USING PEER INSTRUCTION TO PROMOTE CONCEPTUAL UNDERSTANDING IN HIGH SCHOOL PHYSICS CLASSES

by

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ABSTRACT

Students in many physics courses come away with a much stronger ability to solve problems than to explain things conceptually. This difference may largely be due to the way physics classes are traditionally taught. Peer Instruction has been developed to help bridge the gap between conceptual understanding and problem solving ability. This study introduced Peer Instruction to two classes of senior high school physics and monitored over the course of one unit. During instruction, conceptual multiple choice questions were presented and student responses were polled. For questions below a threshold percentage of correct responses, students were given the opportunity to discuss the question before it was re-polled. The use of Peer Instruction showed significant improvement in the conceptual performance of students, without affecting their problem-solving ability. The class room dynamics changed in such a way that student engagement was also improved.

INTRODUCTION

Saint Thomas More Collegiate (STMC) is an independent school in Burnaby, British Columbia, Canada. The school population is roughly 675 students with most coming from middle-income families. There is a range of ethnicities represented in the school with the majority of students being of Caucasian, Filipino or Chinese descent. My study focused on my Physics 12 classes, which have a close to even split of male and female students. Most of the students in these classes have aspirations of going on to post-secondary studies and are generally more motivated and academically capable than the average student at the school.

I have been teaching for ten years, all of them at STMC. During this time I have taught Physics 11 and 12, Biology 12 and Science 8 and 9. Over this time, I have noticed that students in my senior physics classes score lower on the conceptual questions on tests and exams than they do on the problem-solving component of the same assessments. There seems to be a disconnect between their understanding of how to solve problems and how to apply those problem-solving skills and ideas to a conceptual context.

Students have expressed that they have trouble with conceptual questions because they do not include math and that they have a hard time figuring out what these questions are asking. They also expressed that we should spend more time during instruction and class discussion working on the conceptual questions as we mostly focus on solving problems during that time. I feel that the some of the difficulties students face with conceptual questions may be related to their unwillingness to think through work they perceive as too difficult.

Focus Questions

Primary Question: Does Peer Instruction increase students' conceptual understanding in high school physics classes?

Secondary Question 1: Does student engagement increase with the use of Peer Instruction?

Secondary Question 2: Does Peer Instruction impact student performance on problem-solving?

CONCEPTUAL FRAMEWORK

This conceptual framework looks at the importance of fostering conceptual understanding in physics students and a way to help increase that understanding. It begins with a discussion of how traditionally taught physics classes fall short with regards to developing conceptual understanding and then presents how promoting conceptual understanding increases the overall learning of students in physics. Peer Instruction is presented as a possible way of increasing students' conceptual understanding along with some of the published examples where Peer Instruction has been successfully implemented.

The general goal of instruction in physics classes is to develop both conceptual understanding of physical principles and the ability to describe mathematically, those principles. Introductory college level and high school physics classes play an important role in creating an informed population regarding the nature and importance of physics (Freedman, 1996). These courses tend to put a strong emphasis on problem solving and applications, often without stressing and developing conceptual understanding (Hewitt, 2000).

Many students who complete introductory physics courses see physics as something not connected to the real world, something that they memorize rather than understand (Weiman & Perkins, 2005). Traditional lecture-style classes do not result in the majority of students coming away with a strong understanding of concepts, while classes that employ research-based teaching methods (such as Peer Instruction and Just-in-Time Teaching) tend to show increases in conceptual scores and better student opinions and beliefs about the nature of physics (Weiman &Perkins, 2005).

Mazur (1997) included on a midterm examination two questions that investigated the same physics principle. The first question looked at the idea conceptually and the latter question quantitatively. The students scored higher on the quantitative problem than the conceptual problem, suggesting a disconnection between students' problem-solving abilities and their conceptual understanding. Furthermore, McDermott (2001) stated that the ability to solve numerical problems is not a reliable indicator of conceptual understanding. She also suggested that students in a traditionally taught physics course do not always come away with a proper conceptual understanding of the physics principles taught.

These themes have been stated by many other physics educators and researchers. Jordan (2001) found that students tend to appreciate conceptual questions that allow more opportunity to tie physics into their real world experiences. McCausland (2000) lamented that students do not see equations as an expression of conceptual relationships, but simply as mathematical expressions. Alonso (1992) put forth that there is a need to promote physical understanding in students, rather than just training them to be quantitative problem solvers.

From these studies, the importance of promoting conceptual understanding in physics education is clear. It is also apparent that traditional teaching methods (i.e. primarily lecture driven classes) fall short of achieving this goal. As Freedman (1996) suggested, it is important that the general population have a better understanding of physical sciences and their importance to their everyday lives so that funding and support of physics research and innovation remains strong.

It has been shown that increasing focus on conceptual understanding during instruction leads to an increase in student performance in both conceptual and quantitative elements of physics courses. McDermott (1993) found that placing an emphasis on conceptual instruction did not take away from performance on numerical problems and suggested delaying algebraic explanations until after conceptual understanding has been fully developed. Weiman & Perkins (2005) found that an overly strong focus on problem solving can lead students to believe that “reasoning and seeing if the answer makes sense are irrelevant (p. 39)". Hewitt (2000) suggested that a course that starts with a strong conceptual focus, may generate more engagement from the students and result in better understanding of what they are doing in quantitative problems.

Several studies have shown that an increased focus on the conceptual element of physics instruction can lead to improvements in student engagement and performance in all areas of physics courses. Sadaghiani and Aguilera (2013) presented data that showed that a focus on conceptual understanding is beneficial to the students' learning of the material and appears to be more appropriate and effective than traditional methods.

In another study, students who used the problem solving approach that included a conceptual consideration at their discretion had the most significant gains in confidence in their problem solving skills when compared to those students who did not employ the protocol, or used the protocol exclusively (Ridenour, Feldman, Teodorescu, Medsker, & Benmouna, 2013). The researchers concluded that there is an optimal balance between problem-solving focus and conceptual focus and that having a problem-solving strategy that incorporated conceptual considerations may be a way to achieve that balance. Similarly, there was an increase in scores on multiple choice questions and problem-solving questions for students who used a method that incorporated a conceptual focus while solving problems compared to a control group of students who were not using the method (Docktor, Strand, Mestre, & Ross, 2010). The students in the study were asked to solve problems with parallel quantitative and qualitative solutions. It was observed that the teachers involved in the study found value in having students evaluate problem-solving questions in terms of the concept the question is examining.

Hull and Elby (2013) studied a group of students who took a conceptual course in physics after taking an equation based course. Those students stated that the conceptual course helped them see practical applications in their lives and gave them more meaning to the equations used in quantitative solutions.

It has been shown that increasing the focus on conceptual instruction leads to increased performance and understanding. Similarly, increased conceptual focus likely leads to students thinking more analytically about problems they are asked to solve, and the world around them.

Peer Instruction

In response to the gap between performance on quantitative questions and conceptual understanding in his classes, Eric Mazur (1997) developed an instructional method called Peer Instruction. In this setting, students were presented with a conceptual question (referred to as a ConcepTest) and asked to answer it individually. They then had time to discuss their answers and were asked to answer the question again. Mazur found that the process of discussing the answers with peers increased the percentage of students with correct answers and the confidence of the students on the concepts of the material. Mazur (1997) felt that in Peer Instruction classes, students were forced to actively think about the material rather than just passively writing it down and were forced to put their thought into words. This idea is supported by Freedman (1996), who reported that students often find conceptual homework problems more challenging than problem-solving questions, suggesting that the conceptual questions are "very useful tools for teaching and learning physics" (p. 6).

Peer Instruction Structure

In the Peer Instruction method, as outlined by Mazur (1997), classes shift from a traditionally-taught format of lecturing and problem-solving to a more active approach. The material is divided into smaller mini-lectures that are followed by Peer Instruction discussions. The Peer Instruction method was summarized by Lasry (2008), and is represented in figure 1.

