Chapter IV

RESULTS AND DISCUSSIONS

4.0 Introduction

This study attempted to assess students' understanding of concepts in circular motion as well as their misconceptions. It also sought to establish the relationships between students' understanding of concepts in circular motion and their gender and formal reasoning ability. Upper six physics students from Kuching, Sarawak, with ages ranging from 19 to 20 years old were the subjects of the study. This study sought to answer the following questions:

(1) Were there any significant differences between the students of different formal reasoning ability in their understanding of the concepts in circular motion?

(2) Were there any significant differences between the male and female students in their understanding of the concepts in circular motion?

(3) Regardless of gender and formal reasoning ability, what were the students' recurring misconceptions in circular motion?

(4) Regardless of gender and formal reasoning ability, what were the students' common misconceptions in circular motion?

To answer these questions, the Statistical Package for the Social Science, SPSS, (Norusis, 1997) was used to analyze the data obtained from the TOLT and the UCCMT. The results were organized in this chapter according to the following sections:

(1) Descriptive statistics of the subjects of the study

(2) Formal reasoning ability of the students and their understanding of concepts in circular motion

(3) Gender and students' understanding of concepts in circular motion

(4) Students' conceptions in circular motion

(5) Students' recurring misconceptions in circular motion

(6) Students' common misconceptions in circular motion

4.1 Descriptive Statistics of Subjects of Study

4.1.1 Distribution of Gender of Students

Table 4.1 presents the distribution of the gender of students used in the study. As shown in the table, out of the total sample of 89 students, 43.8% of the students were males while the remaining 56.2% were females.

Table 4.1

Distribution of Gender of Students

Gender	No. of Students (%)
Male	39 (43.8)
Female	50 (56.2)
Total	89 (100.0)

4.1.2 Scoring Procedure and Categorization of Formal Reasoning Ability Groups

A score of one was given to each item with the correct response and justification in the TOLT. No score was given for the wrong response or justification. The maximum attainable score of TOLT was ten. A high score indicated that a student was of high formal reasoning ability while a low score indicated that the student was of low formal reasoning ability. The students' scores on the TOLT were categorized into the three formal reasoning ability groups, according to the classification scheme used by Garnett and Tobin (1984) as shown in Table 4.2.

Table 4.2

Categorization Scheme of TOLT Score

Formal Reasoning Ability Group	TOLT Score (Points)
Low	0 – 3
Medium	4 – 7
High	8 – 10

4.1.3 Distribution of Students' Formal Reasoning Ability Groups

Table 4.3 showed the results of the distribution of the formal reasoning ability of the students. Out of the total sample of 89 upper six students, 50.6% were of high formal reasoning ability and the remaining 49.4% were of medium formal reasoning ability. There was no student categorized in the low formal reasoning ability group.

Table 4.3

Distribution of Students' Formal Reasoning Ability

Formal Reasoning Ability	Frequency (%)
High	45 (50.6)
Medium	44 (49.4)
Total	89 (100.0)

The results of this study were a bit different from the findings of Siow's (1993) and Lam's (1994) studies. In Siow's study, 24.3 % of the students were of high formal reasoning ability, while in Lam's study, only 2.2 % of the students were of high formal reasoning ability. Moreover, a total of 30.7 % and 50.3 % of the students showed medium formal reasoning ability in Siow's and Lam's studies respectively. This was reasonable as the respective form four and form five students used in Lam's and Siow's studies were younger and have not learned as much science and mathematics as the upper six students that were used as the subjects in this study.

4.2 Scoring Procedure for the UCCMT

Students' understanding of concepts in circular motion was assessed by the UCCMT which comprised 18 items.

Two formats of items were used in the UCCMT, the multiple-choice items and open-ended items. For the multiple-choice questions, the scores attained by the students were computed on the basis that one point was given to each of the following:

(a) the correct choice of alternatives, *or*

(b) the correct choice to the first part and the correct reason given to the second part of the multiple-choice questions.

For the open-ended questions, a score of one each was given for

(a) the correct answer, and

(b) the correct steps of working leading to the respective correct answer.

The item number, the score for each item and the maximum score that could be awarded to the UCCMT items were shown in Table 4.4.

Table 4.4

Item Number, Score for Each Item And Maximum Score Awarded in UCCMT

Item Number	Score Per Item	Maximum Score Awarded
1, 3, 4, 5, 7, 9, 10, 11, 12, 15, 16, 17, 18	1	13
2, 6, 8, 13, 14	2	10
	Total	23

The total score of all the 18 items obtained by each student was computed. This score was an indicator of the student's understanding of the concepts in circular motion. The higher the score, the better would be the student's understanding of the concepts in circular motion.

4.3 Formal Reasoning Ability and Students' Understanding of Concepts in Circular Motion

As noted earlier, students' formal reasoning ability in this study was classified only into the medium and the high formal reasoning ability groups. In order to answer Research Question 1, as to whether there was any significant difference between the high and medium formal reasoning ability of the students in their understanding of the concepts in circular motion, *t*-test was used.

Table 4.5

Comparison between Formal Reasoning Ability Groups on Their Understanding of Concepts in Circular Motion

	Formal Reasoning Ability		t-value	Level of Significance
	Medium (N=44)	High (N=45)		
Understanding of Concepts in Circular Motion:				
Mean	5.61	7.58	2.61*	.011
Standard Deviation	3.07	3.97		

* denotes *t*-value is significant at $p \leq 0.05$
N denotes the number of students.

The data in Table 4.5 showed that there was a significant difference in the mean scores between the high and medium formal reasoning ability students in the understanding of concepts in circular motion. The high formal reasoning ability students had a mean score of 7.58 with a standard deviation of 3.97 while the medium formal reasoning ability students had a mean score of 5.61 with a standard deviation of 3.07. The *t*-value of 2.61 was significant at $p \leq 0.05$. These results indicated that the high formal thinkers had a better understanding of the concepts in circular motion when compared to the medium formal thinkers.

The above results were consistent with the findings of studies carried out by Lawson and Renner (1975), Liberman and Hudson (1979), Champagne et al. (1980), Hofstein and Mandler (1985) and Giam (1992) where students of higher cognitive levels or higher formal reasoning abilities significantly attained better understanding of physics concepts. However, the above results contradicted the findings of studies carried out by Lew (1987) and Ng (1991) who reported that the late formal thinkers were not significantly different from the early formal thinkers in their understanding of the physics concepts.

4.4 Gender and Students' Understanding of Concepts in Circular Motion

In order to answer Research Question 2, as to whether there was any significant difference between the male and female students in their understanding of the concepts in circular motion, *t*-test was again used.

Table 4.6 showed that there was a significant difference in the mean scores between the male and female students in the understanding of the concepts in circular motion. The male students had a mean score of 7.87 with a standard deviation of 4.17 while the female students had a mean score of 5.62 with a standard deviation of 2.90. The *t*-value of 2.88 was significant at $p \leq 0.01$. The results indicated that the male students performed better in understanding the concepts of circular motion when compared to the female students.

