FORM SIX STUDENTS' CONCEPTIONS IN CIRCULAR MOTION

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ABSTRACT

This study examined upper six physics students' conceptions in circular motion. Participants consisted of 89 students from two schools in Kuching, Sarawak. A pencil and paper test was used to assess the students' understanding of the basic concepts in circular motion and to probe their recurring and common misconceptions. The findings showed that:

(1) (1) Among the recurring misconceptions in circular motion identified were: (a) Perceived an object would continue to travel in curvilinear path in the absence of centripetal force; (b) Regarded centripetal force and resultant force acting on an object as two different forces; (c) Perceived a motive force acting on a body in motion.

(2) (2) A total of six common misconceptions were identified from the students' responses.

Implications arising from the findings and specific recommendations for better understanding of the concepts in circular motion were discussed.

INTRODUCTION

Circular motion is one of topics in the mechanics section of the Form six syllabus. Studies have shown that many students including those at the tertiary level encountered difficulties in understanding the concepts of circular motion. Finley, Stewart and Yarroch (1982) found that circular motion was the most difficult concept for students. Salvage and William (1989) credited some of the students' confusions to the introduction of centrifugal force.

Warren (1971) had asked 148 English university entrants in engineering and science to draw an arrow showing the resultant force acting on a car travelling at constant speed along a horizontal, circular road. About 40 % of the students indicated the resultant force in the direction of the motion, 26 % of the students showed a radial and inward force while 14 % showed a radial and outward resultant force.

Viennot (1979) used paper and pencil tests to investigate spontaneous reasoning in elementary dynamics to physics students in France, Belgium and Britain. He argued that many university students treated circular motion as an example of an equilibrium situation, and this led them to invent an outward centrifugal force to counterbalance the inward centripetal force. He also proposed an explanation of students' spontaneous reasoning in terms of an assumed linear relationship between force and velocity: Zero velocity implied zero force. Thus, if an object has no radial velocity, then it has no radial force acting on it.

In the United States of America, McCloskey, Caramazza and Green (1980) asked 50 undergraduate students at John Hopkins University to sketch the subsequent paths of a moving ball emerging from a simple C-shaped tube, a double C-shaped tubes and a spiral tube. The students were also asked to describe the path of a pendulum bob cut from its string at a certain point of circular motion. A total of 36 % of the paths drawn by the students were of curvilinear paths. More specifically, for the spiral tube problem, 51 % of the students thought that the ball would follow a curved path after emerging from the tube. For the simple C-shaped and double C-shaped tubes, the curved paths drawn constituted respectively 33% and 30 % of the sample. Similarly, about 30% of the students believed that the ball would continue to follow a curved path after the string broke. McClockey et al. (1980) stated that the above students' beliefs were reminiscent of the medieval theory of impetus.

In Australia, Gunstone (1984) and Gardner (1984) respectively investigated the students' pre- and post-instructional alternative frameworks in circular motion using the same paper and pencil test. Among the questions in the test were: a number of questions concerned with drawings of objects in circular motion; questions which asked for labeled arrows to indicate the forces acting on objects; questions which asked the total force acting on objects. Gardner (1984) identified six alternative conceptual frameworks that the students used to account for the dynamics of circular motion. Among the frameworks identified were: (a) the Motive Force Framework, (b) the Equilibrium Framework Type I – Absence of Radial Forces whereby the students treated

circular motion at constant speed as rectilinear motion at constant speed, (c) the Equilibrium Framework Type II – Two Counter-Balancing Radial Forces in which the students' explanations postulated a balance between a centripetal force and an equal and opposite centrifugal force. Gunstone (1984) reported that a total of 84% of the students indicated the Motive-Force Framework while 12% of the students showed a form of centrifugal force concept.
Similarly, Searle (1985) administered a test that contained seven questions of the DOE (Demonstrate, Observe and Explain) type, to 19 first-year engineering students. The test was designed to investigate the following misconceptions in classical mechanics: (i) motion implied force belief, (ii) the impetus theory, and (iii) the commonly held view that an outward centrifugal force acted on objects moving in a circle. Among the six misconceptions held by the students included the impetus theory, motion or displacement implied force and equilibrium framework.

