Chapter II

REVIEW OF RELATED LITERATURE

2.0 Introduction

The purpose of this study was to examine upper six physics students' understanding of concepts in circular motion as well as their misconceptions. The study also sought to establish its relationships between students' understanding of concepts in circular motion and their gender and formal reasoning ability. Therefore, this chapter would review literature covering three areas of research related to the study:

(i) Students' conceptions in circular motion

(ii) Gender and physics achievement

(iii) Formal reasoning ability and science achievement

2.1 Students' Conceptions in Circular Motion

Studies have shown that many students including those at the tertiary level encountered difficulties in understanding the concepts of circular motion. Using questionnaire administered to a sample of 68 high school physics teachers, Finley, Stewart and Yarroch (1982) found that circular motion was the most difficult concept for students even though it was not one of the 15 most important topics listed by the teachers. Salvage and William (1989) credited some of the students'confusions to the introduction of centrifugal force.

Warren (1971) had asked 148 English university entrants in engineering and science to draw an arrow showing the resultant force acting on a car travelling at constant speed along a horizontal, circular road. About 40 % of the students indicated the resultant force in the direction of the motion, which was tangential and in forward direction. Moreover about 26 % of the students showed the resultant force to be radial and inward while 14 % showed the resultant force to be radial and outward. Warren (1979) attributed the outward radial force to the students' misunderstanding of Newton's Third Law. He also reported that some students described the centripetal force on a satellite as equal to the gravitational force, implying a belief that these were two different forces.

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

In the United States of America, McCloskey, Caramazza and Green (1980) asked 50 undergraduate students at John Hopkins University to sketch the subsequent paths of a moving ball emerging from a simple C-shaped tube, a double C-shaped tubes and a spiral tube. The students were also asked to describe the path of a pendulum bob cut from its string at a certain point of circular motion. A total of 36 % of the paths drawn by the students were of curvilinear paths. More specifically, for the spiral tube problem, 51 % of the students thought that the ball would follow a curved path after emerging from the tube. For the simple C-shaped and double C-shaped tubes, the curved paths drawn constituted respectively 33% and 30 % of the sample. Similarly, about 30% of the students believed that the ball would continue to follow a curved path after the string broke. McClockey et al. (1980) stated that the above students' beliefs were reminiscent of the medieval theory of impetus. This impetus theory had the perspective that an object moving through a curved tube (or otherwise forced to travel in a curved path) acquired a "force" or "momentum" that caused it to continue in curvilinear motion for sometimes after emerging from the tube. However, the force or momentum eventually dissipated and the object's trajectory gradually became straight. McCloskey and Kohl (1983) specifically called this naïve physics belief as the curvilinear impetus principle.

Moreover, McCloskey et al. also reported two other misconceptions in the ball and string problem. A total of 6% of the students believed that the ball would follow a straight path that continued the line formed by the string at the point at which it broke. These students believed that a centrifugal force was pulling the ball outward but the string was holding the ball inward. Thus, when the string broke, the centrifugal force pushed the ball outward, causing it to follow a path that continued along the line of the string. Another 6% of the students thought that the ball would travel in a straight line oriented approximately midway between the path the ball would actually follow and the path along the line of the string. These students believed that both the centrifugal force and instantaneous velocity of the ball, at the point where the string broke, would influence the path of motion. Thus, the motion of the ball was seen as a compromise between the motion in the direction of the velocity vector and the motion produced by the supposed centrifugal force.

In South Africa, Helm (1980) conducted a misconception test to 460 grades 9 and 10 physics or physical science students and 65 science teachers. He reported that for a stone tied to the end of a string swung around in a vertical circle, only 11% of the students and 29% of the teachers had the correct conceptions. At the top most point of the stone's position, only the Earth's gravitational force and the downward pull of the string acted on the stone. However, 33% of the students and 20% of the teachers had the conception of the centripetal force acting on the stone besides the Earth's gravitational force and the downward pull of the string. Moreover, 28% of the students and 31% of the teachers stated centrifugal force as one of the forces acting on the stone, besides the Earth's gravitational force and the downward pull of the string. Helm ascribed these misconceptions arising from the erroneous presentation in textbooks or classroom treatments of the topic.