Table 4.6

Comparison between Male and Female Students on Their Understanding of Concepts in Circular Motion

	Gender		t-value	Level of Significance
	Male (N=39)	Female (N=50)		
Understanding of Concepts in Circular Motion:				
Mean	7.87	5.62	2.88*	.005
Standard Deviation	4.17	2.90		

*denotes *t*-value is significant at $p \leq 0.01$
N denotes the number of students

These results agreed with the findings of the studies carried out by Johnson and Murphy (1984), Postlethwaite and Wiley (1991), Ng (1991) and Giam (1992) where the male students exhibited significantly better understanding of the physics concepts as compared to that of the female students. In contrast, the results contradicted the findings of the studies carried out by Lew (1987) and Klanin et al. (1989). Lew (1987) reported that gender was not a significant factor in the understanding of physics concept while Klanin et al. in their study found that their female subjects exhibited significant better performance in physics tests.

4.5 Students' Conceptions in Circular Motion

In order to identify students' conceptions in circular motion, all the students' responses to the 18 UCCMT items were analyzed.

4.5.1 Conceptions of Students in Item 1

The data in Table 4.7 showed the results of the students' responses in Item 1 in which the students needed to indicate the correct direction of the acceleration of a ball rolling down a circular portion of the track through its lowest point B. Only 11.2 % of the students indicated the correct direction of the acceleration, in the upward direction. About three-quarters of the students (74.1%) indicated misconceptions by drawing five other incorrect directions (refer to Category 4 to Category 8 in Table 4.7). A portion of the students (21.3 %) indicated the acceleration in the direction of

Table 4.7

Frequency and Percentage of Students' Responses in Item 1

Category	Responses	% (f)	Total % (f)
1.	Correct direction of acceleration drawn and correct explanation given. Acceleration directed towards the centre of circular part of the track as there existed a resultant force directed towards the centre of the circular track. The resultant force between the reaction of track to the ball and the gravitational force on the ball provided the centripetal force/acceleration for the circular motion.		0 (0)
2.	Correct direction of acceleration drawn and incomplete explanation given. The acceleration followed the direction of centripetal force that was directed towards the centre of circular track.		7.9 (7)
3.	Correct direction of acceleration drawn and no explanation given.		3.4 (3)
4.	Incorrect responses and incorrect explanations given. The direction of acceleration followed the shape of curvature or direction of motion because:		21.3 (19)
	(a) the ball acquired energy.	5.6 (5)	
	(b) the direction of acceleration was the same as the direction of motion.	11.2 (10)	
	(c) of the momentum of the ball or under the influence of gravity.	2.2 (2)	
	(d) no explanation was given.	2.2 (2)	

Table 4.7 continued

Category	Responses	% (f)	Total % (f)
5.	Incorrect response and explanation given. The direction of acceleration was tangential to the circular track because:		24.7 (22)
	(a) it followed the direction of velocity.	7.9 (7)	
	(b) there existed a force from the left.	3.4 (3)	
	(c) the ball acquired energy (potential or kinetic energy).	5.6 (5)	
	(d) the acceleration was zero or constant.	3.4 (3)	
	(e) no explanation was given.	4.5 (4)	
6.	Incorrect response and explanation given. The direction of acceleration is vertically downwards because:		13.5 (12)
	(a) of the presence of gravity.	10.1 (9)	
	(b) the ball is not moving up or down.	1.1 (1)	
	(c) the ball had less potential energy at point B.	1.1 (1)	
	(d) no explanation was given.	1.1 (1)	
7.	Incorrect response and explanation given. The acceleration of the ball was zero as:		12.4 (11)
	(a) the speed was constant or maximum.	4.5 (4)	
	(b) the inertia of the ball moved it up.	5.6 (5)	
	(c) the gravitational force did not change the velocity.	2.2 (2)	
8.	Incorrect response and explanation given. The direction of the ball was at a certain angle to the tangent of the circular path or there were two directions of the acceleration of the ball: vertical upwards and horizontal eastwards because:		2.2 (2)
	(a) the ball had maximum kinetic energy and zero potential energy.	1.1 (1)	
	(b) no explanation was given.	1.1 (1)	
9.	No indication of direction of acceleration and no explanation given.		14.6 (13)
		Total	100 (89)

Note: (f) means frequency of students' responses the motion following the curve path. Another 24.7% of them indicated the acceleration in the direction of the velocity by drawing a tangent to the curved track. Yet another group (12.4 %) of students thought that the acceleration was zero at point B while the remaining 13.5 % of the students had the incorrect idea that the acceleration was always downward, due to the gravitational force.

The students' misconceptions from Categories 5 to 8 in Table 4.7 were also reported in the study carried out by Peters (1982). Table 4.7a showed the comparison of the students' responses in this study and in Peters' (1982) study. As can be seen in Table 4.7a, a higher percentage of students in Peters' study had the correct conception (Categories 1 to 3) of the direction of acceleration of a ball rolling down a circular

Table 4.7a

Comparison between Students' Responses in This Study and Peters' (1982) Study

Category	Responses	Percentage of Students' Responses in	
		Present Study	Peters' Study
1,2 & 3	The acceleration was directed towards the centre of the circular part of the track.	11.2	36
4	The direction of acceleration followed the shape of curvature or direction of motion.	21.3	--
5	The direction of acceleration was tangential to the circular track or in the direction of velocity.	24.7	11
6	The direction of acceleration is vertically downwards.	13.5	21
7	The acceleration of the ball was zero.	12.4	19
8	The direction was at a certain angle to the tangent of the circular path.	2.2	12

-- denotes that this misconception was not reported in the study.

portion of the track through its lowest point, as compared to this study. This result was reasonable as university honor students were the subjects of Peters' study whereas in this study, pre-university students were used.

Table 4.7a also revealed that a higher percentage of students in this study had the wrong conceptions of Category 5 as compared to Peters' study. This finding was reasonable as the university students from Peters' study were used as the subjects as compared to the pre-university students used in this study.

On the other hand, students of this study indicated a lower percentage of the wrong conceptions stated in Categories 6, 7 and 8 as compared to Peters' study. Table 4.7a also revealed that Category 4 misconception, with the direction of acceleration following the shape of curvature of the circular track, was not found in Peters' (1982) study.

4.5.2 Conceptions of Students in Item 2

Table 4.8 showed the results of the students' responses in Item 2 in which the students needed to indicate the correct paths of two balls at the instant they came out of the curved tubes. About 27.0% of the students could draw the correct paths of the balls coming out of the curved tubes. However, only 4.5% of them could give the correct explanation that there was no centripetal force acting on the balls. Therefore, due to their inertia, the balls would continue in linear motion with the velocity at the point they left the tubes. The remaining 22.5% of the students gave wrong reasons for the linear directions of the paths of the balls. Their wrong explanations were either the balls followed the direction of the velocity or the balls followed the direction of

Table 4.8

Frequency and Percentage of Students' Responses in Item 2

Category & Drawing	Responses	% (f)	Total % (f)
1. 	Correct drawing of the paths of the balls at the instant they left the tubes and correct explanations given. There was no centripetal force acting, so the balls would continue to move in linear motion with the velocity at the point they left the tubes due to the inertia of the balls.		4.5 (4)
2.	Correct drawing of the paths of the balls but incorrect explanations given. The balls would continue in linear motion with the velocity at the point they left the tubes because:		22.5 (20)
	(a) they followed the directions of velocity.	5.6 (5)	
	(b) they followed the directions of the tubes at the end.	7.9 (7)	
	(c) there were forces pushing them out of the tubes.	2.2 (2)	
	(d) no explanation given.	6.7 (6)	
3. 	Wrong drawing of the paths of the balls and incorrect explanations given. The balls continued in curvilinear paths because:		29.2 (26)
	(a) the centripetal force was still acting on the balls.	18.0 (16)	
	(b) the balls followed the directions of the curved motion as there was no force acting <u>or</u> only gravitational force acting <u>or</u> only moment of inertia acting on the balls.	7.9 (7)	
	(c) the balls collided with each another.	1.1 (1)	
	(d) no explanation given.	2.2 (2)	
4. 	Wrong drawings and incorrect explanations given. Misinterpreted that the tubes were placed in vertical plane		25.8 (23)
	The balls continued in the these paths because: (a) the ball in upper tube acquired more energy /speed/ acceleration than the ball at the lower tube due to the presence of gravity.	22.5 (20)	
	(b) no explanation given.	3.4 (3)	
5. 	Wrong drawings and incorrect explanations given. The balls continued in these paths because the high speeds of the balls created a low pressure area whereby the two balls converged.		2.2 (2)
6.	No responses or unintelligible answers.		15.7 (14)
		Total	100 (89)

the tubes at the end or there existed forces (which they did not indicate what were these forces) pushing the balls out of the tubes.