In Jamaica, Whiteley (1995) asked 115 upper six students of advanced level physics to give a 'reasonable one-word answer' to the question: "What hold up the Moon?" He found out that some of the 58 students who had answered in the 'gravity' or 'centripetal force' categories indicated that they actually believed in two forces (gravity and centripetal force) rather than recognizing that gravity was the centripetal force that held up the Moon. A small number (6) of students had the belief that a balancing force was needed to counter the attraction of the Earth for the Moon by identifying the attraction of other planets such as Mars or an outward centrifugal force in order to balance the gravity.

The study reported in this paper builds on the studies mentioned above and sought to investigate the students' understanding of the basic concepts in circular motion.

THE SAMPLE AND INSTRUMENT

The subjects of the study comprised 89 students from four intact upper six physics classes in two secondary schools in Kuching, Sarawak. The students' ages ranged from 19 to 20 years old.

The test consists of four open-ended questions intended to test the basis concepts of the circular motion. Two questions adapted from McClockey et al.'s (1980) study required the students to draw the path of motion immediately after the absence of centripetal forces. In the other two questions, the students needed to identify all the forces and resultant forces acting on an object in circular motion. (See appendix)
The test was administered some nine months after the topic had been covered in class.

RESULTS

Students' Common Misconceptions in Circular Motion

The common misconceptions in circular motion were operationally defined, as the misconceptions possessed by 20% or more of the students in this study. These common misconceptions were identified from the analysis of students' misconceptions in all the 4 questions. The common misconceptions, together with the percentages of students having the misconceptions, were shown in Table 1.

As shown in Table 1, the misconception held by the highest percentage of students was extracted from Questions 4. A total of 42.7 % of the students misconceived that the force acting on the moon was not zero and in the direction of the motion. This misconception was similar to that reported in Gunstone's (1984) study carried out on Australian students. Moreover, in Questions 4 (ii), a substantial number of students (21.3%) perceived the force acting on the moon as zero. Australian students in Gardner's (1984) study showed the similar misconception that he classified as Equilibrium Framework Type I – Absence of Radial Forces.

Table 1

Students' Common Misconceptions Identified from Their Responses in the Test

QuestionNumber	Misconceptions Involved	Percentage of Students Having Misconception
1	(a) (a) Perceived the balls would continue to move in curvilinear paths after leaving the double C-shaped tubes. (b) (b) Perceived the double C-shaped tubes were placed in vertical plane	29.2 25.8
3	Regarded centripetal force and resultant force as two different forces acting on the bob.	22.5
4	(a) (a) Perceived there was a motive force acting on the Moon of Jupiter. (b) (b) Perceived the force acting on the Moon was not zero and in the direction of the motion. (c) (c) Perceived the force acting on the Moon was zero.	28.1 42.7 21.3

In Question 1, a total of 29.2% of the students perceived that the balls would continue to move in curvilinear paths after leaving the double C-shaped tubes. Similar curvilinear paths were reported in studies carried out by McCloskey et al. (1980), Gunstone (1984) and Searle (1985). McCloskey et al. (1980) found approximately the same percentage (30%) of students drawing similar curvilinear paths. In addition, in Question 1, a total of 25.8% of the students misconceived that the tubes were placed in a vertical plane. Hence they drew the paths of motion of the ball incorrectly in the absence of centripetal force. Some students in McCloskey et al.'s (1980) study and 16% of the students in Gunstone's (1984) study had the same erroneous views.

In Question 3, a total of 22.5% of the students had the misconception that the centripetal force and the resultant force were two different forces acting on the bob. The correct conception was that the resultant force and the centripetal force were the same force in the context of the problem.

In Question 4, a total of 28.1% of the students had the wrong conception that there was a motive force acting on the Moon of the Earth. This Motive Force Framework was also found in studies carried out by Gunstone (1984) and Gardner (1984). Gunstone (1984) reported a higher percentage (84%) of students having this Motive Force Framework as compared to 28.1 % of the students manifesting the misconception in this study.

