University Students' Alternative Conceptions On Circular Motion

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Abstract: This study attempted to find out university students alternative conceptions on circular motion. An 18-item researcher-compiled and content-validated questionnaire was administered to twenty-six (26) students taking up a program in Bachelor in Secondary Education-Physical Science in their second year enrolled in a course on mechanics. Results revealed that majority of the students possess alternative conceptions on circular motion specifically along velocity, acceleration and force. Moreover, results showed the inconsistencies in the students' understanding of circular motion concepts.

Index Terms: alternative conceptions, circular motion, constructivism, conceptual change

1 Introduction

Circular motion is among the phenomena that anyone experiences every day. It has been among the discourses of natural philosophy even during the time of Aristotle, Ptolemy, Galileo and some of the pillars of science in the ancient times. In the past, a consensus was arrived that the only motion permitted in the heavens or the outer space that we know today is circular motion. Copernicus proved this incorrect after years of study. Students conceptions about circular motion is one of the themes in physics that is widely studied but alternative conceptions held by university students specifically along the context of this study is limited. This study is a part of a developmental research in mechanics to which the researcher explored the alternative conceptions of university students on circular motion particularly those students enrolled in mechanics. The result of this investigation became the basis in the development of a teaching sequence that attempted to address these alternative conceptions and increase conceptual understanding on circular motion.

2 Theoretical Framework

This study is based on the theory of constructivism specifically on the conceptual change model of learning. Constructivism is a theory of learning whereby learners create their own understanding based on an interaction between prior knowledge and new knowledge to which they come into contact [1]. It is believed that the learners, through experience-based activities rather than one directed by teachers generate knowledge [2]. The origin of the said theory is very difficult to trace, however, examining the ideas and philosophies of Socrates, Kant, Dewey and Vygotsky, all of their philosophies possess the characteristics of constructivism [3]. Taking constructivism as a learning theory, prior knowledge of the learner is of vital importance. When new concepts are taught, prior knowledge is among the factors that determines and shapes their understanding of the new concepts. Centered on constructivism, the conceptual change model offers an explanation on how students learn. Its context is similar to Kuhn's notion of paradigm shift and the principle of accommodation according to Piaget. For almost three decades now, many studies conducted along teaching and learning were anchored on the conceptual change model framework. This framework recognizes that students acquire knowledge from their daily experiences. It also assumes that what students already know influences their formal learning and that much of this prior knowledge is highly resistant to change. Thus, conceptual change is a time consuming process. Hewson [4], Posner, Strike, Hewson, and Getzog [5], Hatano and Inagaki [6], Strike and Posner [7] provided a clearer picture of conceptual change. They found out that if the learners' current conception were still functional, such that it can still provide solution to problems within the existing conceptual schema, the learner would not feel to change the current conception. Along these findings, it is therefore important to investigate and find out first the existing knowledge of the learner on certain concepts.

3 Literature Review

A significant number of studies attempted to find out students' conceptions and understanding on circular motion and other related concepts. The earlier work of Searle [8] attempted to find out how first year engineering students understand circular motion. He was able to enumerate a number of alternative conceptions about centripetal acceleration and centripetal force. Similar findings were recorded in the work of Ching [9]. He specifically found that students regarded centripetal force and resultant force as two different entity. Moreover, Antwi et al [10] found that most students understand some concepts in mechanics such as circular motion differently. He proved that being able to solve difficult mathematical problem sets is not an assurance for a complete conceptual understanding. Similarly, the work of Duman, Demerci, and Sekercioglu [11] and Vyas [12] were specific in finding out misconceptions and alternative conceptions on circular motion. In these studies, it was revealed that students in the university have difficulty in mastering, applying and interpreting fundamental concepts in mechanics such as circular motion concepts. Likewise, Viridi, Moghrabi and Nasri [13] made the same findings, but did a more practical work in probing students understanding of circular motion using ordinary appliances, train toy, digital camera and android-