Peters (1982) investigated conceptual difficulties faced by physics students in introductory honors physics course for the classes in 1979 and 1980. One of the questions requested the students to indicate the direction of the acceleration of a ball at the lowest point of the circular portion of a track. The ball, releasing from rest, was rolling down an incline, bottoming out in the circular portion of the track, rolling up the other incline, going off the end of the track, reaching a maximum height after leaving the track, and finally falling down. Peters (1982) reported that in 1979, only 21% of the students indicated the correct direction of the acceleration whereas in 1980, this percentage rose to 36%. A large number of students (37% in 1979 and 21%

in 1980) thought that the acceleration was downwards. Peters ascribed the downward direction to the centrifugal effect of the outward direction of the acceleration in the circular motion. Moreover a substantial fraction of the students (24% in 1979 and 19% in 1980) responded that the acceleration was zero at the lowest point of the circular track, thinking that the speed was maximum at that point. Another group (16% in 1979 and 11% in 1980) indicated that the acceleration was in the direction of the velocity while the remaining students (3% in 1979 and 13% in 1980) assigned directions that were neither vertical nor horizontal but at some angle to these axes.

In Australia, Gunstone (1984) and Gardner (1984) respectively investigated the students' pre- and post-instructional alternative frameworks in circular motion using the same paper and pencil test. In Gardner's (1984) study, the test was administered to 23 seventeen years old physics students who had completed a study of circular motion while Gunstone (1984) administered the test to 67 fifteen years old general science students. Among the questions in the test were:

(1) a number of questions concerned with drawings of objects in circular motion;

(2) questions which asked for labeled arrows to indicate the forces acting on objects;

(3) questions which asked if the total force was zero, or not zero in the direction of motion, or not zero in some other directions; and

(4) questions which asked for an explanation of their answers.

In the same test, the following four situations of circular motion were asked:

(1) a car travelling at constant speed around a circular curve,

(2) a passenger in the car travelling in a circular road,

(3) a tin, attached by a string to a peg at the centre of a smooth table, revolving on the top of a smooth table.

(4) a moon of Jupiter.

From the analysis of the students' responses, Gardner (1984) listed six alternative conceptual frameworks that the students used to account for the dynamics of circular motion. The frameworks were:

(1) The 'Correct' or 'Scientific' Framework whereby the students offered consistent Newtonian explanations of circular motion. The students could identify correctly both the direction and the nature of the force causing circular motion.

(2) Partial Newtonian Framework whereby the students offered Newtonian explanation but failed to explain the physical nature of the force. They might have recognized that an unbalanced, centripetal force was acting but they did not describe the nature of that force.

(3) The Motive Force Framework whereby the students had a naïve belief that forces were required to cause and maintain motion: ' If a body is moving, there is a force acting upon it in the direction of the movement'. This idea conveyed the Aristotelian theory of motion that forward motion required a forward force.

(4) The Equilibrium Framework Type I – Absence of Radial Forces whereby the students regarded circular motion as a phenomenon in which the moving object was in some kind of balance or equilibrium. The students

treated circular motion at constant speed as rectilinear motion at constant speed. All references to radial forces were avoided as if the constant speed of the object was the dominant characteristic and the changing direction of circular motion was not a phenomenon requiring a dynamic explanation.

(5) The Equilibrium Framework Type II – Two Counter-Balancing Radial Forces in which the students' explanations postulated a balance between a centripetal force and an equal and opposite centrifugal force. These explanations stemmed from the attempts made by the students to integrate the new knowledge (a centripetal force acting on a revolving body) with a firmly held prior belief in equilibrium.

(6) Inconsistent Newtonian and Non-Newtonian Frameworks whereby the students' responses showed evidence of inconsistent frameworks: The students might respond to one question showing understanding of Newtonian ideas but when a slightly different question was asked, the students showed an abiding belief in equilibrium which was a non-Newtonian idea.

It should be noted that in Gardner's study involving 23 students, only qualitative analysis with examples from the students' responses to illustrate all the above frameworks were described generally. However, for the Correct Newtonian Framework, he reported that two out of the 23 students showed this framework.