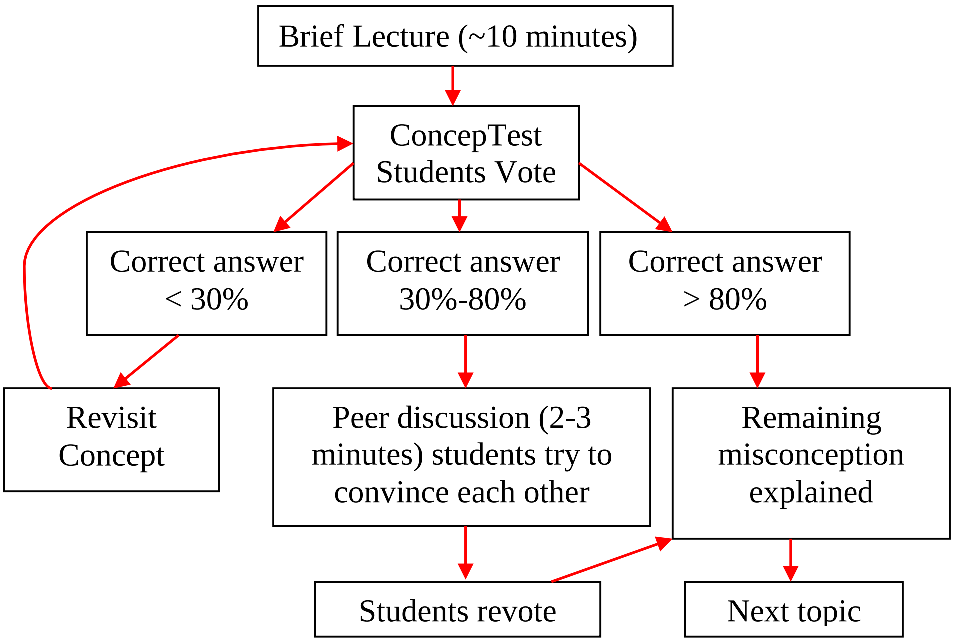


Figure 1. Adapted from "Clickers or Flashcards: Is There Really a Difference" by N. Lasry, 2008, *The Physics Teacher*, 46, p. 242.

In Peer Instruction, students are asked to individually answer conceptual questions (Mazur, 1997). After the initial student response, students engage in a short discussion with the students next to them where they attempt to convince each other of the answer they chose and come to a consensus on the correct answer. Following the discussion period, the students are again asked to display their responses. Ideally, a histogram showing the distribution of responses is generated and displayed for the students. Depending on the percentage of students who still have an incorrect answer to the ConcepTest, varying amounts of time is spent going over the explanation of the correct response and why the other responses are incorrect.

Adaptations of Peer Instruction for Secondary Schools

Campbell (2012) suggested several modifications for adapting the Peer Instruction structure for secondary classes. One suggestion is to use the smaller class size in the secondary setting as a way to open up some flexibility in the Peer Instruction structure, thereby allowing for a potentially richer learning experience than in large college classes. He went on to suggest having a representative present the rationale behind the answer they chose after the second collection of answers as a way to further increase student engagement. He also found that due to the age of secondary students, there is a higher occurrence of off-topic discussions and less student motivation to remain on task. He suggested shortening the lecture time from fifteen minutes down to five or ten minutes and making many of the pre-lecture readings video links for the students to watch before class. Mazur (1997) suggested that a way to help increase the time available in class for student discussions is to give students a copy of the notes for a given lecture, so that they are not focusing on writing, but rather on comprehension.

Monitoring Student Responses

Student responses to ConcepTests can be monitored in several ways – from personal whiteboards, to clickers, to response platforms such as Socrative (www.socrative.com) that make use of students' mobile devices. It has been shown that personal white boards are as effective as clickers in terms of gains in conceptual understanding and performance on tests (Lasry, 2008). Lasry also found that clickers are valued for the immediacy of feedback to the teacher (removing the need to tabulate answers on the fly), the archiving of student responses, and the general appeal both to instructors and students of using new technology.

Improvements in Student Achievement

Peer instruction has been shown to generate improvement in student achievement. Morgan & Wakefield (2012) found that the students who participated in at least seventy percent of peer instruction questions, had a much smaller failure rate than those students who did not participate up to the seventy percent threshold. Cummings and Roberts (2009) showed that there were increases in student understanding in the classes where peer instruction was used. This further supports the initial findings of Mazur (1997) and data compiled over a ten year period (Crouch and Mazur, 2001) proceeding the initial development of the method.

Peer Instruction has been shown to cause a measureable increase in students' conceptual understanding. Oliveira and Oliveira (2013) found that Peer Instruction based conceptual questions better supported students in their learning of material. Students stated that the conceptual questions gave them an opportunity to see how well they understood the concepts and that the discussions were important for clarifying ideas about physical concepts. Crouch and Mazur (2001) showed that increases in conceptual understanding, as measured through the Force Concept Inventory, were seen consistently in Peer Instruction based classes compared to classes taught with a traditional method. In their Peer Instruction settings, the majority of those who revise their answer after class discussion switch to the correct response, which agrees with the results found by Morgan and Wakefield (2012).

Smith et al., (2009) attempted to determine if the cause of increase in student performance on the second asking of the conceptual questions in Peer Instruction was caused by actual increases in understanding or by finding out the correct answer from more confident peers. They found that a significant percentage of those students who answered the initial question incorrectly on the first attempt were able to correctly answer a different follow up question on the same principle. This suggested that an increase in conceptual understanding had occurred.

In addition to improved conceptual understanding, across a ten year period, Crouch and Mazur (2001) also found increases in problem-solving performance for those classes using Peer Instruction. This was measured using the Mechanics Baseline Test, and they found that there were fewer low scores in the Peer Instruction classes. This shows that time invested in the Peer Instruction methodology has benefits to students in all aspects of their learning in introductory physics classes.

Peer Instruction has been shown to improve aspects of student engagement and classroom dynamics in addition to gains in student achievement. Oliveira and Oliveira (2013) found that student enjoyment and participation both increased in classes that used Peer Instruction, as compared to traditional methods. Wieman and Perkins (2005) suggested that the time spent in class for peer discussion gave students a good opportunity to synthesize and process the new information that has been presented to them.

Crouch and Mazur (2001) reported that even the strongest students are challenged by ConcepTest questions. This matches the findings of Takahashi and Nitta (2010) who found that ConcepTest questions that had few correct initial responses were a motivating factor for students. Students reported being surprised by the result and had increased interest in the instructor's subsequent explanation.

Conclusion

The importance of conceptual understanding in physics students has been understated historically in introductory physics courses. In order for students to completely understand the problems they are asked to solve in physics classes they need to have a stronger conceptual base of knowledge. This will also help to foster their understanding of the world around them.

As shown through this literature review, increasing conceptual instruction can lead to increased performance and engagement in introductory physics courses. Peer Instruction as developed by Eric Mazur is easily implemented strategy to help address deficiencies in conceptual understanding. It has a large potential for increasing student conceptual understanding, problem-solving performance and engagement in physics courses.

METHODOLOGY

The intervention in this action research project introduced Peer Instruction, as described in the conceptual framework, to two grade 12 physics classes to see if it would bring about improvements in conceptual understanding, problem solving performance and student engagement.

Participants

The students in this course are generally high achieving students with aspirations of going on to post-secondary education. Fourty-two students were enrolled in the course this year. As this is an elective course, most of the students are motivated and interested in the material. Across the two classes, 37.5 % of students were female and 62.5 % are male. The classes were composed of 52 % Caucasian students, 24 % students of Chinese descent, 14 % Filipino descent, 5 % African descent, 2.5 % Indian descent and 2.5 % Korean descent. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

Comparison Group

This action research based project compared the students in the Peer Instruction treatment with the results from the previous year's class for the same material. The scores from the Circular Motion and Gravitation test from 2014 and 2015 school years were recorded with the conceptual multiple choice score and problem solving score listed separately. The scores from the 2014 first term (January) exam were recorded in a similar fashion and were compared to the 2015 term exam to see how the students in the treatment classes compared to those in the comparison group. T-tests were used to compare the treatment group to the comparison group. By looking at the scores for conceptual questions and problem solving questions for each group on the midterm exam, similarities were found in the performance of the two groups. The comparison group had an average of 81 % with a standard deviation of 18 % on the problem solving component of the midterm exam while the treatment group had an average of 84 % with a standard deviation of 17.5 %. The difference in problem solving scores were not statistically significant, $t(82)=-0.7483$, $p=0.2282$. For the conceptual component of the first term exam the comparison group averaged 72 % with a standard deviation of 16.1 % while the treatment group scored an average of 71 % with a standard deviation of 18.5 %. The difference between these numbers were also not statistically significant, $t(82)= 0.3058$, $p=0.3802$. From this, it was assumed that the two years of students demonstrated similar patterns in terms of their performance on problem solving and conceptual questions.

Treatment

The intervention of this action research project introduced Peer Instruction to high school physics classes with the goal of increasing students' performance on conceptual questions. The standard Peer Instruction structure was followed, with some minor adaptations accounting for the nature of secondary students. The goal of this intervention was to increase student understanding and engagement without taking away from the problem-solving skills of these classes.

The introduction of Peer Instruction shifted the delivery of material in this class away from traditionally taught practices. With the comparison group, class time was spent between lecture-based content delivery followed by problem-solving examples and time for students to practice problems. Peer Instruction took away time from the previous format, so several small modifications were made to the use of classroom time. Some of the lecture material and introductory problem solving was introduced to students via video lectures posted on the class' learning management system. Lectures were limited to seven to ten minutes and were followed by ConcepTest questions, used in class at a rate of roughly three to five per class.