About 29.2% of the students perceived that both balls would continue in curvilinear motion. They drew two diverging curvilinear paths. A portion of these students (18%) believed that the centripetal forces were still acting on the balls, thus enabling them to continue moving in the circular paths. One student (1.1%) thought that the curved paths were due to the collision of the balls at the instant they came out of the tubes. A total of seven (7.9%) students had the notion that the curved paths were due to absence of any force or the action of the gravitational force or the action of moment of inertia on the balls. Similar curvilinear paths were reported in studies carried out by McCloskey et al. (1980), Gunstone (1984) and Searle (1985) as described in Section 2.1 (page 13 to 21) of this research paper. McCloskey et al. (1980) reported approximately the same percentage (30%) of students drawing the curvilinear paths while Gunstone and Searle illustrated this belief with examples of students' responses in their qualitative analysis of their studies.

Another 25.8% of the students misunderstood that the tubes were oriented vertically. Some students in McCloskey et al.'s (1980) study and 16% of the students in Gunstone's (1984) study had the same erroneous views. The students in this study drew parabolic paths of the ball, thinking that the balls were under the influence of gravity.

Two (2.2%) of the students drew two paths that converged. They perceived that the two balls would converge after leaving the curved tubes as they thought that the tremendous high speeds of the balls coming out of the tubes would create an area of low pressure that enabled the two balls to converge.

4.5.3 Conceptions of Students in Item 3

The students' responses in Item 3 were shown in Table 4.9. Item 3 required the students to draw the path of the metal ball, spinning in a horizontal circle at the end of a string, at the point when the string broke. More than half (52.8%) of the students could draw the correct path with an arrow tangential to the point when the string broke. However, only 15.7 % of them could give correct explanations for the ball to continue to travel in the direction perpendicular to the string at the instant the string broke. These students had the correct conception that when the string broke, there was no centripetal force acting on the ball, hence it would continue to move in linear motion, with the velocity at that instant, due to its inertia. The remaining portion of the students (37.1%) thought that the ball either:

(i) followed the direction of 'a motive force' or 'acceleration' or 'velocity' that was tangential to the circle, or

(ii) it was due the torque of the revolving ball.

A total of 47.2% of the students had wrong conceptions (Categories 3 to 7) of the path of motion of the ball. Some students (9.0%) believed that the ball would continue to move in the curved path after the string broke. Another 14.6% of them perceived that the ball would follow the parabolic path. The same number of students (3.4%) believed that the balls would move out either horizontally from the point of release of the ball or in the direction of the velocity, which was at a certain angle to

Table 4.9

Frequency and Percentage of Students' Responses in Item 3

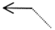
Category & Drawing	Responses	% (f)	Total % (f)
1 	Correct drawing of the path and correct explanation given. The ball moved out in the direction shown because without the presence of centripetal force, the ball would continue to move in linear motion, with the velocity at the point when the string broke, due to the inertia of the ball.		15.7 (14)
2	Correct drawing of the path but incorrect explanation given as follows:		37.1 (33)
	(a) The ball followed the direction of a motive force/linear acceleration/ tangential acceleration/angular acceleration/ velocity/tangential velocity.	32.6 (29)	
	(b) Due to the torque of the revolving ball.	1.1 (1)	
	(c) No explanation given.	3.4 (3)	
3 	Wrong drawing and explanations given. The ball would continue the curvilinear path because:		9.0 (8)
	(a) the centripetal force was still acting on the ball and this kept the ball in original path.	6.7 (6)	
	(b) of the absence of tension of the string.	1.1 (1)	
	(c) no explanation given.	1.1 (1)	
4 	Wrong drawing and explanation given. The students assumed that the ball was rotating in vertical plane, hence it would continue to move in the parabolic path because:		14.6 (13)
	(a) of the influence of gravitational force or a net force.	10.1 (9)	
	(b) the angular velocity of the ball increased, so the ball would travel in bigger circular path in order to maintain the same moment of inertia.	1.1 (1)	
	(c) unintelligible explanations.	3.4 (3)	
5a 	Wrong drawing and explanation given. The ball was moving in the direction shown :		6.7 (6)
	(a) as there was no net force acting or all the forces acting on the ball were balanced.	3.4 (3)	
5b 	(b) as there was no force acting on the ball, so it followed the direction of velocity at that point.	3.4 (3)	

Table 4.9 continued

Category & Drawing	Responses	% (f)	Total % (f)
6. 	Wrong drawing and explanation given. The ball was moving in this direction:		4.5 (4)
	(a) due to the presence of gravity or kinetic energy.	2.2 (2)	
	(b) no explanation given.	2.2 (2)	
7	No responses or unintelligible answers		12.4 (11)
		Total	100 (89)

Note : (f) means frequency of students' responses

the tangent at the point of release of the ball. A total of 4.5% of the students drew the projectile path, stating that the ball would reach a maximum height before it dropped down under the influence of gravity. The remaining 12.4% of the students either gave no responses or had unintelligible answers.

The students' misconceptions from Categories 3 to 5a of Table 4.9 were also reported in the study carried out by McCloskey et al. (1980) which has been described in Section 2.1 (page 13 to 15) of this research paper. A comparison between the students' responses in this study and in McCloskey et al.'s (1980) study was showed in Table 4.9a.

Table 4.9a showed that in McCloskey et al's (1980) study, 30% of the students drew curvilinear paths (Category 3), and 6% of them drew a horizontal path between the velocity vector and the motion produced by the supposed centrifugal force (Category 5a) after the string broke. The above percentages were higher when compared to the respective 9% and 3.4% for Categories 3 and 5a misconceptions reported in this study. A comparison between the two studies on the misconception in Category 4 could not be carried out as no quantitative data were made available in

Table 4.9a

Comparison between Students' Responses in This Study and McCloskey et al.'s (1980) Study

Category	Responses	Percentage of Students' Responses in	
		Present Study	McCloskey et al.'s Study
1 & 2	The ball moved at in the direction of the tangent at the point when the string broke.	52.8	53
3	The ball would continue the curvilinear path.	9.0	30
4	Students assumed the ball was rotating in vertical plane.	14.6	Numerical data not indicated
5a	The ball moved in a horizontal path between the velocity vector and motion produced by the supposed centrifugal force after the string broke.	3.4	6
5b	The ball moved in a path at a certain angle from the tangent at the point when the string broke but the angle was not more than or equal to that of 5(a).	3.4	--
6	The ball moved directly outward in a parabolic path.	4.5	--
	The ball would move outward in a path that continue the line of the string.	--	2

-- denotes that this misconception is not found in the study.