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based smartphone. In addition, another group of studies that are related to circular motion were on designing and implementing teaching and learning strategies that could increase the knowledge and address alternative conceptions in circular motion. Seattha, Yuenyong and Art-in [14] developed a very practical approach in teaching circular motion by using science, technology and society (STS) approach in teaching circular motion to understand the context of science, technology, engineering and mathematics (STEM). Similarly, Stinner [15] advocated in using more common and natural phenomena rather than focusing on textbooks in his strategy called 'linking the book of nature and the book of science' to understand circular motion. Meanwhile, the use of computer and Internet technology [16, 17] and inquiry-based strategy [18] were also found to be effective and efficient in teaching circular motion. Although, a number of studies have argued that it is nearly impossible to change preconceptions of students on physics concepts [19, 20, 21]. According to Ozdemir [19], misconceptions either would tend to coexist with the scientific conceptions or will reappear after sometime even after giving a successful teaching [20, 21]. Finally, another group of studies were on developing tools for assessment of conceptual understanding on circular motion. Among these assessment tools were the three-tier misconception test [22] and the use of diagram [23] in probing conceptual understanding of circular motion concepts. This study was focused on assessing alternative conceptions of university students on circular motion specifically on linear speed and rotational speed, velocity, centripetal acceleration and centripetal force. It combined a number of assessment tools including analysis of diagrams, practical phenomena, written test, individual and group interviews. It also focused on finding out inconsistencies in the understanding of students on the above-mentioned concepts.

4 Objectives of the Study

The main objective of the study is to find out the alternative conceptions held by university students on circular motion. Specifically, it is to find out the following:

1. Alternative conceptions about:
   a. Linear and rotational speed of objects in circular motion,
   b. Velocity of objects in circular motion,
   c. Forces acting on an object in circular motion, and
   d. Acceleration of an object in circular motion, and
2. Problem solving difficulties

5 Methodology

Adopting the design suggested by literatures in conducting researches related to students' conceptions and understanding, this study employed the descriptive design of research [24, 25, 26, 27, 28]. The diagnostic test was an 18-item researcher-compiled and content-validated questionnaire made up of combined multiple choice and open-ended questions. Twenty-six (26) second year students, taking up a program in Bachelor of Secondary Education-Physical Science enrolled on a course in mechanics took part in this study. After the test administration, responses were tabulated and grouped. It was necessary to conduct follow-up individual and group interviews to check, validate and confirm students' responses in the questionnaire. Tabulated and grouped data were analyzed quantitatively using frequency counts and percentages. Qualitative analysis using simple Collaizi method was also important to further analyze and understand the responses of the students in the open-ended questions [29].

6 Results and Discussion

After thorough evaluation of the responses made by the students to the questionnaire and follow up interviews, it revealed that none of the 26 respondents possesses thorough and correct conceptions on the specific circular motion concepts investigated in this study. The study further revealed that students possess a number of alternative conceptions on concepts related to circular motion. Moreover, there appeared inconsistencies in the students' understanding of circular motion concepts in different circumstances.

6.1 Linear and Rotational Speed

Question number 4 of the diagnostic test was to find out students' understanding on linear speed and rotational speed. It specifically asked the description in the change of speed of an object in circular motion as it is moved from the center to the outer edge of the curved path. The table that follows summarizes the responses of the students to this question.

***Table 1**. Distribution of responses to question 4*

Response	Frequency
Decreasing speed as the object is moved from the center to the outer edge.	10
Increasing speed as the object is moved from the center to the outer edge	9
Speed remains the same	5
No response	2

Ten respondents believed that speed decreases as one moves from the center to the outer edge of the circular path. Meanwhile, nine respondents believed that speed increases as one moves from the center to the outer edge of the circular path. Only five respondents responded that speed does not change whether it is near the center or near the outer edge. Two respondents did not make any response to the question. Based on the responses, it can be assumed that nine respondents attributed their answers to linear speed while five respondents to rotational speed. Interviews were conducted for students who answered increasing speed and constant speed. Of those who answered an increasing speed, only one respondent correctly and explicitly attributed the explanation to linear speed. The following is an excerpt from the interview with this respondent.