Grades are sometimes assigned for Peer Instruction participation. It has been shown that students are more likely to participate in Peer Instruction discussions and that there more dissenting opinions when the stakes are low in terms of the grade assigned (James, Barbieri and Garcia, 2008). A correlation has been found between participation in Peer Instruction and overall course performance (Beuckman, Rebello and Zollman, 2007). As such, the initial plan of this project was that students in my Peer Instruction classes would receive participation marks for answering questions during Peer Instruction discussions, but did not lose marks for incorrect responses. Students were very willing to engage in the Peer Instruction process, and there was no need to include a mark-based motivation for participation.

A small number of student conversations were recorded during the Peer Instruction discussions to look at how students were talking about physics. This method has been successfully used to examine student understanding and effectiveness of Peer Instruction (James and Willoughby, 2011). These conversations were used to analyze the quality of conversations the students were having and if they remained on-topic.

James and Willoughby (2011) also provided a list of behaviours for students to consider while having their Peer Instruction conversations. These instructions were conveyed to the students before the first use of Peer Instruction to help direct them while discussing ConcepTests. They are:

(1) Assess aspects of every answer choice even if they seem incorrect.

(2) Generate your own answers when none of the given answers are consistent with your own ideas.

(3) Make note of new questions and ideas that arise as alternatives are considered.

(4) If you find a question confusing and don't know how to begin your conversation, ask for help from your instructor or students nearby. (p. 131)

The unit that was used for the Peer Instruction treatment was circular motion and universal gravitation. The sequence of topics covered was:

I). Introduction to circular motion with applications

a). An objects moving horizontally

b). An object moving horizontally attached to a string at an angle

c). A car going around a curve with friction

II). Vertical circular motion

III). Introduction to universal gravitation and gravitational field strength

IV). Orbiting systems (a_c=g')

V). Gravitational potential energy

VI). Orbiting systems' energy (Virial theorem)

<u>Sources of ConcepTest Questions</u>

The questions used in the Peer Instruction activities were adapted from a variety of sources, including:

- Past provincial exam questions from the British Columbia Ministry of Education

- Eric Mazur's Peer Instruction: A User's Manual (1997)
- Web searches related to ConcepTests or conceptual questions with the topics listed above.

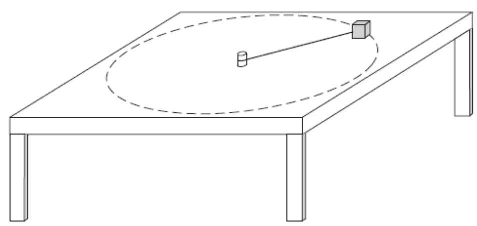
Figures 2 and 3 show examples of ConcepTest questions, both taken from past British Columbia Physics 12 provincial exams.

A satellite is in a circular orbit around a moon. Which of the following changes would require an increase in the satellite's speed in order for it to remain in a circular orbit?

A. an increase in the satellite's mass
B. a decrease in the satellite's mass
C. an increase in the satellite's orbital radius
D. a decrease in the satellite's orbital radius

Figure 2. An example of a ConcepTest used in this intervention. Reprinted from Physics 12 Resource Exam A, n.d., retrieved March 26, 2014, from https://www.bced.gov.bc.ca/exams/specs/resource_exams/physics12/2013ph12_a_mc.pdf

A wooden block attached to a thin string is sliding across a smooth level table in a circular path as shown.



Which of the following best describes what the tension force in the string is doing to the block?

A. slowing the block down
B. speeding the block up
C. changing the block's direction
D. pushing the block outwards

Figure 3. An example of a ConcepTest question used in this intervention. Reprinted from Physics 12 Resource Exam A, n.d., retrieved March 26, 2014, from https://www.bced.gov.bc.ca/exams/specs/resource_exams/physics12/2013ph12_a_mc.pdf

Some of the ConcepTests were chosen to examine common difficulties that are encountered in the teaching of circular motion and gravitation. Warren (1971) found that students have difficulty resolving the direction of net force and frictional forces for a car driving with uniform speed around a curved path. Similarly, students do not properly relate that the inward force on the car is the centripetal force. This matches my own observations in my classes in terms of students not being able to relate the idea of centripetal acceleration to net force. Often, when solving problems requiring centripetal force, they forget to include the mass and only use centripetal acceleration, which shows that they are not making the connection to Newton's Second Law.

Lee & Yee (2006) found that many physics students have a difficulty using the more general expression of gravitational potential energy (i.e. $Ep = -GMm/r$). Some of the common difficulties they found were: when to use this form rather than $Ep = mgh$; why there is a negative sign at the beginning of the equation; and how an inverse relationship (Ep proportional to $1/r$) affects the potential energy. Some of the ConcepTests were chosen to examine this relationship.

Data Instruments

During the treatment, student responses were monitored using personal white boards. Students held up their white boards at the end of each question and the class set of responses was photographed. Student responses were tabulated and used to see how their performance on in-class ConcepTests related to performance on the end of unit test.

A random sampling of student conversations was recorded to analyse the nature of the conversations that students were having during Peer Instruction discussions. This information was used to help qualitatively assess the effectiveness of Peer Instruction.

In addition to comparing test scores of the treatment and comparison groups, student opinions of the effectiveness of Peer Instruction were measured using a survey examining their conceptual understanding, problem solving ability and engagement after the treatment. Students were asked to volunteer to share their thoughts in an interview setting, on the differences between Peer Instruction and the regular method of delivery of material in this class. Students chosen for interviews represented a diverse range of student performance.

Data collection instruments are summarized in Table 1.

Table 1
Triangulation Matrix

Focus Question	Data Source 1	Data Source 2	Data Source 3
Primary Question: Does Peer Instruction increase students' conceptual understanding	Compare test scores (conceptual component) between students in the treatment classes and previous years (control) for the same unit.	Analysis of student responses to ConcepTest questions	Student Interviews and Surveys
Secondary Question: Does student engagement increase with the use of Peer Instruction	Student Interviews	Student Surveys	Observations of students behaviour and discussion during Peer Instruction conversations
Secondary Question: Does Peer Instruction impact student performance on problem-solving?	Compare test scores (problem solving component) between students in the treatment classes and previous years (control) for the same unit.	Student Interviews	Student Surveys

DATA AND ANALYSIS

In the spring of 2015, Peer Instruction was introduced to two blocks of grade 12 physics to examine its influence on conceptual scores, problem solving ability and student engagement. The treatment classes were compared to the previous year's classes. Data collected included test scores, responses to ConcepTest questions, audio recordings of student discussions, student interviews, surveys and instructor observations.

The primary purpose of this action research project was to determine if the introduction of Peer Instruction increased student performance on the conceptual component of physics tests. The data collected showed that student performance on the conceptual component of the circular motion and gravitation test was higher for the treatment group. The comparison group averaged 64 % with a standard deviation of 21.7 % on the conceptual component of this test, while the treatment group scored 79 % with a standard deviation of 21.3 %. The difference between these scores was found to be significant, $t(82)=-3.174$, $p=0.001058$. This showed a large increase in student performance on the conceptual component between the two years.

Data from student responses to ConceptTest questions was recorded and tabulated. Tables 2 and 3 summarize the percentage correct for each ConcepTest question before and after re-polling. Of those questions that were re-polled, 86 % showed an increase in the percentage of correct responses following peer discussion. This suggested that there was an overall positive impact on understanding as ConcepTest questions were discussed.

When looking at the nature of student responses on re-polled questions (Figure 4), nearly eighty percent of responses ended up as correct after peer discussion opportunities. Sixty % of those students who modified responses changed from incorrect to correct, with re-polled questions having a total of seventy nine % correct after peer discussions. This suggested that the discussion portion of Peer Instruction had an overall positive effect on student understanding.

Table 2.
Percentage of Correct Responses to ConcepTest Questions on the Initial Polling and After Peer Discussion for the Circular Motion Component of the Treatment Unit

Question Name	Block 1		Block 2	
	Initial Percentage Correct	Final Percentage Correct	Initial Percentage Correct	Final Percentage Correct
CMCT1	81 %	100 %	86 %	NA
CMCT2	76 %	95%	62 %	100 %
CMCT3	95 %	NA	95 %	NA
CMCT4	100%	NA	90 %	NA
CMCT5	38 %	43 %	81 %	90 %
CMCT6	53%	100 %	80 %	100 %
CMCT7	65 %	88 %	42 %	84 %
CMCT8	100%	NA	90 %	NA
CMCT9	100 %	NA	100 %	NA
CMCT10	94%	NA	95 %	NA
CMCT11	NA	NA	NA	NA
CMCT12	67 %	61 %	95 %	NA
CMCT13	94 %	NA	81 %	NA
CMCT14	NA	NA	NA	NA
CMCT15	39 %	83 %	71 %	100 %

Table 3.
Percentage of Correct Responses to ConcepTest Questions on the Initial Polling and After Peer Discussion for the Gravitation Component of the Treatment Unit

Question Name	Block 1		Block 2	
	Initial Percentage Correct	Final Percentage Correct	Initial Percentage Correct	Final Percentage Correct
GCT1	24 %	100%	53 %	100 %
GCT2	38 %	52 %	52 %	90 %
GCT3	90 %	NA	89 %	NA