Gardner (1984) also identified the rationales of some of the above alternative frameworks. Two beliefs held by the students who adopted an equilibrium frameworks were: (1) Constant speed implied no acceleration and hence zero force;

(2) A force was required to hold a revolving object at a fixed distance from the centre. Gardner (1984) also argued that an equilibrium framework adopted by the students might be due the misuse of the action-reaction principle stated in the Newton's Third Law of Motion.

Gunstone (1984) reported that a total of 84% of the students indicated the Motive-Force Framework while 12% of the students showed a form of centrifugal force concept. For a ball rolling into a horizontal pipe of 90° curve and coming out of it, he reported that a total of 15% of the students showed the impetus belief. For the ball rolling into a pipe of 270° curve, a total of 47% of the students showed the impetus belief. Gunstone (1984) also revealed the following conceptions in his findings:

(1) A total of 69% of the students regarded gravity as a push rather than a pull.

(2) By drawing multiple arrows to indicate the directions of forces acting on an object, more than three-quarters (76%) of the students did not regard the object as a point mass.

(3) A total of 13% of the students regarded the 'zero total force' as "nothing at all".

(4) The students were unable to interpret the diagrams presented in the test. A total of 16% of the students interpreted the curved pipes on a table top in two of the questions as vertically placed.

Similarly, Searle (1985) conducted a specific analysis of circular concepts of tertiary students. He administered a test that contained seven questions of the DOE

(Demonstrate, Observe and Explain) type. The test was designed to investigate the following misconceptions in classical mechanics:

(i) motion implied force belief,

(ii) the impetus theory, and

(iii) the commonly held view that an outward centrifugal force acted on objects moving in a circle.

The subjects were 19 first-year engineering male students, with ages ranging from 18 to 30 years old and with an average age of 21 years old. The results of Searle's study showed the following misconceptions and frameworks held by the students:

(i) displacement implied a force,

(ii) equilibrium framework whereby the net force acting on the mass was zero,

(iii) motion implied force,

(iv) impetus theory,

(v) the partial intuitive science and partial formal science frameworks, and

(vi) the resultant force misconception whereby the students added the vectors of the outward force and the weight, but ignored the tension on an object hanging from the string. The resultant force was often drawn by the students as being opposite to the direction to the tension, with the implication that the net force of the resultant force and the tension was zero. In this context, the students perceived the mass as being in equilibrium.

It should be noted that only qualitative analysis with examples to illustrate the different frameworks and misconceptions were reported by Searle in his study. There were no quantitative data given for the frameworks and misconceptions held by the students.

Moreover, Halloun and Hestenes (1985b) in his survey investigated the common sense concepts about motion of a group of 478 students in university physics. They used a diagnostic test consisting of multiple-choice questions. An example of a question from their test was shown in Item 4 of UCCMT (see Appendix A). Item 4 required the students to draw the path of motion of a ball in the absence of centripetal force, and in the presence of gravitational force. The multiple-choice alternatives to a number of the questions were classified as manifesting characteristics of either Aristotelian, or Impetus, or Newtonian theories. Halloun and Hestenes reported that the prestest responses to the diagnostic test could be classified as predominantly Aristotelian for 18% of the students, predominantly the Impetus type for 65% of the students, and predominantly Newtonian for the remaining 17%. Moreover, they also reported that nearly every student used some mixture of concepts from the three theories, and appeared to be inconsistent in applying the same concept in different situations.

Halloun and Hestenes (1985b) did not report any other quantitative data of the students' performance in the diagnostic test. From the students' responses, they illustrated their qualitative analysis of the test with examples of specific common sense concepts about motion.

Similarly, in Jamaica, Whiteley (1995) asked 115 upper six students of advanced level physics to give a 'reasonable one-word answer' to the question: "What hold up the Moon?" He grouped the students' answers into the following eight categories (the number in the parenthesis indicated the percentage of students' responses):

(1) gravity (31.3 %),

(2) centripetal force (19.1%),

(3) nothing (13.9%),

(4) forces (11.3%),

(5) centrifugal force/reaction (5.2%),

(6) attraction/Mars (5.2%),

(7) humorous (8.7%), and

(8) various other (5.2%).