> *"An speed madako kay mas mahalaba man an iya distance nga itratravel tapus asya la gihap an time para umabot hiya han the same nga point." (The speed will increase because the total distance to be travelled increases but the time to arrive at the same point is still the same).*

Without any clear explanations, three respondents who initially explained an increasing speed have eventually changed their answers to decreasing speed. Meanwhile, all of the five respondents correctly attributed their explanations to rotational speed. The following is an excerpt from an interview with one of the students.

> *"Kay it iya paglidong hin makausa an object bis diin igbutang maabot hin the same nga point at the same time." (Because the object as it completes one rotation, wherever the object is located, it will arrive at the same point at the same time.)*

> *"It is the same because they rotate at the same time and will arrive after completing one turn at the same time."*

However, notably, no one in the two groups were able to explicitly differentiate linear speed and rotational speed. They only thought of one or the other. Similarly, question number 18 was to compare the speed of the two boxes placed in a rotating plate. One box placed near the center while the other box placed near the outer edge as shown in the Figure 1.

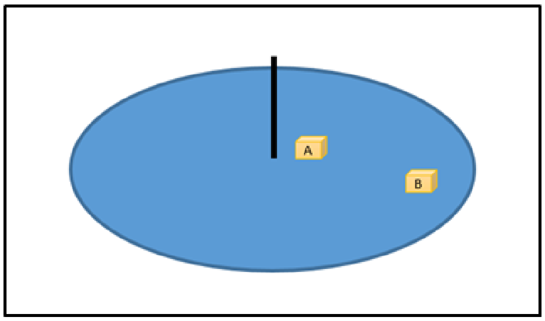

Figure 1. *Two boxes placed on a rotating plate.*

The following table summarizes the explanations of the students to question 18.

Table 2. *Distribution of responses to question 18*

Responses	Frequency
Box on the outer edge will move faster than the box near the center	11
Box near the center will move faster than the box on the outer edge	9
Both boxes will move with the same speed	4
No answer	2

With these responses, assumption can be made again that 11 respondent attributed their explanations to linear speed while four respondents attributed their answers to rotational speed. It could be noticed that three respondents were added to those who claimed that an object on the outer part of a rotating plate moves faster. However, of the 11 respondents, only five have the same answer with question 4. It was revealed that there exist inconsistencies in the responses and explanations of the students. During the interviews conducted to this group, only three respondents have correctly explained their attribution to linear motion. The rest did not have either any explanations or unclear explanations. Here is an excerpt in one of the interviews with the students.

> *"Box on the outer edge will travel a bigger diameter so it will have a greater speed than the box near the center."*

Notably, the number of students who attributed their answers to rotational speed was reduced to four respondents from five in the previous question. In the interview with this group, all of them were able to attribute correctly their answers to rotational speed. Here is another excerpt in one of the interviews made with this group.

> *"Maski diin nga part han plate igbutang an box. Ma kompleto an iya bug-os na pag turn at the same time." (Whichever part of the plate will the box be placed does not matter. The entire turn will be completed at the same time.)*

The following is an illustration made by the student, which attributed his explanation to rotational speed.

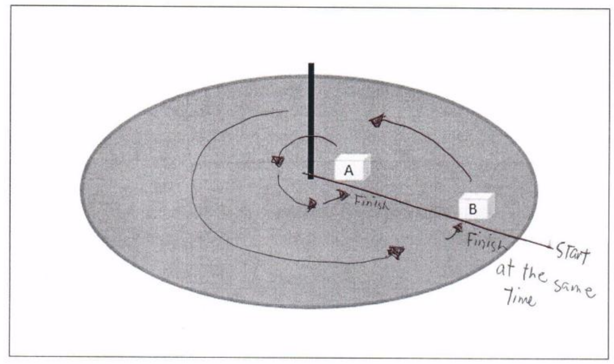

Figure 2. *Illustration attributing explanation to rotational speed*

Similar to the responses and explanations in question 4, none of the two groups were able to explicitly differentiate linear speed and rotational speed.