GCT4	19 %	10 %	37 %	58 %
GCT5	90 %	NA	95 %	NA
GCT6	76 %	NA	95 %	NA
GCT7	95 %	NA	76 %	100 %
GCT8	85 %	NA	60 %	100%
GCT9	71 %	67 %	95 %	NA
GCT10	95 %	NA	100 %	NA
GCT11	95 %	NA	100 %	NA
GCT12	71 %	57 %	40 %	70 %
GCT13	100 %	NA	100 %	NA
GCT14	100 %	NA	62 %	100 %
GCT15	19 %	38 %	15 %	65 %
GCT16	76 %	NA	89 %	NA
GCT17	38 %	76 %	39 %	89 %
GCT18	86 %	NA	94 %	NA
GCT19	90 %	NA	89 %	NA

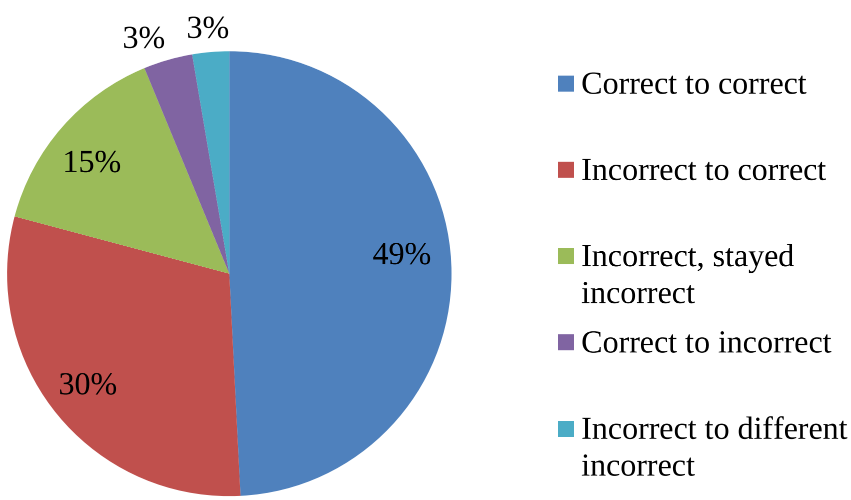


Figure 4. Changes in student responses to re-polled ConcepTest questions.

The increase in conceptual understanding and performance was supported by student surveys and interviews. The data showed that 55 % of students surveyed reported that Peer Instruction helped their performance somewhat on conceptual questions, while 29 % found that it helped greatly. Surveyed students also reported that Peer Instruction helped with their confidence in dealing with conceptual questions, with 47 % somewhat agreeing and 34 % strongly agreeing to the survey question.

All fifteen students interviewed found that Peer Instruction had a positive impact on their conceptual understanding throughout this unit. Some students reported that their improvement on conceptual questions came from an increase in practice and exposure to conceptual questions. Others stated that they had a better understanding of the material when compared to other units, particularly for those questions that were based on changes in variables in a physical context. For example, one student stated, “I kind of knew why the answer was right rather than just plugging it in to a formula. I could better relate the formula to the situation than just plugging numbers in.” Several students reported that their increase in conceptual performance was related to their increased confidence, while others found that being exposed to multiple view points during group discussions helped him come to a better conceptual understanding.

A secondary question investigated in this action research project checked to see if Peer Instruction hindered students’ problem-solving performance by taking time away from working through example problems. The data collected suggested the contrary – students problem-solving scores did not suffer, but may have in fact improved. There was an increase in the averages on problem-solving scores on the circular motion and gravitation test between the two classes with the comparison group scoring 82 % with a standard deviation of 18.9 % and the treatment group scoring 88 % with a standard deviation of 14.5 %. While the difference between the two averages was not significant

($t(82)=-1.6378$, $p=0.05264$), it was enough to consider that there may have been some benefit to using Peer Instruction with respect to problem-solving skills.

While 50 % of survey respondents found that Peer Instruction had no effect on their problem-solving skills, 42 % reported that it at least somewhat helped their problem-solving. Only 8 % of students found that Peer Instruction hindered their problem-solving skills. This matched the responses given by students in interviews. Several students brought up that the discussion of conceptual questions helped give more meaning to the equations they were using and they had an easier time starting numerical questions. One student said, “I knew the theory behind it so the problems were easier. I wasn’t just relying on steps for solving an equation. I could better figure it out as I went.” Some students reported that they noticed we had spent less time solving problems in class and were forced to work harder on that aspect outside of class, but that this was an overall positive trade-off for increased conceptual understanding.

Figures five and six show conceptual scores plotted against problem solving scores for both the comparison and treatment groups on the circular motion and gravitation test. For the comparison group (Figure 5), a large percentage of the class scored lower on the conceptual component than on the problem-solving component. This can be seen as those students lie below the diagonal line that represents equal performance on the two components. For the treatment group (Figure 6), there are more students that lie above the same diagonal line. Of those students below the line, they are generally closer to the line than those in the comparison group, suggesting that their conceptual performance more closely relates to their problem-solving performance. This was quantified by looking at the students' conceptual score divided by their problem solving score. The comparison group had an average of 0.833 with a standard deviation of 0.307, while the treatment group had an average of 0.913 with a standard deviation of 0.04. These groups were significantly different (t(84)=1.66, p=0.192), reinforcing that Peer Instruction may have helped bring students' conceptual understanding closer to their problem-solving ability.

The last sub-question of this action research project looked to see if Peer Instruction increased student engagement with the material covered and the course in general. Students felt that the Peer Instruction discussions increased their engagement with the material. 40 % percent of survey respondents somewhat agreed and 47 % strongly agreed that Peer Instruction increased their engagement while 97 % of students responded that they found Peer Instruction discussion opportunities at least somewhat enjoyable.

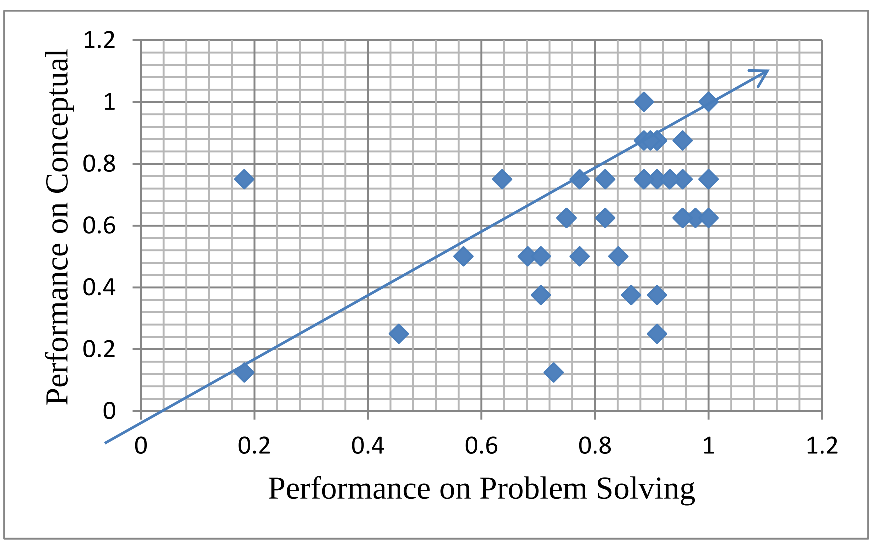


Figure 5. Scatter Plot of Conceptual Performance vs. Problem Solving for the 2014 circular motion and gravitation test (*N*=42). The line indicates an equal score on both the conceptual and problem solving components of the tests.

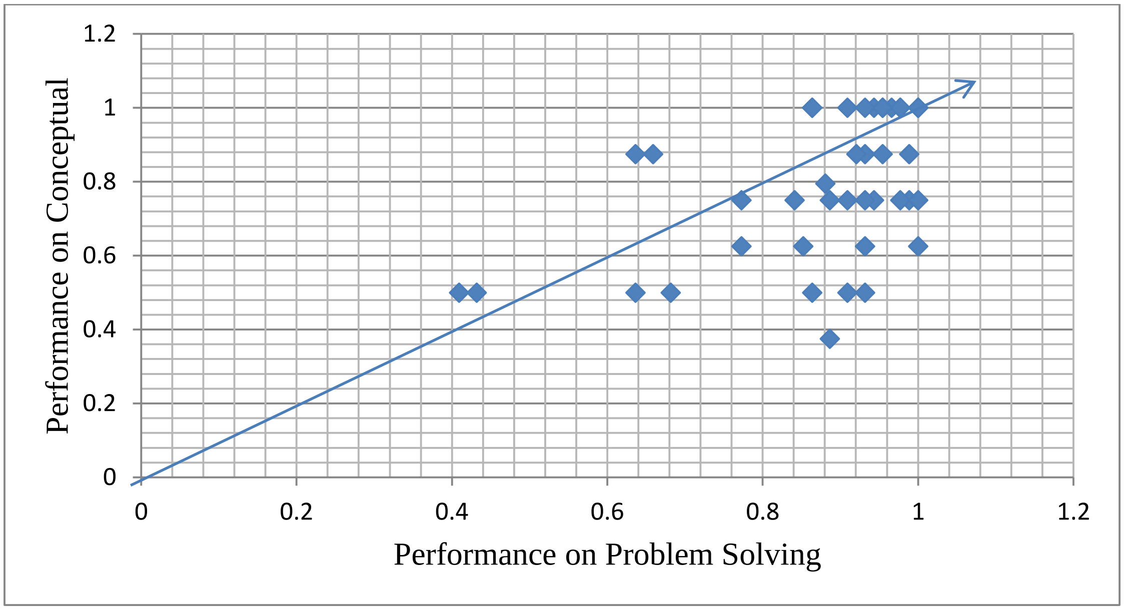


Figure 6. Scatter Plot of Conceptual Performance vs. Problem Solving for the 2015 circular motion and gravitation test (*N*=42). The line indicates an equal score on both the conceptual and problem solving components of the tests.

