceptual descriptions when describing their grade choice, along with noticing when units for the final answer did not work out, and when their peer was confusing two different topics.

Along with developing the ability to better distinguish between the correct and incorrect solutions, the exercises had the unexpected benefit of students recognizing that the same problem can be solved many different ways. Professors and teaching assistants frequently try to instill the notion that there exist multiple correct ways to solve the same problem. However, students usually do not pay attention to this fact and gravitate towards a single solution process (usually the first one they are exposed to). If they do not arrive at the solution using this process, they tend to feel lost or resort to “formula mining” instead of trying a different approach to the solution. After performing the exercise multiple times, some students started making comments while grading their peers such as: “That solution is so much simpler than mine.”, or “I never would have thought of doing it that way.” In the final survey, majority of the students (64%) reported that peer review helped them realize that there are multiple correct ways to solve the same physics problem. Unfortunately, the verbal responses are only anecdotal and we do not have any written record of them.

The average score on the first midterm for the whole class was 60.22% and it increased to 68.92% on the second midterm. (See Figure 1 “Exam Grades”) We did expect the scores to increase from the first to the second midterm because of prior experience with teaching this class. Historically, the students have easier time understanding the material in the second half of the semester because, even though they are introduced to new concepts, the set of skills required to understand these new concepts is the same as in the first half of the semester. Thus in the first part of the semester they are expected to absorb both a new set of skills and non-intuitive concepts, while in the second part of the semester, they are only exposed to the new ideas, while still utilizing the same set of skills. Hence, even though the material is equally difficult, familiarity with the required set of skills results in higher exam scores over time.

A closer look at the grades reveals that the two groups (groups A and B) participating in the peer review exercises, have shown a much greater increase in the scores than the rest of the class. The average for group A improved from 57.67% on the first midterm to 72.38% on the second midterm. Similarly, the average for group B increased from 66.45% to 77.96%. (See Figure 1 “Exam Grades”)

FIGURE 1: Exam Grades



The final evaluation shines some light on why peer review helped the students perform better on the exams. I had anticipated that peer review would instruct students to evaluate their own work and to recognize when they have made calculation errors. I have also hoped that practicing peer review was going to help students understand that there are, more often than not, multiple ways of approaching the same physics problem. While being exposed to different ways of arriving at a solution, they are going to develop a deeper understanding of the concepts. In the final survey only 64% of the students recognized that there were multiple ways of solving the problem. However, in the narrative response part of the survey, quite a few students remarked that peer review forced them to think in more depth about the concepts and to think more thoroughly than in regular discussion sections. I believe that this is the real reason why the students that have participated in the exercises have shown a greater increase in their test scores. Students have been more critical of their own work, and hence they were more likely to provide the correct answer to the problem. This is backed up by the anecdotal evidence from my interaction with the students during the office hours. During the course of the exercise, students started noticing more often when the answer resulting from inputting the numbers into the calculator at the end of the problem did not make sense. They have started developing some physical intuition, which is frequently missing even in some physics majors who are about to graduate. Thus, this being the introductory course, peer review exercises provided additional benefit of teaching the students to develop a scientific perspective which is useful beyond an introductory physics class and has benefits that extend beyond the rote learning process.

Students frequently complain about not understanding the concepts presented in the book and the wording of the problems. The main cause of this problem usually stems from students not being well versed in the language of science. This in turn creates a lot of frustration and causes the students to stop using the textbook explanations as a tool to understand the presented material. Instead, they resort to "formula mining" in order to solve the problems. The result of this is approach is poor understanding of the subject and reduced performance on the exams. Interestingly, practicing peer review showed a significant increase in the self perceived comfort level with the use of the scientific, especially physics, language. In the opening survey, 58% of the students reported being comfortable using scientific language, and in the closing survey, the number rose to 78.6%. I believe the constant practice evaluating their peer's work made the subject more approachable and less intimidating. Students were then able to use the book more efficiently and gain deeper understanding of the material.

Finally, 64% of the students would recommend using the peer review in the future physics classes. Even though this number shows that the majority of the students did think that the peer review was a valuable learning tool, I expected the number to be higher. The possible reasons why more students did not fully endorse this approach stems from the fact that in order to participate in this exercise, the students were asked to grade each other before the correct answer to the problem was provided. Some students wrote about this process in the free response part of the final survey. Their responses signal that they were asked to step far out of their comfort zone when they were grading each other, and they complained mostly about not knowing whether what they are writing down as an explanation for their grade was correct or not. On the other hand, these responses signal that the students were much more concerned about their knowledge when they were asked to evaluate another work than when they were providing the answers to the homework or the test problem.