6.2 On Speed and Velocity

Question number 3 was related to velocity of objects in uniform circular motion (UCM). Students were asked to illustrate and explain the direction of the velocity of an object moving in a circular path represented by the moon revolving around the earth as shown in Figure 3.

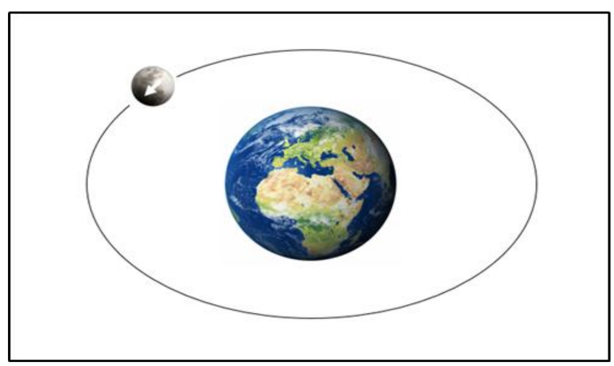

Figure 3. *Illustration of the moon revolving around the Earth.*

Twenty-two respondents pointed out that the direction of velocity is along the circular path. In a number of cases, some illustrations showed a tangential direction like the responses shown in Figure 5. However, during the interview, it was confirmed that the students meant that it was along the circular path. On the other hand, three respondents illustrated an inward direction of velocity such as the one shown in Figure 6. One respondent illustrated an outward direction of the velocity as shown in Figure 7.

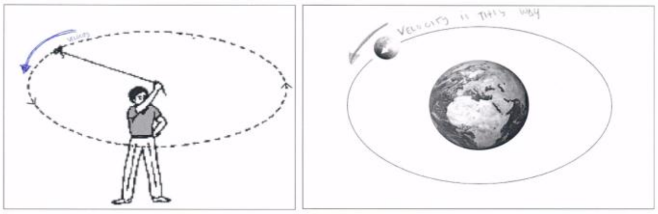

Figure 4. *Illustrations of students' responses showing a curve direction of velocity*

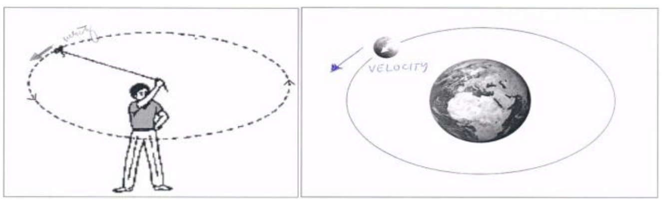

Figure 5. *Illustration of a student response showing a tangential direction of velocity but explanations in the interview meant a curve direction*

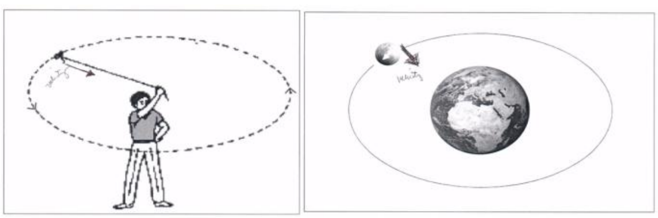

Figure 6. *Illustrations of students' responses showing an inward direction of velocity*

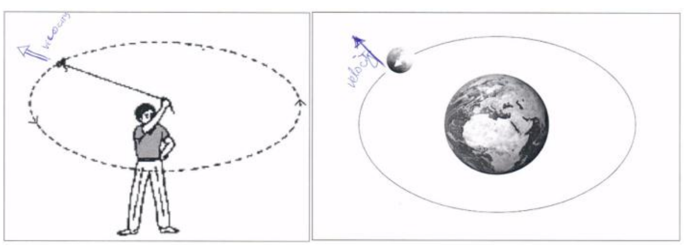

Figure 7. *Illustration of students' responses showing an outward direction of velocity*

Another remarkable finding of the study is that nine respondents confused velocity, force, and acceleration. During the interviews, it appeared that these students interchangeably used velocity, force, and acceleration.