Students' Recurring Misconceptions in Circular Motion

The recurring misconceptions in circular motion were students' misconception identified from their responses in more than one of test questions. It should be noted that these recurring misconceptions refer to the misconceptions that appear in the different questions and not referring to the same students having the misconceptions. Six recurring misconceptions, (shown in Table 2) were identified:

(1) (1) Misconceptions that objects would continue to travel in curvilinear paths in the absence of centripetal force. In this study, these misconceptions were shown in questions 1and 2. These erroneous views were considered to be reminiscent of the medieval impetus theory as reported in McCloskey et al.'s (1980) study. This impetus theory had the perspective that an object moving through a curved tube (or otherwise forced to travel in a curved path) acquired a "force" or "momentum" that caused it to continue in curvilinear motion for sometimes after emerging from the tube. However, the force or momentum eventually dissipated and the object's trajectory gradually became straight. McCloskey and Kohl (1983) specifically called this naïve physics belief as the curvilinear impetus principle.

(2) (2) Misinterpretations of diagrams in perceiving objects in horizontal plane as vertically placed. The students showed this weakness in interpreting diagrams in both qestions 1 and 2. Similar misinterpretations were reported in studies carried out by Gunstone (1984) and McCloskey et al. (1980) to the respective Australian and American students.

Table 2

Students' Recurring Misconceptions Identified from Their Responses in the Test.

Misconceptions	Ques. No.	Percentage of Students Having Misconceptions
Perceived an object would continue to travel in curvilinear path in the absence of centripetal force.	1 2	29.2 9.0
Misinterpreted diagrams in horizontal plane as vertically placed.	1 2	25.8 14.6
Regarded centripetal force and resultant force (e.g. gravitational force) acting on an object as two different forces.	3 4	22.5 7.9
Perceived a motive force acting on a body in motion.	3 4	4.5 28.1
Perceived that an outward force acting on a body in motion.	3 4	10.1 9.0

(3) (3) The misconception that centripetal force and resultant force acting on a body were two different forces. Students described centripetal force as a type of force acting on a body in circular motion rather than a synonym for the specific force acting 'towards the centre' (Gardner, 1984). The students showed this misconception in Questions 3 and 4. Similar erroneous conception was reported in the study carried out by Whiteley (1995).

(4) (4) The misconception that a motive force was acting on a body in the direction of motion. The students showed this idea of motive force in Questions 3 and 4 by drawing an arrow in the direction of motion to indicate a force acting in that direction. This erroneous conception indicated that the students had an Aristotelian idea that forward motion required a forward force: ‘ If a body is moving, there is a force acting upon it in the direction of the movement’. Similar misconceptions were reported in studies carried out by Warren (1979), Gunstone (1984), Gardner (1984) and Searle (1985).

(5) (5) The misconception that an outward force acted on a body in circular motion. The students showed this wrong conception in Questions 3 and 4. Students in studies carried out by Warren (1979), McCloskey et al. (1980) and Gunstone (1984) showed similar misconceptions.

IMPLICATIONS AND RECOMMENDATIONS

This study revealed that the students held several common and recurring misconceptions in circular motion despite receiving formal instructions from their teachers. This finding might suggest that the students could not understand or assimilate their teachers’ instruction or that the preconceptions of the students were quite resistant to change even after formal instruction. Hence identifying students’ preconceptions is essential for the teachers to devise appropriate instructional strategies to bring about the desired conceptual change. There should be more opportunities for practical activities and discussions so that the students could clarify their views. This will help them to resolve any preconceptions that are not consistent with their observations of the ideas or phenomena discussed in the classroom.

Some of the students’ conceptions in circular motion were indeed the wrong conceptions such as the Aristotelian motive force and the Impetus theory of motion which were also held by the scientists in the past ages. Thus the topic of history of science should be included in the teacher-training programme for physics teachers so that the trainees will have the knowledge of how the past scientists altered their wrong reasoning with the passage of time. The trainees could also compare and contrast the students' and historical misconceptions with the correct scientific conceptions. The teachers could also use the wrong reasoning of the past in convincing their students to discard any misconceptions and to acquire the accepted scientific conceptions.

The findings of this study indicated that some students had a poor understanding of Newton's First and Second Laws of motion. Newton's First Law implies that if a body changes its state of motion, there is a force acting on it. Newton's Second Law states that if a body experiences an acceleration, there is a force acting on it, or conversely, if there is a force acting on a body, it will accelerate. Findings in this study showed that some students could not apply Newton's First and Second Laws in the cases of motion provided. They did not have a profound understanding of the fundamental concepts of acceleration, velocity, and force. These students did not grasp the fact that acceleration could be either due to any change of speed or any change of direction of motion. Thus, with any change of speed or change of direction of speed, a body will definitely experience a force acting on it. Teachers should provide sufficient concrete examples of different situations of motion for the students to engage in peer-group or teacher-student discussions so that the students could firmly grasp the essence of the two laws of motion. This is important, as understanding of these two laws will affect mastery of other concepts related to mechanics.