After noticing the positive influence of the peer review on the midterm exam scores, we decided to continue using the exercises until the end of the semester. However, the students have also observed the beneficial effects of evaluating one's own work on the exam scores, and the whole class showed a significant increase in performance on the final exam. The average for the whole class increased to 72%, and the two groups participating in the peer review exercises remained at 71% and 74%. We were not able to fully isolate the two groups from the rest of the class, and the students were encouraged to work in groups while working on homework. From anecdotal evidence, we know that the majority of the students did form study groups that included students outside their discussion/lab groups. Hence, we were reaching a much larger population than initially intended. We assume that the students from our test groups used their new set of skills in study groups and since their midterm scores drastically increased from the first to the second midterm, the rest of the students started to include evaluation of their problem solutions before submitting the final answers.

In conclusion, we deduce that the use of peer review in physics class fosters the development of scientific perspective which helps students perform better on the exams. Furthermore, initial data suggests that peer review has a positive influence on development of the scientific language, which increases the usefulness of the textbooks and decreases student's frustration with understanding the objective of a given homework or exam question.

Appendix 1

Here we present the full results from our initial and final surveys. In order to avoid a student always picking the middle answer, we only provide even number of choices. We also only count responses as favorable or not favorable. Favorable includes the following responses: Yes, Comfortable, Very Comfortable, Agree, Strongly Agree. Not favorable consists of the following responses: No, Very Uncomfortable, Uncomfortable, Strongly Disagree, Disagree.

INITIAL SURVEY (N=12)

The following are the results to the initial survey. Twelve students completed the survey and the results are presented by counting the number of students that responded to each question. For the full survey, including the free response questions, see the attached file.

Question	Favorable	Not Favorable
Have you ever participated in peer review?	10	2
Have you ever used peer review in a math or physics class?	1	11
At this time, how comfortable are you with using scientific (physics) language?	7	5
How comfortable do you feel grading your peers?	7	5
Receiving peer feedback on my work helps me understand physical concepts.	9	3
Describing the problem in words helps to guide me to the problem solution.	10	2

Appendix 2

FINAL SURVEY (N=14): The following are the results to the final survey. The results are presented by counting the number of students that responded to each question. For the full survey, including the free response questions, see below.

Question	Favorable	Not Favorable
At this time how comfortable are you with using scientific (physics) language?	11	3
How comfortable do you feel grading your peers?	9	5
I feel I have a good grasp on the topics covered in this class.	9	5
Receiving peer feedback on my work helps me understand physical concepts.	9	5
Describing the problem in words helps to guide me to the problem solution.	11	1
Peer review helped me realize that there are multiple correct ways to solve the same physics problem.	9	5
Would you recommend using peer review in the similar class in the future?	9	5

The answer to the question: "Describing the problem in words helps to guide me to the problem solution." included two answers where students really wanted the middle answer. We do not include those in our final count because we did not provide that option.

Appendix 3

GRADING RUBRIC

When grading your peers please follow the grading scale provided below.

0 points: The paper is blank or what is written on the paper is in no way connected to the assigned problem. (This is equivalent to a letter grade F.)
1 point: The solution seems to be on the right track, but it is incomplete or there are some notable errors present. (This is equivalent to letter grades D and C.)
2 points: The solution is completely error free, or there are some minor parts missing or some minor algebra errors snuck in. (This is equivalent to letter grades B and A.)

You are going to be graded using the following criterion. Maximum number of points is five. You will get one point for correctly assigning the point value to the quality of your peer's work. The rest of the points are going to be based on verbal explanation of your grading.

The following should guide you in determining how to explain your grading.

. (1.) If there is nothing written on the paper you are grading, you have to explain in your own words what is happening in the given system and how to solve the problem. The easiest way to think about this is to verbally describe the solution you wrote down as your own solution. Giving only the formulas is not going to earn you any credit even if they are the correct formulas used in a solution of the problem.

0.(2.) If you get a paper that has some writing on it, but the solution is not complete, first determine whether what you are reading makes sense. If it does, and you determine that your peer was on the right track, describe in words how you would finish the problem. If what is written seems wrong to you, describe in words why it is wrong. (You can also give a counterexample that backs you up.) At this point, you might have some time left over, and if you do describe in words how you would solve the problem.

0.(3.) If you get a paper that seems to have the complete solution, first determine whether the solution is right or wrong. If it is wrong, explain in your own words why you think the provided solution is wrong, and if you have any time describe how you would solve it. Finally, if the solution is correct, you still have to explain why you think it is correct. (The easiest thing to do in this case is to tell the story about the problem and point to where the story is backed up by the solution to the problem.)

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