Student: *The direction is curve. The velocity or force follow a curve direction.*

Teacher: *What do you mean by velocity or force?*

Student: *Paraprehos la ito sir. Force, velocity, and acceleration. (They are just the same sir. Force, velocity, and acceleration.)*

Twenty-three respondents thought that speed and velocity are the same thing for objects in UCM. Although in the interview, a number of them were able to differentiate between speed and velocity, speed being a scalar quantity and velocity being a vector quantity, for objects in UCM, it revealed that the direction of velocity was not within their frame of thinking. This was confirmed by 12 respondents who argued that any object in UCM has zero acceleration for reason that velocity is uniform. The following is an excerpt in one of the interviews conducted.

Student: *Speed and velocity are the same.*

Teacher: *What do you mean? Are they the same thing?*

Student: *Of course not. An speed scalar quantity while an velocity vector quantity it hiya. Pero ha object in circular motion, pareho la ito hiya. (Of course not. Speed is a scalar quantity while velocity is a vector quantity. But, for objects in circular motion, they are just the same.*

Teacher: *Then how can they be the same if one is a scalar and the other is a vector?*

Student: *I mean direction of velocity is curving so speed is also curving.*

Teacher: *What about acceleration?*

Student: *I think it is zero sir.*

Teacher: *Are you sure? Why?*

Student: *Kay an speed ngan velocity pareho man la. Waray pag bag-o asya nga zero an acceleration. (Because speed and velocity are both the same. It did not change, therefore acceleration is zero.)*

Teacher: *Is that so?*

Student: *Yes sir. Because acceleration is change in velocity or speed. In uniform circular motion, speed and velocity did not change so acceleration is clearly zero.*

Teacher: *Suppose, the circular motion is not uniform, do you think there is acceleration?*

Student: *Yes sir, because speed and velocity is changing.*

Teacher: *Then, if there is, what do you think is its direction?*

Student: *It will be along the path. Curve or along the circular path.*

However, despite their limited understanding of velocity of objects in circular motion, this did not mean that they cannot predict the direction of the object if it get lost in its path such as a stone being whirled in a circle and suddenly the string is cut as shown in the figure below.

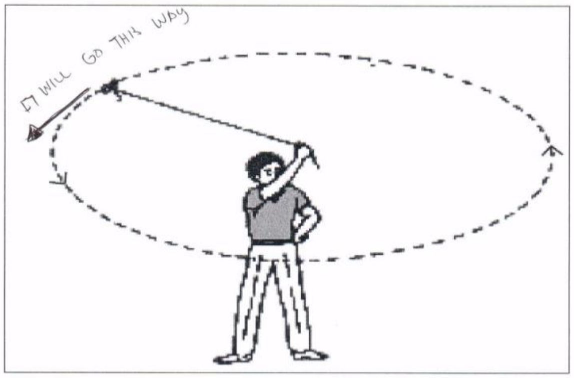

Figure 8. *Illustration of a student response predicting the direction of the stone when the string is cut while it was whirled.*

Examining the illustrations, about 15 respondents correctly predicted the path of the stone when the string breaks. However, only eight of them confirmed a tangential direction during the individual interviews conducted. The rest confirmed their answers to curve along the circular path. One notation made in these interviews is that no one of the students who predicted a tangential direction were able to connect this specific event to the direction of the stone's velocity. Instead, a number of students mentioned an outward force, which they call centrifugal force.

Student: *It will go straight.*
Teacher: *Are you sure? Why will it not curve?*
Student: *Because of the outward force.*
Teacher: *What do you mean by outward force?*
Student: *An opposite force han string. Baga baga it hiya hin centrifugal force ada. (The opposite force of the string. It is like centrifugal force I think.)*

6.3 Centripetal Acceleration
Along centripetal acceleration, it was relevant to use the illustration of the boy whirling a stone because, during the interviews conducted on velocity and speed, majority of the students have already thought that acceleration is zero for UCM because the velocity was constant. In the illustration, an assumption was made in that, the boy whirled the stone such that its velocity was not constant. Figure 9 shows the illustrations made by the students on the direction of centripetal force.