The 'various other' category included acceleration, angular acceleration, velocity and momentum and the 'humorous' category included glue, rope and God. Some of the 58 students who had answered in the 'gravity' or 'centripetal force' categories indicated that they actually believed in two forces (gravity and centripetal force) rather than recognizing that gravity was the centripetal force that held up the Moon. A small number (6) of students had the belief that a balancing force was needed to counter the attraction of the Earth for the Moon by identifying the attraction of other planets such as Mars or an outward centrifugal force in order to balance the gravity.

Locally, Lim (1976) investigated the effect of inductive or deductive approaches in the teaching of two topics from Nuffield-based Modern Physics. The two topics: the uses of radioisotopes and derivation of equations in circular motion were chosen. The subjects of his study were 36 student teachers enrolled in the Physics Methodology Course of the postgraduate of Diploma of Education programme. The student teachers were given similar training in questioning techniques and were matched on two premeasures – critical thinking and knowledge of science processes. The teachers were then randomly assigned to teach 1189 form four science students, following either one of the two experimental instructional approaches (inductive or deductive). These students came from six girl schools and nine boy schools. The experimental design was the pretest-posttest-control group design, where the control group was one the treatments itself. The effects of the two teaching approaches on the students were measured by comparing the students' scores in the physics achievement posttests on the two topics. In the physics achievement test, half of the questions were concerned with the understanding of the concepts of circular motion and the another half dealt with the uses of radioisotopes. Lim (1976) reported only the mean scores obtained by the students in the pre- and post- achievement tests in physics. Calculating the percentages of the mean scores and comparing them to the total achievement score, the present researcher found that the students obtained less than 17% of the total score in the physics achievement pretest and less than 37% of the total score of the physics achievement posttest. From the above calculated values, it could be concluded that the students had little prior knowledge of the two content areas and quite a low level of knowledge acquisition concerning uses of radioisotopes and circular motion even after implementing the two approaches of instruction. The above calculated value could not be used as a measure of the level of the students' understanding of circular motion as the test measured more than just the concepts of circular motion.

2.2 Gender and Physics Achievement

A review of literature on physics achievement at upper secondary school level showed that the achievement tended to favor the males than the females. Studies by Johnson and Murphy (1984), Postlethwaite and Wiley (1991), Ng (1991) and Giam (1992) found that boys attained better achievement in physics as compared to girls, whereas Lew (1987) reported no significant gender difference in understanding physics concepts. In contrast, in Thailand, Klainin, Fensham and West (1989) found better achievement by girls in physics than the boys.

Billeh and Khalili (1982) investigated the relationship between cognitive development of the students and their understanding of concrete and formal concepts in physics. The sample of the study was 389 eleventh grade science students, of which 209 were males and 180 were females. The results indicated that gender was not a factor in students' understanding of concrete concepts in physics. However, it was a significant factor in the understanding of formal concepts in physics where the male students scored significantly higher than the females.

Johnson and Murphy (1984), in their comprehensive review of the performance data accumulated in the APU (Assessment of Performance Unit) science surveys conducted in England, Wales and Northern Ireland, reported significantly lower performances for girls in tests dependent on physics knowledge. Boys showed higher mean scores than girls in physics on more than 90% of the questions at each age, and for about half of all the questions, the performance differences reached statistical significance. Boys actually performed more successfully than girls on about half of the questions relating to each of the physical science concepts or topics areas included in the assessment (e.g. force, pressure, speed, energy, etc.). They found that these performance differences, in favor of boys, might be due to the differential experiences of the boys and girls in their everyday out-of-school activities. The boys liked to involve in activities such as the dismantling of mechanical objects, playing with constructional toys while the girls would involve more in domestic and 'nature study' activities like cooking and caring for animals. The boys' activities thus provided greater opportunities for them to acquire experiences and to understand physics concepts than the girls.

Postlethwaite and Wiley (1991), in their report of the Second IEA (International Education Achievements) study of science achievements in 23 countries, showed that physics achievements had the highest sex differences, followed by chemistry and biology. The male students were reported to score higher in physics achievements than the female students. Similar finding was reported in the earlier IEA study of science achievements in 19 countries (Comber & Keeves, 1973).