In circular motion instruction, it is important for teachers to first identify the physical nature of the force acting on an object in circular motion, rather than just stating the term 'centripetal force' that enables the object to travel in circular motion. Teaching circular motion in a well-conceptualized qualitative approach without using numbers in the early part of a lesson will prevent unnecessary rote learning of formulae. This will encourage the students to understand the concepts presented.

This study showed that form six students still held a number of common misconceptions in circular motion even after undergoing formal instruction by their teachers. Research could be done to determine whether these misconceptions were from students' existing preconceptions arising from their own experiences or were due the unclear and incorrect instructions by their teachers. Data could be collected at two stages, that is, before and after instruction of the topic in circular motion.

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Appendix

1. 1. Figure 1 shows two thin curved metal tubes placed horizontally. A small metal ball is put into the end of each of the tubes indicated by the arrows. The balls are then shot out of the other ends of the tubes at high speed. Assume that the balls will come out of the tubes at the same speed. Ignoring air resistance and friction inside the tube, draw the paths the balls will follow immediately after they come out of the tubes.

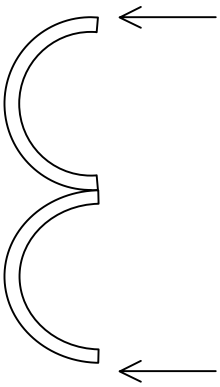

Figure 1

Explain why the balls move in the paths drawn by you.

2. 2. A boy has a metal ball attached to a string and is swinging it at a constant speed in a *horizontal circle* above his head. In Figure 2 you are looking down on the ball. The circle shows the path followed by the ball and the arrows show the direction of its motion. The line from the centre of the circle to the ball is the string. Assume that when the ball is at the point P, the string suddenly breaks.

   Ignoring air resistance, draw the path of the motion of the ball immediately after the string breaks.

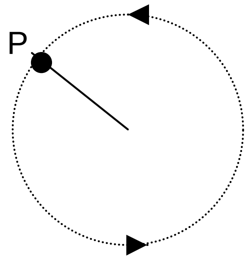

Figure 2

Explain why the ball moves in the path drawn by you.

3. 3. Figure 3 shows a bob of mass *20g* attached to the end of a light and inextensible string of length *48 cm* rotating in a horizontal circle of radius 10 *cm* with a constant angular speed about the vertical. Ignoring air resistance,

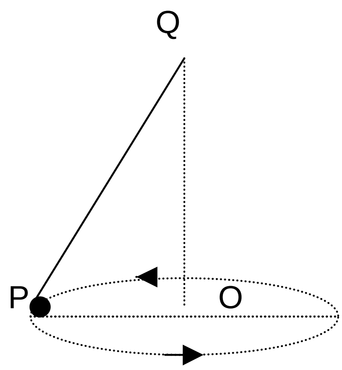

Figure 3

(i) indicate and label the forces acting on the bob at the point P.

(ii) (ii) indicate and label the resultant force.

4. 4. The Moon of the Earth is travelling at a constant speed in a circle around it.

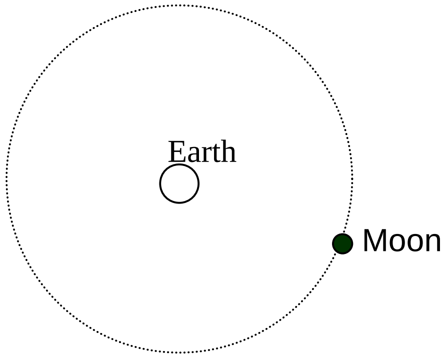

Figure 4

(i) (i) On Figure 4, draw arrows to represent the forces acting on the Moon. Name the forces.

(ii) (ii) The total force acting on the Moon is

A. A. zero.

B. B. not zero, and in the direction of motion.

C. C. not zero, and in some other direction.

Explain your answer.