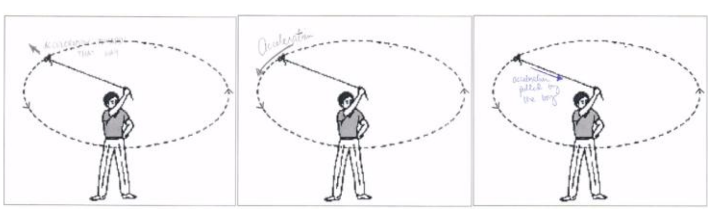

Figure 9. Illustration of students' responses on the direction of centripetal acceleration

It was revealed that 19 respondents thought of a curved direction of centripetal acceleration. This is expected since majority of them assumed the likeness among velocity, force, and acceleration. The following is an excerpt in one of the interviews made with the students.

Teacher: *Suppose the velocity was not constant, do you think there will be acceleration?*
Student *Yes sir mayda na niya acceleration.*
Teacher*:* *So kun mayda na acceleration, tikain man an iya direction? (So if there is already acceleration, what will be its direction?)*
Student: *Pareho la gihap ito hiya ha velocity. Ma curve hiya along han path sir. (It will be the same as the velocity. It will curve along the path.*

Meanwhile, two respondents illustrated an inward direction of acceleration. In the interview, it was confirmed that they interchangeably thought of acceleration being the centripetal force.

Teacher: *Now that you think there is already acceleration, what will be its direction?*
Student: *It will be inward sir along the string.*
Teacher: *What made you say that?*
Student: *Kay asya ito sir an ada ha string nga nakapot han bato para lumidong an iya path. (Because it is the one present on spring that holds the stone so that it will have a circular path.)*

On the other hand, one respondent showed an outward direction of centripetal acceleration. In the interview, these students have very vague explanations on centripetal acceleration.

6.4 Centripetal Force
Eleven respondents were not familiar of centripetal force. A number of them argued that it was their first time to hear such a word. Upon examining their illustrations on the direction of centripetal force, 23 respondents pointed out that its direction is along the circular path. Again, this is expected because of the students' assumption on the likeness of velocity, force and acceleration. Two respondents pointed out that its direction is inward while one respondent illustrated it as outward. Figure 10 shows the representative illustrations of students' responses concerning the direction of centripetal force.

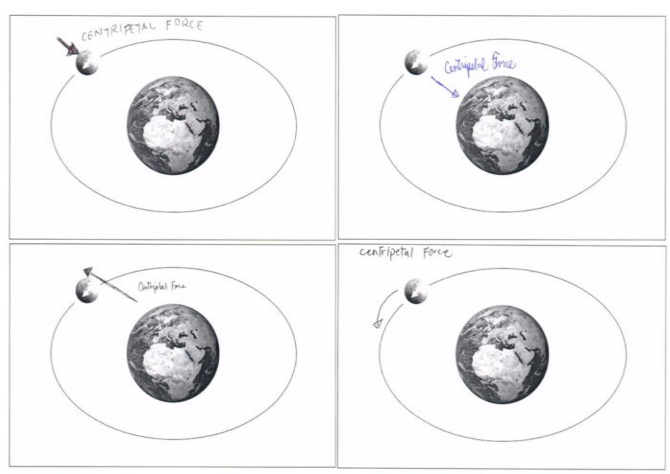

Figure 10. *Illustrations of students' responses on the direction of centripetal force.*

The directions of centripetal acceleration represented by the illustrations in Figure 10 were confirmed in the interview conducted for the group saying that the direction of the centripetal force is along the curved path.

> *"The direction is like velocity. They are the same. It curves along the circular path."*

6.5 Identifying and Naming Forces

Three (3) illustrations were given to students for them to identify and name the forces acting on every object in the illustrations.