Similarly, Ng (1991) obtained gender differences among Malaysian students' understanding of concepts in electricity. The sample involved 303 form five science students, comprising 151 males and 152 females. Ng (1991) reported that the male students exhibited significantly better understanding of the overall concepts in electricity than the female students.

Moreover, using 224 form four students Giam (1992) found similar result in his investigation of students' understanding of concepts in mechanics. The male students performed significantly better than the female students in the understanding of the overall concepts in mechanics.

In contrast, Lew (1987), found no significant differences between the males and the females (218 form four science students) in the understanding of physics concepts concerning measurement, motion, kinematics, force and motion.

On the other hand, Klainin et al. (1989) carried out a study of physics learning with grades 10 to 12 students in Thailand. The learning in physics of these students was assessed by using the following inventories: (1) Practical tests involving manipulative skills and problem-solving, (2) theoretical tests of physics knowledge and of source of evidence, and (3) an attitude to science test. Their findings indicated that the girls performed at least as well as the boys in all these measures of learning. In the practical tests, the girls in single-sex schools outperformed both girls and boys in coeducational schools and the boys in single-sex schools.

2.3 Formal Reasoning Ability and Science Achievement

A review of literature revealed evidences that formal reasoning ability was one of the cognitive variables that have substantial influence on student achievement in science (Lawson, 1982, 1985; Liberman & Hudson, 1979; Hofstein & Mandler, 1985; Lawson & Thompson, 1988; Zeitoun, 1989; Bitner, 1991).

Lawson and Renner (1975) conducted a study on students' cognitive levels and their achievement in science subject matter. They administered four Piagetian tasks (conservation of weight, conservation of volume, separation of variables and equilibrium) to 143 science students, including 33 high school physics students to measure their cognitive levels. The science subject matter tests were then administered to determine their achievement in the respective science subjects. The results indicated that for the physics students, there were significant differences at 0.001 level between students' cognitive levels and their understanding of physics. Though Lawson and Renner did not explain why students of different cognitive levels differed in their understanding of physics concepts, the results of the mean percentages of the physics concepts scored by the students suggested that students at high cognitive level achieved better understanding of physics concepts.

Liberman and Hudson (1979) studied the correlation between logical abilities and success in physics by administering a test of formal operational reasoning to 60 freshmen in a second semester physics class. The Tomlinson-Keasy/Campbell test was administered to assess the formal operational reasoning. This test examined the seven logical operations, namely, proportional reasoning, combinatorial reasoning, isolating variable, drawing verbal analogies, correlational reasoning, probabilistic reasoning and abstraction of the generating principle of verbal and numerical chains. Correlating the composite logical test score with students' final examination grade yielded a correlation of 0.49, significant at $p < 0.001$. The results provided evidence that the ability to employ formal operational reasoning was a necessary condition for student success in physics.

Additionally, Champagne, Klopfer and Anderson (1980) investigated the factors that were most likely to be significant in predicting students' achievement in classical mechanics. The study was carried out on 110 physics students. One of the factors studied was logical reasoning skills. The Logical Reasoning test administered to the students required them to apply the logical reasoning to verbal and diagrammatic representations of the physical world. (However Champagene et al. (1980) did not specify the nature of the logical test used.) The results indicated that the mechanics achievement score was correlated significantly with logical reasoning skills score of the students.

Tobin and Capie (1982) used the Test of Logical Thinking (TOLT) to investigate the relationship between formal reasoning ability, locus of control, academic engagement and integrated process skill achievement of 156 middle science students. The results of their study revealed that formal reasoning ability was the strongest predictor of process skill achievement and retention, accounting for approximately 36% of the variance in each case.

Hofstein and Mandler (1985) used Lawson's (1978) test of formal reasoning in the Israel educational context to investigate the relationship between students' achievement in science and mathematics. The formal reasoning abilities in Lawson's test included conservation of weight, displaced volume, proportional reasoning, controlling variables, combinatorial reasoning and probabilistic reasoning. Their findings indicated that the formal thinkers scored significantly higher than the non-formal thinkers in achievements in biology, chemistry, physics and mathematics.