McCloskey et al.'s (1980) study. Table 4.9a also revealed that misconceptions in Categories 5b and 6 were not found in McCloskey et al.'s (1980) study. On the other hand, McCloskey et al. (1980) reported one student's belief not observed in this study, that was, a centrifugal force was pulling the ball outward and the string was holding the ball inward before the string broke. The student drew a path outward that continued the line of the string.

4.5.4. Conceptions of Students in Items 4 and 5

The data in Table 4.10 indicated that more than half of the students (57.3%) had the correct conception of the path of motion of a ball which was let go at certain point under the influence of gravity. The ball, attached to a light string, was swung with a high speed in a horizontal plane. These students chose the correct Option A,

Table 4.10

Frequency and Percentage of Students' Responses in Items 4 and 5

Category	Responses	% (f)	Total % (f)
1.	Correct response to Item 4 and correct responses to Item 5. Chose Option A. The speed of the ball decreased and reached zero at the maximum point and then increased when falling to the ground.		14.6 (13)
2.	Correct response to Item 4 and incorrect responses to Item 5. Chose Option A. The incorrect responses to Item 5 were:		42.7 (38)
	(a) there was a change in speed.	18.0 (16)	
	(b) vertical speed of the ball decreased and later increased while falling. The horizontal speed did not change.	7.9 (7)	
	(c) The speed was zero at maximum point and then increased while falling.	5.6 (5)	
	(d) The speed decreased or decreased till zero at maximum point and decreased further.	2.2 (2)	
	(e) No responses or unintelligible responses to Item 5.	9.0 (8)	
3.	Wrong responses to Items 4 and 5. Chose Option B in Item 4. The speed in Item 5 was:		10.1 (9)
	(a) constant.	1.1 (1)	
	(b) 'decreased'/ 'decreased till zero'/ 'decreased till maximum point and then increased'.	5.6 (5)	
	(c) increased and then decreased.	1.1 (1)	
	(d) increased.	1.1 (1)	
	(e) changing.	1.1 (1)	

Table 4.10 continued

Category	Responses	% (f)	Total % (f)
4.	Wrong responses to Items 4 and 5. Chose Option C in Item 4. The speed in Item 5 was:		18.0 (16)
	(a) constant or not changing.	4.5 (4)	
	(b) decreased or decreased till zero at maximum point.	4.5 (4)	
	(c) increased.	2.2 (2)	
	(d) constant and then decreased.	1.1 (1)	
	(e) decreased, then became zero and then increased.	1.1 (1)	
	(f) change.	2.2 (2)	
	(g) no responses.	2.2 (2)	
5.	Wrong responses to Items 4 and 5. Chose Option D in Item 4. The speed in Item 5 was:		9.0 (8)
	(a) decreased till the ball stopped.	1.1 (1)	
	(b) constant or not changing.	4.5 (4)	
	(c) decreased.	3.4 (3)	
6.	Wrong responses to Items 4 and 5. Chose Option E in Item 4. The speed in Item 5 was:		5.6 (5)
	(a) decreased or decreased till zero.	3.4 (3)	
	(b) constant.	1.1 (1)	
	(c) changing.	1.1 (1)	
	Total		100 (89)

Note : (f) means frequency of students' responses

that, indicated a parabolic path, with a highest point reached by the ball after being released from the string at certain point and falling under the influence of gravity. However, only a small number (14.6%) of the students had the correct conception of *both* the speed and path of motion of the ball. One portion of the students (18.0%) only stated that there was a change in the speed of the ball without stating what changes had occurred. Another portion of the students (7.9%) thought that the horizontal speed of the ball would not change while the vertical speed of the ball would decrease and then increase while falling. Yet a small section of the students (5.6%) thought that the speed was zero at the maximum point and then further increased while falling. The remaining responses (2.2%) were that the speed would decrease or decrease till zero at the maximum point and decrease further.

Less than half of the students (42.7%) had wrong conceptions of the path of travel of the ball. A total of 10.1 % of them chose Option B, which showed that the ball would move in an initial straight path until reaching the highest point and then falling down vertically. Moreover, 18.0% chose Option C, thinking that the ball would move in linear motion after it was released. These students did not consider the effect of gravity on the path of travel after the ball was released. Yet there were 9.0 % and 5.6 % of the students who respectively chose Option D and E. Those who chose Option D perceived that the ball would continue in the circular path after it was released. However, the students who chose Option E thought that the ball would fall down immediately after it was released. All the students who chose Options B to E gave the incorrect change of speed of the ball after it was released under the influence of gravity.

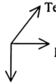
Similar conceptions of the path of motion of the ball released from circular motion and moving under the influence of gravity were reported by Halloun and Hestenes (1985b) in their qualitative analysis of the students' responses in their study.

4.5.5. Conceptions of Students in Item 6

Table 4.11 showed that only 25.8% of the students could draw all the three forces acting on the bob swinging in horizontal plane. A total of 2.2% of the students could only identify the resultant force acting on the bob. Another 5.6% of them were able to identify the tension and gravitational force acting on the bob but they

Table 4.11

Frequency and Percentage of Students' Responses in Item 6

Category	Responses	% (f)	Total % (f)
1.	Correct identification of all the forces acting on the bob swinging in a horizontal plane.  		25.8 (23)
2.	Correct identification of tension of the string and gravitational force but wrong identification of resultant force.		5.6 (5)
3.	Correct identification of the resultant force only.		2.2 (2)
4.	Wrong identification of forces in which the students identified the following combinations of forces:		48.3 (43)
	(a) regard centripetal force and resultant force as two different forces.	22.5 (20)	
	(b) there was a motive force acting besides tension, weight, resultant force or centripetal force.	4.5 (4)	
	(c) there was an outward force acting away from the centre.	10.1 (9)	
	(d) tension, weight, centripetal force but no resultant force being indicated.	5.6 (5)	
	(e) unintelligible answers given.	5.6 (5)	
5	Unlabeled wrong forces		18.0 (16)
		Total	100 (89)

Note: (f) means frequency of students' responses.

wrongly identified the resultant force. However, 22.5% of the students could not see that the centripetal force and resultant force were the *same* force as they drew the two as separate forces. A total of 10.1% of the students perceived that there was a force acting on the bob in the outward direction from the centre. A small fraction (4.5 %) of the students had the notion that there was a motive force acting on the bob. Other forces identified by the students were the normal reaction, resistance, tangential force or 'torque'.

The notions of an outward force and a motive force possessed by the students were in agreement with those reported by Gardner (1984) and Searle (1985) in their qualitative analysis of students' responses in their studies as described in Section 2.1 (page 16 to 21) of this research paper.