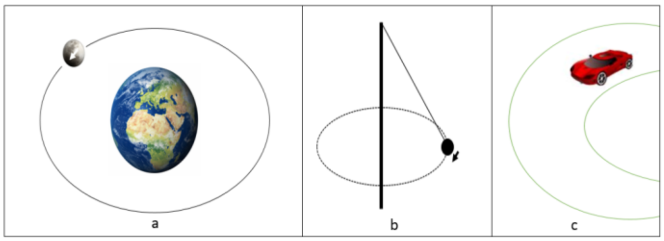

Figure 11. *Illustrations that need force identification and naming. [a] moon revolving around the Earth; [b] stone whirled with a string; [c] car moving in a curved road*

In the first illustration, figure 11a, 22 respondents identified only the presence of the force of gravity. The remaining four respondents identified two (2) forces, the force of gravity and a force opposite to the force of gravity.

Figure 12. *Illustration of students' responses to identification and naming of forces in figure 11a*

The following is an excerpt in the interview conducted related to figure 11a.

Student: *Mayda force of gravity. (There is force of gravity.)*
Teacher: *What else?*
Student: *The moon will also pull the earth. That is another force.*
Teacher: *How do you call that force?*
Student: *Baga hin gravity of the moon. Centrifugal force at ada. (It is like the gravity of the moon. I think it is centrifugal force.)*
Teacher: *What about centripetal force? Do you think there is one?*
Student: *Oh yes, there should be. It is along the orbit of the moon.*

Meanwhile, in figure 11b, 22 respondents identified both force of the string (tension) and force of gravity. Three respondents identified only force of gravity while one respondent identified only the force of the string.

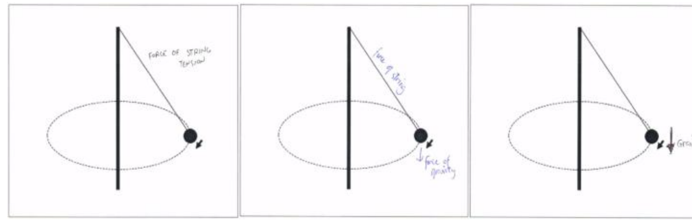

Figure 13. *Illustration of students' responses to identification and naming of forces in figure 11b*

The following is an excerpt in one of the interviews conducted for figure 11b.

Student: *There are two forces. The force of the string and the force of gravity.*
Teacher: *Only two forces? What about centripetal force?*
Student: *Ah yes. There is centripetal force. It is curving. The one that makes the stone move in circular path.*

In figure 11C, all students only identified the presence of the force of gravity in the illustration. However, during the interview, two respondents were able to identify the presence of friction force between the ground and the tire.

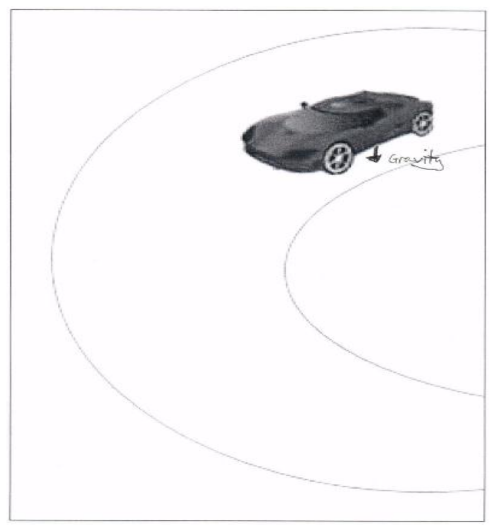

Figure 14. *Illustration of a student response to identification and naming of forces in figure 11c*

Student: *There is gravity of the earth.*
Teacher: *Only gravity? What about the force that allow the car to move in curve path?*
Student: *There is friction force from the ground. It will help the car curve.*
Teacher. *Let us imagine the car will be able to complete a circular path, do you think there is also centripetal force?*
Student: *Waray ada niya centripetal force sir. Yes there is none. (I think there is no centripetal force sir. Yes there is none.)*
Teacher: *Why?*

Student: *Kay waray man niya baga hin string nga mabulig paglibot. (Because there is none like the string that will help in the curving.*

All the interviews have revealed that students do not have an understanding that centripetal force can come in different forms such as the tension of the string, the force of gravity or the friction force. They think that centripetal force is an entirely different entity that they can hardly understand its presence and effect to any objects.