This matched what was observed in the classroom during the treatment period. From the outset, students seemed very pleased using the personalized white boards to convey answers to questions. Many students took the opportunity to creatively present their letter of choice, a sample of which is shown in Figure 7. The fact that they were taking the time to illustrate their boards to this extent suggested that they were enjoying the process of giving answers via the white boards. This was supported by recordings of student conversations during Peer Instruction discussions. Most recordings captured multiple discussions going on around the classroom with logical, sometimes heated discussions going on about the ConcepTest questions.

Figure 7. A sample of student white-boards photographed during Peer Instruction response collection.

When asked to give more detail in interviews as to how Peer Instruction increased their engagement, many students brought up that they had to pay much more attention and that they could no longer lose focus during instruction. One student explained, “It makes you pay attention more, honestly because you’re always answering questions in class so you always have to be on your toes paying attention and ready to answer a question at any time.” Other students felt that Peer Instruction made them feel more responsible for the collective understanding and they had to pay more attention so that they could participate in discussions. Another found that Peer Instruction appealed to her competitive nature and so she was more involved in class as she wanted to “get more right than (her) friends”. Lastly, several students found that the change in dynamic and pacing in class was beneficial. They preferred the change from a constant teacher centred instruction to regular breaks in the flow to answers ConcepTests.

INTERPRETATION AND CONCLUSION

The data collected in this action research project suggested that Peer Instruction was indeed successful at increasing performance on conceptual questions for high school physics students. It may be that for some students, the increased performance came from a genuine increase in conceptual understanding, while for others improvement may have been the result of greater exposure to and practice with conceptual questions. Regardless of the cause of the increase in conceptual understanding, the data collected showed that this increased conceptual emphasis did not hinder students' problem-solving ability, reinforcing the findings of McDermott (1993).

There was a wide range of reactions to the different difficulties presented in the ConcepTest questions. Questions that had a low percentage incorrect were still valuable to present to the students. These questions reinforced ideas that we had very recently discussed in class. Several students expressed in interviews that these questions were worthwhile in helping them prevent careless mistakes on the test and for helping to build their confidence in the Peer instruction process. Weiman and Perkins (2005) had a similar finding – that Peer Instruction provided an opportunity for students to synthesize new material and build their understanding.

The students were generally unwilling to re-poll questions more than once as they wanted an explanation for those questions that did not hit the 80 % correct after one round of discussion. This meant that some of the most challenging questions never reached a high percentage of students with the correct answer. These questions generated a more vigorous discussion when the reasoning of the correct answer was presented than the other questions that were re-polled. This suggested that these challenging questions were very important elements of developing conceptual understanding, supporting the conclusions drawn by Freedman (1996) and Takahashi and Nitta (2010) who noted that questions with a low correct response rate tend to motivate students to understand physical concepts.

Not all students found the Peer Instruction discussion sessions useful. Two bright students stated on the open response question of the survey and in their interviews that they felt that the increase in their conceptual understanding and corresponding performance was due to the time that spent explaining questions on the board and not from discussing the questions with their fellow students. Both of these students pointed out that we had not previously spent significant class time devoted to conceptual questions, so an increase in the class' performance was not surprising. One said, "I'm far more willing to listen to a teacher than a student who is also new to the subject." They did however concede that the Peer Instruction element with the whiteboards offered a very engaging class dynamic.

Another student had a different reason behind her reservations with the Peer Instruction discussions. As a student who at times struggles with the conceptual component of tests, she felt like she wasn't getting many of the conceptual questions correct, while most of those around her were. She found the discussions intimidating and would have preferred if after the initial polling of their responses, one student was called upon to make the case for their chosen response. This matches on of the possible modifications suggested by Campbell (2012), though he proposed it as way to increase engagement, rather than to help ease the potential pressures put upon students in the discussion process.

Even if Peer Instruction only increased performance through providing practice on conceptual questions, it seemed to be a worthwhile teaching method due to the changes in classroom dynamic and student engagement. The polling and discussion of ConcepTests provided a welcome interruption in the flow of the class and shifted the focus from the instructor to the students. Many students stated in their interviews, they had to pay more attention throughout the class, which would generally improve their performance.

From a teaching point of view, there seemed to be more questions during instruction than on past units as students seemed sought clarification during instruction so that they would be ready for ConcepTest discussions. Classes felt more energetic and there was little time left at the end for students to work on problems. This represented one of few problems encountered in using Peer Instruction - it took time away from other elements of the course. It was difficult to fit in all of the regular elements of this class, such as working through homework problems, conducting small quizzes and having time for students to work on problems in class. Campbell (2012) addressed this issue and suggested generating pre-class videos for students to watch to lessen the amount of material taught in class. Mazur (1997) provided his students with copies of class notes so that they could focus on the content rather than the delivery. Both of these would open up time in class for Peer Instruction and will be used in this class going forward with the use of Peer Instruction.

The main critique of the use of Peer Instruction from the students was that we had done too much of it. All students interviewed and 95 % of those surveyed recommended that the use of Peer Instruction be continued. Eighty percent of the students interviewed suggested that the primary change that should be considered was fewer questions per class. They felt that the pace of class was too rushed at times and they would have preferred a little more time devoted to problem-solving in each class.

Some minor adjustments to the Peer Instruction structure occurred during the course of this project. Students had difficulty creating answers in silence and ended up discussing questions as they generated their initial responses. They were encouraged to find peers with differing answers for the discussions after the initial polling to engage people of a differing opinion. Interestingly, students in the same area of the room did not necessarily have the same answer even if they discussed the question together during their initial response time. This suggested that they were actively evaluating the problem and not just following their peers' answers.

VALUE

This study has shown me that there are many merits of using Peer Instruction in my grade 12 physics classes. There appeared to be significant gains in conceptual understanding along with moderate gains in problem-solving ability. It may be that these improvements are a result of more time spent focused on conceptual questions compared to traditional teaching methods. However, the shift in classroom dynamics as a result of the implementation of Peer instruction was notable, and I feel, represented a big part of the improvement as well. Overall, student involvement in the lessons was considerably higher than before. Peer Instruction allowed more opportunity for discussion in class between my students and me and between the students themselves.

Peer Instruction also changed the pacing of the class which is something I need to be better prepared for when I use it again in the future. Time spent by students considering the questions, polling responses and discussing their answers reduced the time available for working through numerical problems, going over homework and doing short assessments. While tutorial videos created for students to use outside of class helped, I may need to consider creating more of those to cover more of the introductory material to help free up more class time. Posting homework solutions online or in my classroom could also help alleviate the need to go through all of the homework questions in class.   I will likely need to follow Mazur's suggestion and remove some of the topics from the course to allow more time for Peer Instruction to be used.

Peer Instruction worked as an effective method of formative assessment for the conceptual component of this course, which was lacking in previous teaching formats used. Before the use of Peer Instruction, I largely viewed the conceptual component of the course as something students could master purely from my lecture-based teaching of the material and their practicing questions in the end-of-unit review. The intense discussions that followed the more challenging ConcepTest questions and the dialogue I had with students as I explained the solutions showed me that merely covering the material through lecture was ineffective at building student understanding. Formative assessment existed in this course for the problem-solving aspect prior to this research project and Peer Instruction provides a very suitable way to assess student understanding on conceptual questions, which make up a sizeable part of their summative assessments.

As a teacher, I like to try new ideas and teaching methods and work to regularly improve my instruction. Before this action research project, my judgement of the worth of an activity or method was largely qualitative. I considered it valuable if it made sense, if it ran smoothly from a teaching stand point and if I received positive feedback from my students. This project has shown me a way to systematically and quantitatively evaluate the new teaching techniques that I bring in to my class, providing a better way for me to gauge the benefits of these practices. I am confident that this should help improve the instruction in my classes overall.