In Australia, Chandran, Treagust and Tobin (1987) investigated the role of four cognitive factors, namely, formal reasoning ability, prior knowledge, field dependence/independence, and memory capacity on achievement in chemistry. Four tests, namely, the TOLT, the Hidden Figures Test, the Figural Intersection Test and the multiple-choice prior knowledge test were administered to measure the above four cognitive variables. The results of their study indicated a distinctly higher correlation (r = 0.38) between formal reasoning ability and achievement of chemistry concepts as compared to other cognitive variables measured.

Lawson and Thompson (1988) investigated the role of student variables, namely, mental capacity, verbal intelligence, cognitive styles and formal reasoning necessary for students to overcome the naïve prior misconceptions and develop valid biological conceptions concerning genetics and natural selection. The sample comprised 131 grade seven students with an average age of 13.1 years. An essay test on principles of genetics and natural selection was administered to the students after instruction. Responses were categorized in terms of the number of misconceptions. The formal reasoning ability was measured using the Lawson Classroom Test of Formal Reasoning (Lawson, 1978). The formal reasoning test consisted of 11 items requiring students to isolate and control variable and use proportional, probabilistic and conservation reasoning. Their results indicated that the only student variable consistently and significantly related to the number of misconceptions was formal reasoning ability. A correlation of -0.41 was obtained. The negative coefficient indicated that better reasoning ability corresponded to fewer misconceptions. Using a stepwise multiple regression analysis, they reported that the only predictor variable showing a statistically significant correlation with the number of misconceptions was formal reasoning ability which, by itself, accounted for 18% of the misconceptions' score variance.

Similarly, Zeitoun (1989) in his study investigated the relationship between abstract concept achievement and prior knowledge, formal reasoning ability and gender. He administered the TOLT to 160 secondary school students, with a mean age of 17.6 years. Six major abstract concepts in molecular genetics were tested. The results from his study showed that there was a moderate, positive correlation between formal reasoning ability and achievement in abstract concepts ($r = 0.53$). Moreover the results of stepwise regression analysis suggested that the formal reasoning ability was a good predictor of abstract concept attainment.

Bitner (1991), in her study of 101 grades 9 to 12 science students, investigated whether formal operational reasoning modes were predictors of critical thinking abilities and grades assigned by teachers in science and mathematics. She used the Group Assessment of Logical Thinking (Roadrangka, Yeany & Padilla, 1982) to measure the logical thinking abilities of students. The five formal operational reasoning modes were proportional reasoning, controlling variable, probabilistic reasoning, correlational reasoning and combinatorial reasoning. The results indicated that the formal operational reasoning modes explained 62 % of the variance in science achievement. Therefore, it was a significant predictor of achievement in science.

Similarly, BouJaoude and Giuliano (1994) investigated the relationships between students' approaches to studying, prior knowledge, logical thinking ability, and gender and their performance in a non majors' college freshman chemistry course. The subjects of their study were 220 students enrolled in the second semester of a freshman chemistry course. The instruments used included seven subscales of the

Approaches on Studying Inventory and the TOLT. The students' prior knowledge was measured by the grades on an hour-long examination held early in the semester while the cumulative final examination scores were used as measures of chemistry achievement. The correlation between the TOLT and final chemistry examination scores yielded a coefficient of 0.24, significant at $p < 0.0005$. The results of a stepwise multiple regression showed that the TOLT scores accounted for 4 % of the variance in chemistry achievement.

In Malaysia, Lew (1987), Ng (1991) and Giam (1992) used Longeot Test to measure the cognitive level of the students and to determine if there were any relationships between the cognitive level and the students' understanding of the physics concepts. Lew (1987) found that at the form four level, the Formal IIIB students (late formal thinkers) were not significantly different from Formal IIIA (early formal thinkers) in their understanding of both concrete and formal physics concepts. Similar findings of no significant effects between Formal IIIA and Formal IIIB on understanding of physics concepts were also obtained by Ng (1991) when he investigated the form five students' understanding of concepts in electricity. However, Giam (1992) investigated the form four students' understanding of concepts in mechanics, found that the Formal IIIB students significantly attained better understanding of overall concepts in mechanics as well as the concepts of velocity and acceleration when compared to the Formal IIIA students.

From the above reviews of literature relating to formal reasoning ability and science achievement, it could be concluded that research studies in general revealed that students at higher cognitive level tended to attain better performance in science.