6.6 On Problem Solving

Majority of the students were able to get the exact value of linear speed (question 1) and rotational speed (question 2) when asked to compute. However, the interview revealed that most of them did not really know the context of linear speed and rotational speed; instead, they attempted to perform the simple operations in mathematics leading them to the responses they made. The following is an excerpt in the interview.

Teacher: *How did you arrive this answer?*
Student: *Actually sir, dire talaga ak maaram. An ak maaram la kay an speed meter per second man asya nga gindivide ko la ini nga duha para makakuha ak hin meter per second. (Actually sir, I really don't know. What I know is that speed is in meters per second so I divided this to quantity to get meter per second.*

Meanwhile, majority of the students were not able to get the correct answer when asked to solve for problem sets related to centripetal acceleration in question number 8 and centripetal force in question number 9. Individual interviews revealed that five respondents have not encountered circular motion yet. This was confirmed as the same students had difficulty in understanding technical terms included in the test such as velocity, centripetal acceleration and centripetal force. For some, it was discussed lightly such that no problem sets were given to them. Majority of the students resulted to guessing their answers in these items.

7 Implications

A number of implications were derived from the result of the study. For one, it is evident that there exist a number of alternative conceptions on circular motion specifically along the concepts of linear speed and rotational speed, velocity, acceleration and centripetal force. Despite the introduction of the description and examples of vectors and scalar quantities before taking up the theme on circular motion, for linear speed and rotational speed, students hardly differentiate the two concepts. In addition, they consider speed and velocity as the same thing for an object in circular motion. About 35% of the respondents interchangeably use velocity, centripetal force, and acceleration appearing to have the same meaning. Moreover, all respondents failed to extend their understanding of centripetal force on other phenomena such that it can appear in different forms. In the case of this study, it can be the force of gravity, string tension, and or friction. In addition, the foregoing study have revealed the existing inconsistency on students' understanding of circular motion concepts. It also showed the difficulty of the students in doing mathematical problem sets. This is true since 19% of the respondents did not have the opportunity to encounter circular motion upon taking their secondary school physics and physical science in the general education at the university while the rest did not have an in-depth learning of these concepts.

8 Recommendations

Concepts on circular motion is part of the learning competencies in the secondary school science curriculum and physical sciences in the general education curriculum. The result of the study have revealed a limited understanding and a considerable number of alternative conceptions on circular motion. Hence, it may be necessary to conduct an in-depth study and investigation on the reasons for failing to develop concrete conceptual mastery of circular motion concepts across level. Likewise, as these issues were proven to exist, appropriate strategies to address them may be developed and implemented. A number of literatures suggested that using inquiry-based approaches in teaching might be effective in addressing alternative conceptions and increasing students' understanding [30, 31, 32]. In addition, there may be a need to review the learning competencies related to circular motion in both the secondary science curriculum and the physical sciences of the general education curriculum. This is to ensure the appropriate, smooth and successful spiral progression in the teaching and learning of circular motion concepts across different levels. Moreover, literatures suggest that teachers' mastery of the subject matter is an important factor that affects students' achievement [33, 34, 35]. It may be necessary to find out the conceptual mastery of the teachers on circular motion to develop issue-specific solutions related to the teaching of circular motion in the basic education and higher education. Similarly, along the conduct of this study, a similar study may be conducted across different levels, groups and races to compare and verify the results reported in this study. Moreover, an in-depth study may be conducted to trace the origin of their understanding of circular motion concepts and the changes it could undergo when implementing research-based pedagogies. Likewise, other phenomena with the presence of circular motion may be added to ensure consistency in the understanding of circular motion concepts such that it can come in different forms.

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