In the end, Peer Instruction proved to be successful at helping to improve the overall conceptual understanding that my students had for this unit. There seemed to be no negative impacts on their problem-solving skills and perhaps even moderate improvements as a result of this research project. Lastly, student involvement and engagement during lessons was significantly increased as a result of the addition of Peer Instruction. This action research project had positive effects on my students' performance, my classes' dynamics and the way I approach teaching that course.

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APPENDICES

APPENDIX A

STUDENT SURVEY

Peer Instruction Survey

Participation in this research is voluntary and participation or non-participation will not affect a student's grade or class standing in any way.

Answer all questions on the multiple choice response page

1. What is your gender? Female: A Male: B

2. What was your approximate 1st Term grade:

0-60%	A	60-70%	B	70-80%	C	80-90%	D	90-100%	E

On the circular motion & gravitation test:

3. What was your grade on conceptual component?

0-60%	A	60-70%	B	70-80%	C	80-90%	D	90-100%	E

4. What was your grade on problem solving component?

0-60%	A	60-70%	B	70-80%	C	80-90%	D	90-100%	E

5. Compared to other units that we have completed, did the use of peer instruction improve your level of conceptual understanding?

Strongly disagree	A	Somewhat disagree	B	No change	C	Somewhat agree	D	Strongly agree	E

6. Did the use of peer instruction result in an improvement on your score on the conceptual component of the end of unit assessment.

Hindered greatly	A	Hindered somewhat	B	No change	C	Helped somewhat	D	Helped greatly	E

7. Did the use of peer instruction affect your performance on the problem solving component of the unit test?

Hindered greatly	A	Hindered somewhat	B	No change	C	Helped somewhat	D	Helped greatly	E

8. Did the use of peer instruction affect your engagement with the material covered in this unit?

Hindered greatly	A	Hindered somewhat	B	No change	C	Helped somewhat	D	Helped greatly	E

9. Before this unit, did you feel confident answering conceptual multiple choice questions on tests? Yes: A No: B

10. State your level of agreement with the following statement: The use of peer instruction improved your confidence in answering conceptual questions in this unit.

Strongly disagree	A	Somewhat disagree	B	No change	C	Somewhat agree	D	Strongly agree	E

11. Did you find the online video tutorials helped your problem solving ability in this unit?

Strongly disagree	A	Somewhat disagree	B	No change	C	Somewhat agree	D	Strongly agree	E

12. Did you find the online video tutorials helped your conceptual understanding in this unit?

Strongly disagree	A	Somewhat disagree	B	No change	C	Somewhat agree	D	Strongly agree	E

13. State your level of agreement with the following statement: The peer instruction discussions were enjoyable.

Strongly disagree	A	Somewhat disagree	B	No change	C	Somewhat agree	D	Strongly agree	E

14. State your level of agreement with the following statement: There is value in using Peer Instruction in some form on a regular basis in this course.

Strongly disagree	A	Somewhat disagree	B	No change	C	Somewhat agree	D	Strongly agree	E

15. Are you willing to be interviewed as part of this study? Yes: A No: B

Do you have any other feedback that you would like to share related to the use of Peer Instruction in Physics 12?

APPENDIX B

POST TREATMENT STUDENT INTERVIEW PROMPTS

Participation in this research is voluntary and participation or non-participation will not affect a student's grade or class standing in any way.

Preamble: Thank you for agreeing to be interviewed. This is a follow-up to the use of Peer Instruction in our Physics 12 class over the past unit. The following questions deal with how the use of Peer Instruction influenced your opinion of conceptual questions, problem solving and engagement with this unit. The interview should take under 10 minutes and will be included in my data analysis for my research project.

Name:_______________ Date:____________

Explain your impressions on why Peer Instruction was implemented in this class.

What were the positive ways that peer instruction impacted your learning?

What were the negative ways that peer instruction impacted your learning?

Did peer instruction affect your conceptual understanding? Explain how.

Did peer instruction affect your problem solving ability? Explain how.

Did peer instruction affect your engagement with the material? Explain how.

Should peer instruction be used again in this class (either for this year or future years)? What are your reasons for your answer?

How would you change the use of peer instruction for future use?

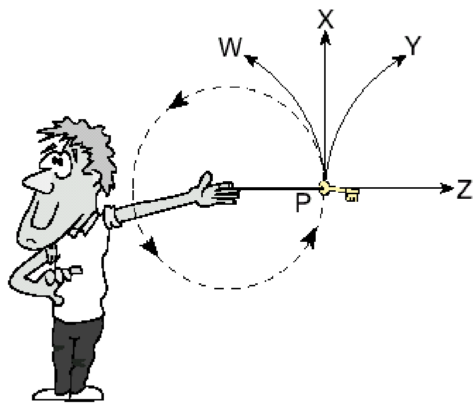
APPENDIX C

CONCEPTEST QUESTIONS

I). Introduction to circular motion with applications

CM ConcepTest 1 (CMCT1)

The diagram shows a student "twirling" a car key in a circular path on the end of a string.



If the string snaps at P, which path will the keys follow?

A. W
B. X
C. Y
D. Z

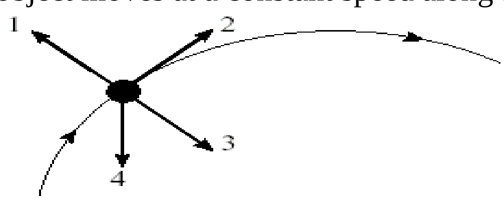
CM ConcepTest 2 (CMCT2)

A carnival has a Ferris wheel where some seats are located halfway between the center and the outside rim. Compared with the seats on the outside rim, the inner cars have

A. The same period and a smaller speed
B. The same period and a larger speed
C. A shorter period and the same speed
D. A longer period and the same speed
E. The same period and the same speed

CM ConcepTest 3 (CMCT3)

An object moves at a constant speed along a circular path as shown.

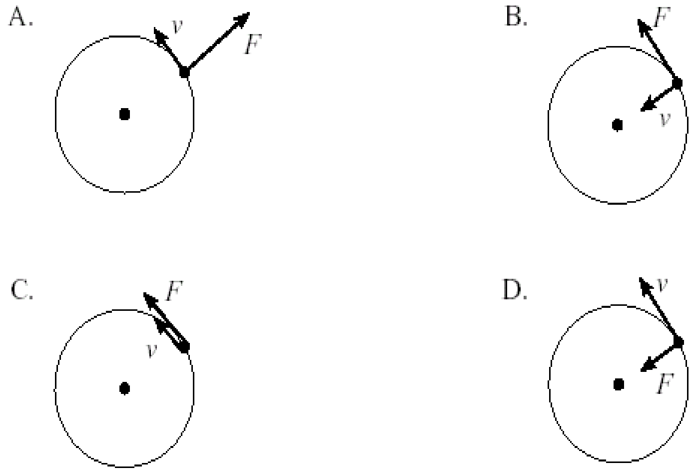


Which vector best represents the centripetal acceleration of the object at this point?

A. 1
B. 2
C. 3
D. 4

CM ConcepTest 4 (CMCT4)

Which of the following diagrams shows the instantaneous velocity *v* and centripetal force *F* for an object in uniform circular motion.



CM ConcepTest 5 (CMCT5)

An object travels along a circular path with a constant speed v when a force F acts on it. How large a force is required for this object to travel along the same path at twice the speed (2v)?

A. ½ F
B. F
C. 2F
D. 4F

CM ConcepTest 6 (CMCT6)

If the speed of an object moving in circular motion is tripled and the mass and radius remain constant, the centripetal force

A. triples
B. is 1/3 as much
C. is nine times as much
D. is 1/9 as much
E. remains the same

CM ConcepTest 7 (CMCT7)

Two equal-mass rocks tied to strings are whirled in horizontal circles. The radius of circle 2 is twice that of circle 1. If the period of motion is the same for both rocks, what is the tension in cord 2 compared to cord 1?

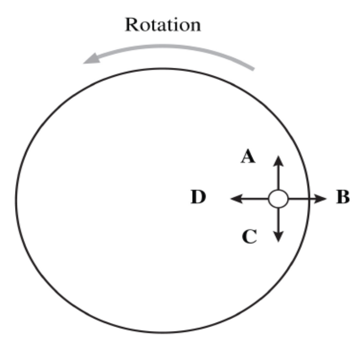
A. $T_2 = \frac{1}{4} T_1$
B. $T_2 = \frac{1}{2} T_1$
C. $T_2 = T_1$

D. $T_2 = 2T_1$
E. $T_2 = 4T_1$

CM ConcepTest 8 (CMCT8)
When a car turns a corner on a level road, which force provides the necessary centripetal acceleration?
A. Friction
B. Tension
C. Normal force
D. Air resistance
E. Gravity

CM ConcepTest 9(CMCT9)
A coin sits on a rotating turntable.
Which of the following correctly shows the direction of velocity, frictional force and centripetal force?