4.5.6 Conceptions of Students in Item 7

The data in Table 4.12 showed students' conceptions of the direction of acceleration experienced by the bob swirling in a horizontal plane. A total of 58.4 % of the student chose Option C. However, only about 14.6 % of the students had the correct conception and provided the correct explanation. They stated that the bob experienced an acceleration in the direction from P to O due to the presence of a resultant force arising from the combined effect of the tension of the string and gravitational force. A total of 25.8% of the students gave incomplete explanations to their choice. They explained the presence of a centripetal force but they did not state the nature of that force. Yet another 7.9 % of the students attributed the direction of the acceleration (from P to O) to 'the change of direction of velocity' or 'constant

Table 4.12

Frequency and Percentage of Students' Responses in Item 7

Category	Responses	% (f)	Total % (f)
1.	Correct responses and correct explanations given. Chose Option C. The bob experienced acceleration in the direction from P to O due to the presence of a resultant force (the effect of tension of the spring and gravitational force acting on the bob) that contributed to the centripetal force. The resultant force was directed from P to O.		14.6 (13)
2.	Correct responses and incomplete explanations given. The bob experienced acceleration in the direction from P to O due to centripetal force.		25.8 (23)
3.	Correct responses and incorrect explanations given. The bob experienced acceleration in the direction from P to O:		18.0 (16)
	(a) due to 'change of direction of velocity'/ 'constant angular velocity'/ 'gravity'/ 'outward resultant force'.	7.9 (7)	
	(b) as acceleration or force was needed to ensure circular motion or equilibrium.	4.5 (4)	
	(c) no explanation given.	5.6 (5)	
4.	Wrong responses and explanations given. Chose Option A. The bob experienced zero acceleration as:		19.1 (17)
	(a) there was no resultant force acting on the bob or all the forces acting on the bob were balanced.	5.6 (5)	
	(b) it was travelling in 'constant speed'/ 'constant angular acceleration'/ 'constant angular speed or velocity'.	10.1 (9)	
	(c) no explanation or unintelligible answers given.	3.4 (3)	
5.	Wrong responses and explanations given. Chose Option B. The bob experienced an acceleration in the direction from O to P:		3.4 (3)
	(a) as there was a centripetal force acting from O.	1.1 (1)	
	(b) to oppose the direction of resultant force.	2.2 (2)	
6.	Wrong responses and explanations given. Chose Option E. The bob experienced an acceleration in the direction from P to Q. No intelligible explanations given.		1.1 (1)

Table 4.12 continued

Category	Responses	% (f)	Total % (f)
7.	Wrong responses and explanations given. Chose Option D. The bob experienced an acceleration in the same direction as its velocity at P:		14.6 (13)
	(a) so that there was a presence of a resultant force enabling the bob to maintain in circular motion.	6.7 (6)	
	(b) due to the tension of string and tangential force.	2.2 (2)	
	(c) due to change of velocity.	1.1 (1)	
	(d) no explanation given.	4.5 (4)	
8.	No responses and no explanation given.		3.4 (3)
		Total	100 (89)

Note: (f) means frequency of students' responses

angular velocity' or 'gravity' or 'outward resultant force'. A small section of the students (4.5%) gave the explanation that acceleration or force was needed to ensure circular motion or equilibrium. The remaining 5.6% students did not give any explanation.

A total of 19.1% of the students chose Option A, stating that the bob experienced zero acceleration. Some 5.6% of them explained that there was no resultant force acting on it or that all the forces acting on the bob were balanced. Yet another 10.1% of them explained that the bob experienced no acceleration as it was travelling in 'constant speed' or 'constant angular acceleration' or 'constant angular speed or velocity'. The remaining 3.4% of the students did not give any explanation.

Only 3.4 % of the students chose Option B, which stated that the bob would experience an acceleration in the direction from O to P. One student (1.1%)

explained that there was a centripetal force acting from O while the remaining students (2.2%) said that the direction of acceleration was to oppose the direction of resultant force.

A total of 14.6% of the students chose Option D, which stated that the bob would experience an acceleration in the same direction as its velocity at P. Some 6.7 % of them explained that this was necessary so that there was a resultant force that enabled the bob to maintain in circular motion. The remaining students either thought that it was due to the tension of the string or the tangential force or the change of velocity or they did not give any explanation.

Only one (1.1%) students choose Option E and he did not give correct explanation.

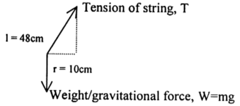
4.5.7 Conceptions of Students in Item 8

Table 4.13 showed students' conceptions in Item 8. The percentage of students that could compute correctly the tension was 42.7 %. These students could resolve the forces and calculate the value of the angle θ (or α) and thus they could get the correct answer. A portion of students (9.0%) could resolve the forces correctly but they did not use the correct SI units for the mass of the bob or they calculated wrongly the angle θ (or α). Moreover, about a third of the students (36.0%) could not compute the tension correctly as they either resolved the forces wrongly or they used wrong equations of forces or they could not calculate the value of θ (or α).

Table 4.13

Frequency and Percentage of Students' Responses in Item 8

Category	Responses	% (f)	Total % (f)
1.	Correct computation of the tension of the string. Correct steps of working and correct answers.		42.7 (38)



$T \sin \theta = mv^2/r$ or $T \sin \alpha = mg$

$T \cos \theta = mg$; $T \cos \alpha = mv^2/r$

$T = mg/ \cos \theta$; $T = mg/ \sin \alpha$

$\sin \theta = 10/48$; $\cos \alpha = 10/48$

$T= mg/ \cos(\sin^{-1} 10/48)$; $T = mg/ \sin(\cos^{-1} 10/48)$

$= 0.020 x 9.81/ \cos(\sin^{-1} 10/48)$; $=0.020 x 9.81/ \sin(\cos^{-1} 10/48)$

$= 0.20N$; $= 0.20N$

Category	Responses	% (f)	Total % (f)
2	Correct resolutions of force but		9.0 (8)
	(a) did not used the correct SI units for the mass (kg) of the bob.	7.9 (7)	
	(b) wrong calculation of the angle θ or α.	1.1 (1)	
3.	Wrong computation of the tension of the string.		36.0 (32)
	(a) Wrong resolution of forces or using wrong equation.	32.6 (29)	
	(b) Could not calculate the angle θ or α.	3.4 (3)	
4.	No responses		12.4 (11)
		Total	100 (89)

Note: (f) means frequency of students' responses

4.5.8. Conceptions of Students in Item 9

The data in Table 4.14 showed that more than half of the students (62.9%) could identify the direction of the motion experienced by the bob swinging in a horizontal plane when it was cut suddenly at point P. These students had the correct conception that the bob would move in the direction of its velocity at point P.

Table 4.14

Frequency and Percentage of Students' Responses in Item 9

Responses	Frequency	Percentage
A	3	3.4
B	2	2.2
C	4	4.5
D	23	25.8
*E	56	62.9
NS	1	1.1
Total	89	100.0

NS denotes the students did not attempt the question.
* denotes the correct response.

The data in Table 4.14 also indicated that 36.0 % of the students chose Options A to D. These students had wrong conceptions of the direction of the motion of the bob. By choosing Option D, about 25.8% of them thought that the bob would drop down vertically under the influence of gravitational force. In choosing Option A, a total of 3.4% of the students perceived that the bob would move inward to the centre of the circle while a small percentage of the students (2.2%) thought that the bob would move horizontally outward by choosing Option B. The remaining 4.5% of the students that chose Option C had the notion that the bob would move in the direction QP due to the absence of tension when the string was cut suddenly.

4.5.9 Conceptions of Students in Item 10

Table 4.15 showed the students' responses in Item 10. In general, the students had a poor conception of the force acting on the Moon as only 6.7 % of them could identify correctly the nature and direction of the force acting on the Moon. About 16.9 % of the students did not give a complete answer by not stating the nature of the force. They just stated that a centripetal force was acting on the Moon. This partial or incorrect conception of centripetal force was also reported in the findings of the studies carried out by Warren (1979) and Gardner (1984) as described in Section 2.1 (page 12 to 19) of this research paper.