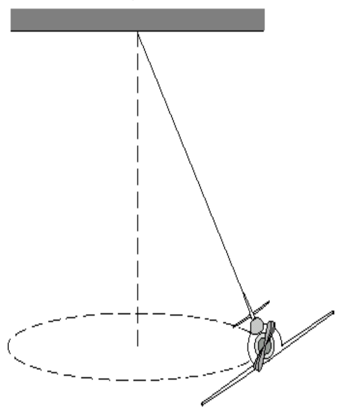
	Velocity	Friction Force	Centripetal Force
1	A	D	D
2	A	C	D
3	C	D	B
4	C	C	B



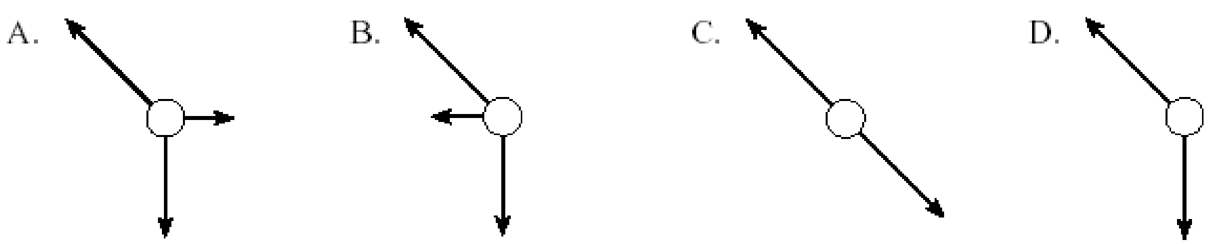
CM ConcepTest 10 (CMCT10)
A car going around a curve with friction. You drive your Dad's car too fast around a curve and the car starts to skid. What is the correct description of this situation?
A. The car's engine is not strong enough to keep the car from being pushed out
B. Friction between the tires and the road is not strong enough to keep the car in the circle.
C. The car is too heavy to make the turn.
D. Frictional force decreases with increasing speed.

CM ConcepTest 11 (CMCT11)

A small toy airplane suspended as shown below flies in a circular path.



Which of the following free body diagrams best describes the forces acting on the airplane at the position shown?

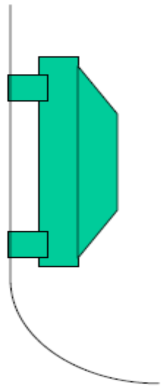


CM ConcepTest 12 (CMCT12)

You are shown a photo of a car which is driven on a vertical wall inside a huge cylinder. Is it possible?

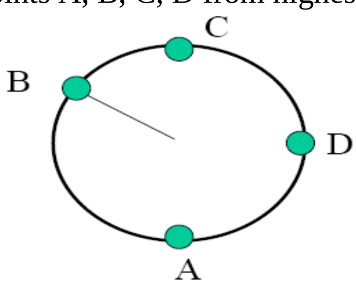
A. Yes

B. No



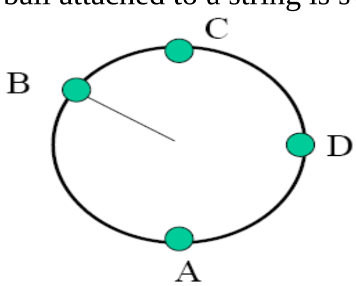
II). Vertical circular motion

<u>CM ConcepTest 13 (CMCT13)</u>
A ball attached to a string is swung in a vertical plane. Rank the tension in the string at points A, B, C, D from highest to the lowest tension. Take gravity into account.



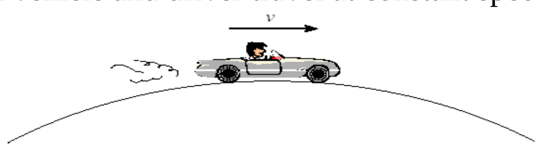
1. All points have the same tension.
2. C > B > D > A
3. A > D > B > C
4. B > A > D > C

<u>CM ConcepTest 14 (CMCT14)</u>
A ball attached to a string is swung in a vertical plane.

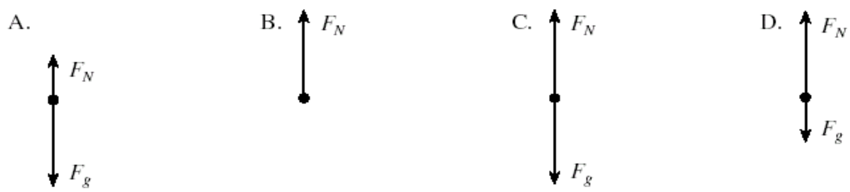


Compare the centripetal force on the ball at points A, B, C & D.
1. All points have the same value of force.
2. C > B > D > A
3. A > D > B > C
4. B > A > D > C

CM ConcepTest 15 (CMCT15)
A vehicle and driver travel at constant speed over the hill as shown.

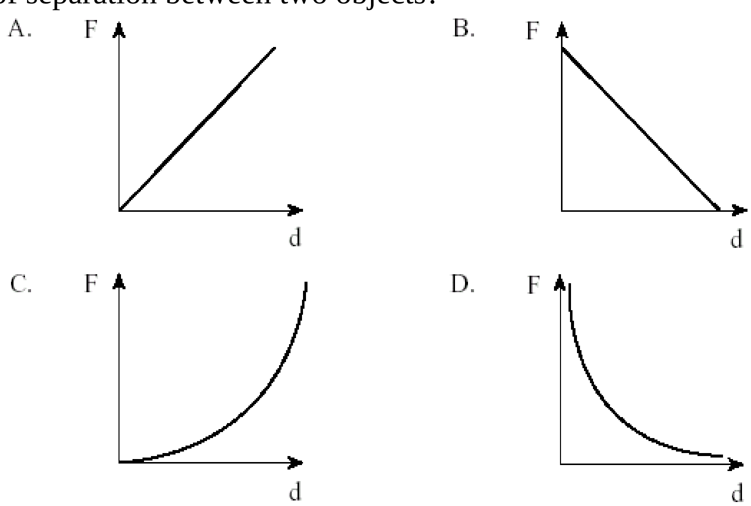


Which of the following free body diagrams best describes the vehicle at this position?



III). Introduction to universal gravitation and gravitational field strength

Gravitation ConcepTest 1 (GCT1)
Which of the following graphs shows how the gravitational force varies with the distance of separation between two objects?



Gravitation ConcepTest 2 (GCT2)
Which is stronger, Earth's pull on the Sun, or the Sun's pull on Earth?
A) the Earth pulls harder on the Sun
B) the Sun pulls harder on the Earth
C) they pull on each other equally
D) there is no force between the Earth and the Sun

Gravitation ConcepTest 3 (GCT3)
If the distance to the Moon were doubled, then the force of attraction between Earth and the Moon would be:
A) one quarter
B) one half
C) the same
D) two times
E) four times

Gravitation ConcepTest 4 (GCT4)
Masses of M and 2M exert a gravitational force F on each other when the distance between their centres is r. What is the gravitational force between masses of 2M and 4M when the distance between their centres is 4r?
A. 0.25 F
B. 0.50 F
C. 0.75 F
D. 1.00 F

Gravitation ConcepTest 5 (GCT5)
Compared to the Earth, Planet X has twice the mass and twice the radius. This means that compared to the Earth's surface gravity, the gravitational field strength at the surface of Planet X is
A. 4 times as much.
B. twice as much.
C. the same.
D. ½ as much.
E. ¼ as much.

Gravitation ConcepTest 6 (GCT6)
A planet has a larger gravitational field strength on its surface than does Earth. Which of the following is a possible comparison of this planet's mass and radius with Earth's?
A. Larger mass, equal radius
B. Equal mass, larger radius
C. Smaller mass, equal radius
D. Smaller mass, larger radius

IV). Orbiting systems (ac=g')

Gravitation ConcepTest 7 (GCT7)

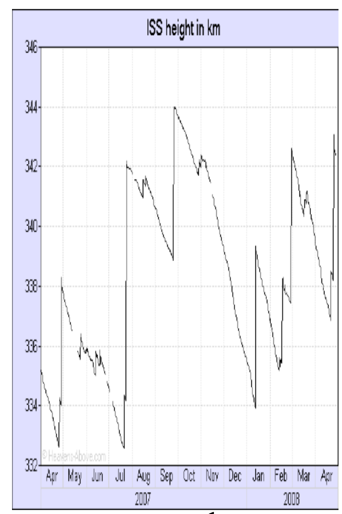
Which of the following correctly describes the changes that occur in gravitational field strength, centripetal acceleration, period and speed as an object moves further away from the central object around which it orbits?

	Gravitational Field Strength	Centripetal Acceleration	Period of Orbit	Orbital Speed
A	Increases	Increases	Decreases	Increases
B	Increases	Decreases	Increases	Decreases
C	Decreases	Increases	Decreases	Increases
D	Decreases	Decreases	Increases	Decreases
E	Remains Constant	Remains Constant	Increases	Decreases

Gravitation ConcepTest 8 (GCT8)

The international space station altitude gradually decreases due to drag and is periodically boosted back up. Assuming perfectly circular orbits, is the station velocity higher before or after the boosts.

A.Before
B.After
C.Same
D.Can't tell



Gravitation ConcepTest 9 (GCT9)

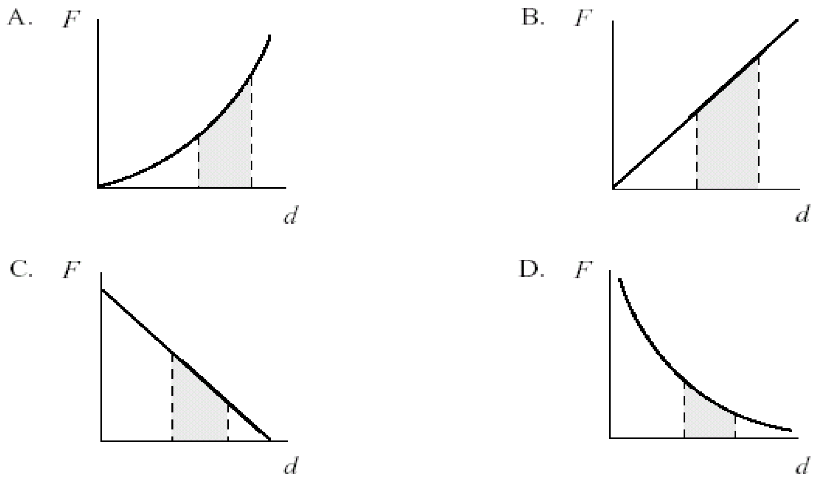
Star X has twice the mass of the Sun. One of Star X's planets has the same mass as the Earth, and orbits Star X at the same distance at which the Earth orbits the Sun. The orbital speed of this planet of Star X is

A. faster than the Earth's orbital speed.
B. the same as the Earth's orbital speed.
C. slower than the Earth's orbital speed.
D. not enough information given to decide

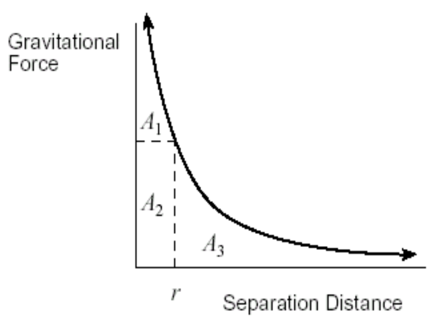
V). Gravitational potential energy

Gravitation ConcepTest 10 (GCT10)

Which of the following illustrates the work required to move an object in a gravitational field?



Gravitation ConcepTest 11 (GCT11)



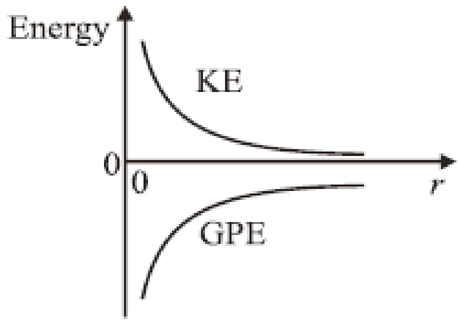
Which of the indicated areas of the graph represent the work needed to send an object from separation distance r to infinity?

A. A1 + A2
B. A2
C. A2 + A3
D. A3

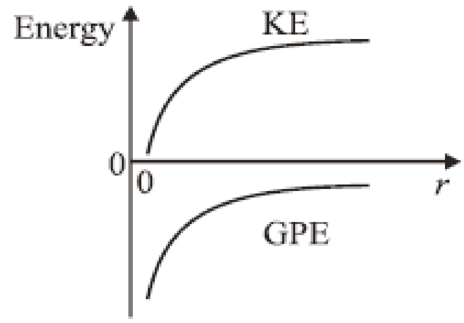
Gravitation ConcepTest 12 (GCT12)

An object is launched with an initial speed upward from the surface of the Earth. Which set of graphs correct shows the objects kinetic energy (KE) and gravitational potential energy (GPE) of the object as it rises?

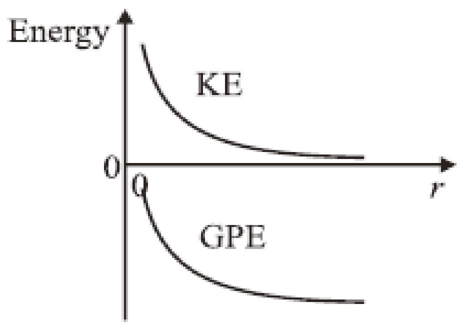
A.



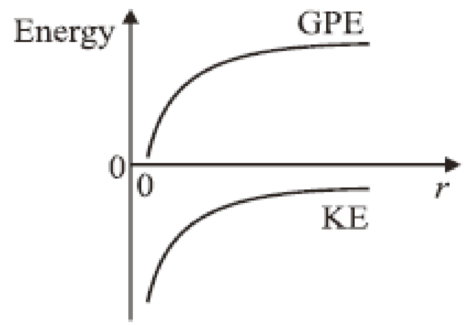
B.



C.



D.



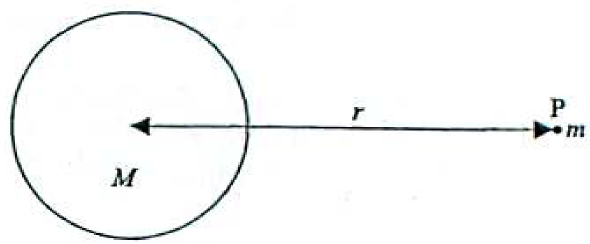
Gravitation ConcepTest 13 (GCT13)

Compared to the Earth, Planet X has twice the mass and twice the radius. This means that compared to the amount of energy required to move an object from the Earth's surface to infinity, the amount of energy required to move that same object from Planet X's surface to infinity is

A. 4 times as much.
B. twice as much.
C. the same.
D. 1/2 as much.
E. 1/4 as much.

Gravitation ConcepTest 14 (GCT14)

An object of mass m is brought from infinity to a point P, a distance r from the centre of a planet of mass M.



The work done by the gravitational force in bringing the object from infinity to point P is

A. GM / r

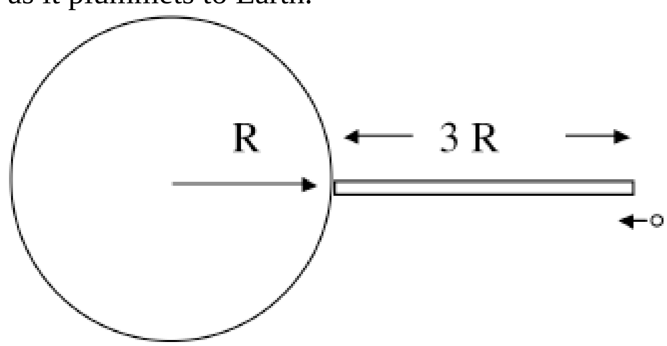
B GMm/r

C. - GM/r

D. -GMm/r

Gravitation ConcepTest 15 (GCT15)

A rock, initially at rest with respect to Earth and located far away is released and accelerates toward Earth. An observation tower is built 3 Earth-radii high to observe the rock as it plummets to Earth.



Neglecting friction, the rock's kinetic energy when it hits the ground is

A: twice

B: three times

C: four times

D: eight times

E: sixteen times

...its kinetic energy at the top of the tower.

VI). Orbiting systems' energy (Virial theorem)

Gravitation ConcepTest 16 (GCT16)

A satellite orbiting the Earth has

A. Gravitational Potential Energy only

B. Kinetic Energy only

C. Both Kinetic & Potential Energy

D. Neither Kinetic nor Potential Energy

Gravitation ConcepTest 17 (GCT17)

What is the kinetic energy of a satellite of mass m that orbits the Earth of mass M in a circular orbit of radius R?

A. $E_K = -\frac{1}{2} G M m / R$
B. $E_K = 2 G M m / R$
C. $E_K = 0$
D. $E_K = \frac{1}{4} G M m / R$
E. $E_K = \frac{1}{2} G M m / R$

Gravitation ConcepTest 18 (GCT18)

Which of the following could represent the kinetic energy, the gravitational potential energy and the total energy for an orbiting satellite in a stable circular orbit?

	Kinetic Energy	Gravitational Potential Energy	Total Energy
A	40 000 J	- 80 000 J	- 40 000 J
B	40 000 J	40 000 J	80 000 J
C	80 000 J	40 000 J	120 000 J
D	80 000 J	- 40 000 J	40 000 J

Gravitation ConcepTest 19 (GCT19)

Two satellites orbit the Earth in circular orbits. The orbital radius of satellite A is larger than that of satellite B. For which Earth-satellite system is the total energy largest?

A. Earth-satellite A
B. Earth-satellite B
C. Both the same