The percentage of students having the conception that centripetal force and gravity were two different forces was 7.9%. This finding concurred with that of Whiteley (1995) who reported that some of the 58 students of his study had the similar notion that the centripetal force and gravity were two different forces.

Another 28.1% of the students believed that a motive force (Categories 3(b) and 4(b) of Table 4.15) was needed for the Moon to orbit around Jupiter. The motive force carried names such as velocity, accelerating force, etc when it appeared on diagrams. This Motive Force Framework was also reported in studies carried out by Gunstone (1984) and Gardner (1984) as described in Section 2.1 (page 16 to 19) of this research paper. Gunstone reported a higher percentage (84%) of students having

Table 4.15

Frequency and Percentage of Students' Responses in Item 10

Category	Responses	% (f)	Total % (f)
1.	Correct identification of the force and its direction acting on the Moon of Jupiter. The force acting on the Moon was the gravitational pull of the planet acting on the Moon and was directed towards the centre of Jupiter.		6.7 (6)
2.	Incomplete identification of force. The force acting on the Moon was the centripetal force (nature of force not identified).		16.9 (15)
3.	Wrong identification of forces in which the students identified one or two wrong forces.		53.9 (48)
	(a) centripetal force and gravity towards the centre of Jupiter	7.9 (7)	
	(b) c.f./gravity and motive force	23.6 (21)	
	(c) c.f./gravity and weight	12.4 (11)	
	(d) two opposite attractive forces between Moon and Jupiter	5.6 (5)	
	(e) c.f./gravity and outward force in term of normal reaction	4.5 (4)	
4.	Wrong identification of forces in which the students identified 3 wrong forces.		12.4 (11)
	(a) c.f., weight of moon and outward force in terms of 'normal reaction' or 'gravitational field' or 'repulsive force'	4.5 (4)	
	(b) motive force in terms of 'velocity' or 'accelerating force' and tension or weight or c.f. or resultant force	4.5 (4)	
	(c) c.f., tension and weight	1.1 (1)	
	(d) gravity, outward force in term of 'normal reaction' and motive force in terms of 'velocity'*	2.2 (2)	
5.	No responses or unlabeled forces or unintelligible answers		10.1 (9)
		Total	100 (89)

Note: (f) means frequency of the students' responses.

* denotes 2 students showed both outward force and motive force.

the Motive Force Framework as compared to 28.1% of the students manifesting the misconception in this study. This finding was reasonable as younger students who had learned less physics were used in Gunstone's study when compared to the pre-university students used in this study. However no quantitative data were reported in Gardner's study on the motive force.

An outward force was indicated by 9.0% of the students shown in Categories 3(e) and 4(a) of Table 4.15. The outward force was shown in diagrams as repulsive force, normal reaction or gravitational field. An outward force in the form of centrifugal force or reaction was reported in the studies carried out by Gunstone (1984) and Whiteley (1995). Gunstone (1984) reported 12% of his sample indicating an outward force and this percentage was a bit higher when compared to the result of this study. Whiteley (1995) reported 5.2% of his sample indicating such an outward force and his percentage was lower when compared to the finding of the present study.

The remaining students either identified wrongly one or more forces like weight or/and tension or/and centripetal force or as forces acting on the Moon.

4.5.10 Conceptions of Students in Item 11

Table 4.16 indicated that only 5.6% of the students could give the correct response and explanation in Item 11. These students could identify the gravitational pull of Jupiter acting on the Moon which was directed towards the centre of Jupiter. A total of 20.2% of the students chose the correct Option C but gave incorrect or incomplete explanations. Some 4.5% of the students perceived an imbalance between

Table 4.16

Frequency and Percentage of Students' Responses in Item 11

Category	Responses	% (f)	Total % (f)
1.	Correct response and correct explanation given. The force acting on the Moon was not zero and was in certain direction because there was an attractive gravitational force of the planet acting on the Moon and was directed towards the centre of Jupiter.		5.6 (5)
2.	Correct response and incorrect explanations given.		20.2 (18)
	(a) There was an imbalance between the centripetal force (c.f.) and another force (e.g. gravitational force) that enabled the Moon to circle around Jupiter.	4.5 (4)	
	(b) 'An attractive force between planet and Moon supplied c.f.'/ 'the system of the pendulum had c.f.' / 'there was a force acting on the Moon directed towards Jupiter'.	11.2 (10)	
	(c) Presence of force was needed to ensure motion.	4.5 (4)	
3.	Incorrect responses and explanations given. Responses to Option B: The force acting on the Moon was not zero and was in the direction of the motion.		42.7 (38)
	(a) 'A force was needed to move in circular motion and in the direction of circular path'/ 'a force was needed to maintain in the circular path.'	34.8 (31)	
	(b) There was a change in the velocity or acceleration, hence the force was not zero.	5.6 (5)	
	(c) 'The gravitational force'/ 'c.f.' was needed in the direction of motion to enable it to travel in a circle.	2.2 (2)	
4.	Incorrect responses and explanations given. Responses to Option A: No force was acting on the Moon. (a) The Moon was travelling or orbiting with constant velocity or same circular path, so no force was needed or the forces acting on the Moon were balanced.		21.3 (19)
5.	Incorrect responses with no explanation given.		10.1 (9)
		Total	100 (89)

Note : (f) means frequency of students' responses.
c.f. means the centripetal force.

the centripetal force and gravitational force that enabled the Moon to circle around Jupiter while the same percentage of students thought that forces should be present to ensure the motion of Moon around Jupiter. Another section (11.2 %) of the students had the wrong conceptions that 'an attractive force between the planet and Moon supplied the centripetal force,' or 'the system of the pendulum had centripetal force,' or 'there was a force acting on the Moon directed towards Jupiter'.

A total of 64.0% of the students had wrong conceptions (Categories 3 & 4) of the force and its direction acting on the Moon. In choosing Option B, about 42.7% of the students had the conception that the force acting on the Moon was in the direction of the motion. They gave either one of the following reasons:

(a) a force was needed in the direction of motion to enable it to travel in circle,

(b) a force was needed to maintain the circular path,

(c) there was a change of velocity or acceleration, thus the force should not be zero, and

(d) there existed a gravitational force or centripetal force in the direction of motion to enable the Moon to travel in circular orbit.

Similar reasons as the above listed reasons (a) to (b) were also reported in Gunstone's (1984) study carried out on Australian students as described in Section 2.1 (page 19) of this project paper.

The remaining 21.3% of the students chose Option A, which stated that there was no force acting on the Moon. They thought that the Moon was travelling in constant velocity or same circular path. Thus no force was needed or all forces acting on the Moon were balanced. The above conception fit in with the Equilibrium Framework Type 1 – Absence of Radial Forces as reported by Gardner (1984) in his qualitative analysis of the students' responses in his study. This Framework was described in Section 2.1 (page 17) of this research paper.

4.5.11 Conceptions of Students in Item 12

Table 4.17 showed that 59.6 % of the students had the correct idea that the angular speed of a satellite should be the same as that of the Earth when it was moving in synchrony with the Earth. However, about 22.5 % of the students had misconceptions by choosing Options A, C, and D. There were respectively 5.6% and 3.4% of the students having the view that the velocity (or speed) of the satellite

Table 4.17

Frequency and Percentage of Students' Responses in Item 12

Responses	Frequency	Percentage
A	3	3.4
*B	53	59.6
C	5	5.6
D	12	13.5
E	14	15.7
NS	2	2.2
Total	89	100.0

NS denotes the students did not attempt the question.
* denotes the correct response.

should be the same as the Earth's if they were moving in synchrony. Moreover, about 13.5 % of the students had the notion that the angular acceleration of the satellite should be the same as that of the Earth. The remaining 17.9 % of students either stated that there were no answers provided in the item by choosing Option E or they did not attempt the question.

4.5.12 Conceptions of Students in Item 13

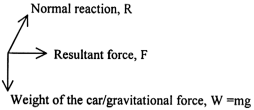
Table 4.18 showed the students' conceptions in Item 13. The data from Table 4.18 indicated that the students had a poor conception of the forces acting on the car that was travelling on a banked circular track. Only 9.0% of them could label and indicate the correct directions of the normal reaction, gravitational force and the resultant force acting on the car. A small portion of the students (11.2%) could draw and label the normal reaction and gravitational force but they wrongly indicated the direction of the resultant force. Only a small portion of the students (3.4%) could indicate the correct direction of the resultant force, but they indicated wrongly the normal reaction and gravitational force.

A total of 55.1 % of the students, who responded to Item 13, had wrong conceptions of forces acting on the car. Some of the students (18.0%) perceived that the resultant force and circular force were two different forces in the context of the problem. A portion of these students (13.5%) thought that there was a motive force acting on the car in addition to 'the normal reaction, gravitational force and resistance' or 'centripetal force' or 'resultant force'. This belief was reported in study carried out by Warren (1971) as described in Section 2.1 (page 12) of this research

Table 4.18

Frequency and Percentage of Students' Responses in Item 13

Category	Responses	% (f)	Total % (f)
1.	Correct drawings and labels of normal reaction and weight of the car/ gravitational force and resultant forces acting on the car travelling in banked circular track.		9.0 (8)



2.	Correct drawings and labels of normal reaction and weight of the car/ gravitational force acting on the car but wrong indication of resultant force acting on the car.		11.2 (10)
3.	Correct drawings and labels of resultant force acting on the car and wrong labels or directions indicated either for normal reaction or weight of the car.		3.4 (3)
4.	Wrong drawings or labels of forces acting on the car travelling on a banked circular track by :		55.1 (49)
	(a) drawing multiple normal reactions acting on the car, thus not regarding the car as a point mass.	5.6 (5)	
	(b) drawing an outward force.	1.1 (1)	
	(c) drawing a motive force in addition to R, mg, 'resistance'/ 'centripetal force'/ 'resultant force'	13.5 (12)	
	(d) indicating a single centripetal force acting in the direction of the incline plane.	6.7 (6)	
	(e) regarding the centripetal force and resultant force as two different forces acting on the car.	18.0 (16)	
	(f) drawing a combination of wrong forces in terms of resistance, weight of the car, normal reaction, resultant force or centripetal force.	10.1 (9)	
5.	No responses or unlabeled drawings		21.3 (19)
		Total	100 (89)

Note : (f) means frequency of students' responses paper. However, the percentage of the students having this motive force was low when compared to the 40% reported in Warren's study. The remaining students had the following misconceptions:

(a) the car was not regarded as a point mass since the students drew multiple normal reactions acting on the car. This problem was not so serious as only 5.6% of the students in this study had this misconception as compared to 76% reported in Gunstone's (1984) study.

(b) an outward force acting on the car travelling on a banked circular road. Only 1.1 % of the students in this study had this misconception and this was low when compared to the study carried out by Warren (1971) who reported that 14% of his subjects having this conception of an outward force.

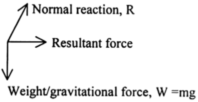
(c) the car travelling on a banked circular track was acted by a combination of the following forces: resistance, gravitational force, normal reaction, and resultant force or centripetal force.

4.5.13 Conceptions of Students in Item 14

Table 4.19 showed that the students were very poor in computing the safe speed for the car to travel in a circular track without slipping. Only 7.9% of the students could compute the safe speed of the car travelling in a circular track without slipping. A total of 66.3% of the students either did not attempt the question or gave unintelligible answers not related to the question. Moreover, 18.0% of the students could not identify the correct forces or could not resolve them correctly. Yet another 3.4% of the students did not regard the car as point mass by indicating two or more

Table 4.19

Frequency and Percentage of Students' Responses in Item 14

Category	Responses	% (f)	Total % (f)
1.	Correct computation of the safe speed of the car travelling in a circular track without slipping. Correct steps of working and correct answers.  $R \sin\theta = mv^2/r$ $R \cos\theta = mg$ $\tan\theta = v^2/rg$ $v^2 = rg \tan\theta$		7.9 (7)
2.	Wrong computation of the safe speed of the car arising from		25.8 (23)
	(a) resolving the forces wrongly or identify forces wrongly.	18.0 (16)	
	(b) not regarding the car as point mass, thus indicating 2 or more reaction forces which were conceptually wrong.	3.4 (3)	
	(c) regarding the car as if it was moving in vertical plane.	4.5 (4)	
3.	No responses and not intelligible answers.		66.3 (59)
		Total	100 (89)

Note : (f) means frequency of students' responses

reaction forces acting on the car. This problem was also found in Gunstone's (1984) study as described in Section 2.1 (page 19) of this research paper. The above misconceptions had contributed to the wrong computation of the safe speed of the car travelling in a circular track without slipping. A small number (4.5%) of the students regarded the car as if it was moving in a vertical plane. Hence they resolved the forces incorrectly or used the wrong equation of forces.

4.5.14 Conceptions of Students in Item 15

Table 4.20 presented the results of the students' responses in Item 15. The table shown that 41.6 % of the students could identify correctly the relationship of time traveled by the cars around one complete circle with angular speeds. Thus they could correctly compute the ratio of the angular speeds between the two cars. Some of the students who chose Option D probably believed that the speeds of the cars were the same while those who chose Option E probably had the wrong concepts of ratio and thought that the speeds of the cars were the same.

Table 4.20

Frequency and Percentage of Students' Responses in Item 15

Responses	Frequency	Percentage
*A	37	41.6
B	3	3.4
C	4	4.5
D	25	28.1
E	19	21.3
NS	1	1.1
Total	89	100.0

NS denotes the students did not attempt the question.
* denotes the best response.

4.5.15 Conceptions of Students in Item 16

The data in Table 4.21 indicated that 60.7% of the students could compute the ratio of the speeds of the two cars travelling in circular paths. Other students who could not compute correctly may be due to their wrong conceptions of ratio and the wrong assumption that the speeds for both cars were the same.

Table 4.21

Frequency and Percentage of Students' Responses in Item 16

Responses	Frequency	Percentage
A	6	6.7
B	7	7.9
C	10	11.2
*D	54	60.7
E	11	12.4
NS	1	1.1
Total	89	100.0

NS denotes the students did not attempt the question.
* denotes the correct response.

4.5.16 Conception of Students in Item 17

Table 4.22 showed that about half of the students could compute the ratio of the centripetal acceleration between two cars racing in the circular tracks. Some of the students probably had the wrong conceptions believing that the centripetal accelerations were the same as the radial accelerations. So when angular speeds and periods were the same, they perceived that centripetal or radial accelerations should be the same.

Table 4.22

Frequency and Percentage of Students' Responses in Item 17

Responses	Frequency	Percentage
A	12	13.5
B	12	13.5
C	7	7.9
*D	44	49.4
E	11	12.4
NS	3	3.4
Total	89	100.0

NS denotes the students did not attempt the question.
* denotes the correct response.

4.5.17 Conceptions of Students in Item 18

The data in Table 4.23 showed that 62.9% of the students could compute the ratio of the centripetal forces acting on the two cars travelling in circular tracks. Some of the students (20.2%) probably had the notion that the speeds of the cars were the same, hence they chose the wrong Option C.

Table 4.23

Frequency and Percentage of Students' Responses to Item 18

Responses	Frequency	Percentage
A	6	6.7
*B	56	62.9
C	18	20.2
D	4	4.5
E	2	2.2
NS	3	3.4
Total	89	100.0

NS denotes the students did not attempt the question.
* denotes the correct response

4.6 Students' Recurring Misconceptions in Circular Motion

In order to answer Research Question 3 (What were the students' recurring misconceptions in circular motion, regardless of students' gender and formal reasoning ability?), the students' conceptions, which were reported in Section 4.5, were further examined to see whether there were any recurring misconceptions in different UCCMT items. The following six main recurring misconceptions, shown in Table 4.24, were identified:

(1) Misconceptions that objects would continue to travel in curvilinear paths in the absence of centripetal force. These erroneous views were considered to be reminiscent of the medieval impetus theory as reported in

McCloskey et al.'s (1980) study. In this study, these misconceptions were shown in Items 2 and 3.

(2) Misinterpretations of diagrams in perceiving objects in horizontal plane as vertically placed. The students showed this weakness in interpreting diagrams in both Items 2 and 3. Similar misinterpretations were reported in studies carried out by Gunstone (1984) and McCloskey et al. (1980) to the respective Australian and American students.

(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 Items 6, 10 and 13. Similar erroneous conception was reported in the study carried out by Whiteley (1995).

(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 Items 6, 10 and 13 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. Similar misconceptions were reported in studies carried out by Warren (1979), Gunstone (1984), Gardner (1984) and Searle (1985).

Table 4.24

Students' Recurring Misconceptions Identified from Their Responses in UCCMT

Misconceptions	Item No.	Percentage of Students Having Misconceptions
Perceived an object would continue to travel in curvilinear path in the absence of centripetal force.	2	29.2
	3	9.0
Misinterpreted diagrams in horizontal plane as vertically placed.	2	25.8
	3	14.6
Regarded centripetal force and resultant force (e.g. gravitational force) acting on an object as two different forces.	6	22.5
	10	7.9
	13	18.0
Perceived a motive force acting on a body in motion.	6	4.5
	10	28.1
	13	13.5
Perceived that an outward force acting on a body in motion.	6	10.1
	10	9.0
	13	1.1
Did not regard the object as point mass by drawing multiple forces acting.	13	5.6
	14	3.4

(5) The misconception that an outward force acted on a body in circular motion. The students showed this wrong conception in Items 6, 10 and 13. Students in studies carried out by Warren (1979), McCloskey et al. (1980) and Gunstone (1984) showed similar misconceptions.

(6) Did not regard an object as a point mass by drawing multiple forces or normal reactions. The students showed this wrong conception in Items 13 and 14, which resulted in their wrong computation of the safe speed of the car travelling in a circular track. The students in Gunstone's (1984) study also manifested this erroneous view.

4.7 Students' Common Misconceptions in Circular Motion

In order to answer Research Question 4 (What were the students' common misconceptions in circular motion, regardless of students' gender and formal reasoning ability?), 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 18 UCCMT items, described in Section 4.5 of this study. The common misconceptions, together with the percentages of students having the misconceptions, were shown in Table 4.25.

As shown in Table 4.25, the misconception held by the highest percentage of students was extracted from Item 11. 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 Item 11, 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. This Framework was described in Section 2.1 (page 17) of this research paper.

In Item 1, a total of 24.7% of the students perceived that the direction of acceleration of a ball rolling through the lowest point of a circular track was tangential to the circular track or in the direction of velocity. Peters (1982) also observed this misconception in his study of university honor students. Moreover, in Item 1, a total of 21.3 % of the students also held the erroneous view that the direction of acceleration of the ball followed the shape of curvature or the direction of motion.

In Item 2, 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) as described in Section 2.1 (page 13 to 21) of this research paper. McCloskey et al. (1980) found approximately the same percentage (30%) of students drawing similar curvilinear paths. In addition, in Item 2, 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 Item 6, 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.

Table 4.25

Students' Common Misconceptions Identified from Their Responses in UCCMT

Item Number	Misconceptions Involved	Percentage of Students Having Misconception
1	(a) Perceived the direction of acceleration of the ball at the lowest point of a circular track was tangential to the circular track or in the direction of velocity.	24.7
	(b) Perceived the direction of acceleration of the ball at the lowest point of a circular track followed the shape of curvature or direction of motion.	21.3
2	(a) Perceived the balls would continue to move in curvilinear paths after leaving the double C-shaped tubes.	29.2
	(b) Perceived the double C-shaped tubes were placed in vertical plane	25.8
6	Regarded centripetal force and resultant force as two different forces acting on the bob.	22.5
8	Wrong resolution of forces or using wrong equations for the computation of the tension of the string with a bob tied to one end of the string.	32.6
9	Perceived that for a bob swinging in a horizontal plane, at the instant that the bob was cut suddenly, it would drop down vertically under the influence of gravitational force.	25.8
10	Perceived there was a motive force acting on the Moon of Jupiter.	28.1
11	(a) Perceived the force acting on the Moon was not zero and in the direction of the motion.	42.7
	(b) Perceived the force acting on the Moon was zero.	21.3
15	(a) Perceived the ratio of angular speeds between two cars travelling in circular tracks as $r_1 : r_2$	28.1
	(b) Perceived the ratio of angular speeds between two cars travelling in circular tracks as $r_2 : r_1$	21.3
18	Perceived the ratio of the centripetal forces acting on two cars travelling in circular tracks as $m_1 r_2 : m_2 r_1$	20.2

In Item 8, a total of 32.6 % of the students could not resolve the forces correctly or could not write correct equations of forces in order to compute the tension of the string, with a bob tied to one end of the string.

In Item 9, a total of 25.8 % of the students had the wrong conception that for a bob swinging in a horizontal plane, it would drop down vertically under the influence of gravitational force at the instant the string was cut suddenly.

In Item 10, a total of 28.1% of the students had the wrong conception that there was a motive force acting on the Moon of Jupiter. This Motive Force Framework was also found in studies carried out by Gunstone (1984) and Gardner (1984) as reported in Section 2.1 (page 16 to 19) of this research paper. 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.

In Item 15, a total of 28.1% of the students wrongly perceived the ratio of the angular speeds of the two cars travelling in circular tracks as $r_1 : r_2$. In addition, a total of 21.3 % of the students had the misconception that the ratio of the angular speeds was $r_2 : r_1$.

The common misconception that was possessed by the lowest percentage (20.2%) of the students was found in Item 18. The students wrongly perceived the ratio of the centripetal forces acting on the two cars travelling in circular tracks as $m_1 r_2 : m_2 r_1$.