CHAPTER 6 ANALYSIS OF WRITTEN RESPONSES

6.1. Introduction

This analysis was carried out in order to obtain insight into the students' understanding of concepts, instead of just relaying on the multiple-choice responses. Chase (1999) documented that multiple-choice questions are good at assessing learning at face value, but are lacking at assessing creative thinking and reasoning as well as higher order process skills. Analysis of the written responses was not done for all the cohorts of students, participating in the study. Instead, all the UL cohorts and one UP cohort were chosen for the analysis. The students from UL were selected for this analysis because of their geographical location, which was convenient for the researcher and because the results would enrich the teaching practice of the researcher at that institution. The UPmaj was chosen as a benchmark, because this cohort showed best overall performance in the test. A total of 257 students' written responses were used in the analysis, i.e. 224 students from the combined UL cohorts (ULfy, ULsc and ULmaj) and 33 students from UPmaj.

6.2. Coding and Analysis of Written Explanations

Analysis of the written responses, for each item, was carried out using a coding system. Each code corresponds to a particular group of responses supplied by students. The code for the scientifically acceptable explanation(s) for each item is given in brackets and is underlined. The response distribution is given as the number of students who provided a particular explanation for their multiple-choice answer to the item, and as a percentage of the total number of responses to that item. In each of the tables (Tables 6.1(a) to 6.1(t)) the percentage of students (frequency %) responding according to a particular code, was calculated by using the following formula

$$Frequency(\%) = \frac{n}{N} \times 100$$

where n represents the number of students, whose explanations belong to the same code, N represents the total number of students in a group.

6.2.1. Item 6 – Coding of written explanations

A01: No response

A02: Uncodable response

A03: The force of gravity acting on the two balls is the same, because they are of the same size. The two balls will therefore reach the ground at the same time.

A04: The frictional force acting on the lighter ball is smaller than the frictional force acting on the heavier ball. The lighter ball will thus travel at a higher velocity than the heavier ball, and hence reaches the ground first.

(<u>A05</u>): The acceleration due to gravity experienced by the two balls is the same, since it is independent of the mass of the object. The rate of change of velocity of the two balls will be the same, and thus they will reach the ground at the same time. The two balls will reach the ground at the same time, because they both experience free-fall.

A06: The force of gravity depends on the mass of the object; a heavier ball will therefore be pulled down with a bigger force, than the lighter ball. Therefore the heavier ball will reach the ground first.

Table 6.1(a) Frequency of written responses for item 6 for the combined UL cohorts and UPmaj cohort.

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
A01	3	1.3	0	0.0
A02	4	1.8	0	0.0
A03	31	13.8	5	15.2
A04	66	29.5	0	0.0
(A05)	52	23.2	22	66.7
A06	74	33.0	6	18.2

Explanation A05 corresponds to the correct answer to the multiple-choice component of this item. Explanation A03 indicates the inadequate level of understanding of students. The students have an idea that the two balls would reach the ground at the same time, but lack the understanding of the reasoning involved. Explanation A06 represents a classical alternative conception associated with gravity that heavier objects fall faster than lighter objects (Gunstone *et al.*, 1981; Halloun & Hestenes, 1985a; Hestenes *et al.*, 1992). This alternative conception is almost twice more prevalent in the

UL cohorts than in the UPmaj cohort. Alternative conception A04, that lighter objects fall faster than heavier objects, is less prominent among UL students and non-existent in the UP cohorts.

From Tables 5.3(a) and 6.1(a) it can be deduced that students have some idea that the two balls, having different masses, would reach the ground at the same time. There are those students who believe that the two metal balls will reach the ground at the same time because they experience the same gravitational acceleration downwards. However, some of the reasons for the two balls to reach the ground at the same time are not scientifically correct. Some students believe that the two balls reach the ground at the same time because they are both acted upon by the same amount of gravitational force. Even though the masses are different, the students believe that they (the two metal balls) experience the same pulling force downwards. It would seem that the students confuse gravitational force and gravitational acceleration. It is true that falling objects of different masses would experience the same gravitational acceleration; that is their velocity while falling down would increase at the same rate. The gravitational force acting on them depends on (among others) the masses of the objects involved. Therefore different objects would not experience the same gravitational force, while falling down. There are those students who believe that a heavy metal ball would reach the ground first. A heavier object would fall faster, a belief that was documented by Planinic *et al.* (2006) and Halloun *et al.* (1985a), as a common alternative conception among the physics students.

6.2.2. Item 7 – Coding of written responses

B01: No response

B02: Uncodable response

(B03): They all exert the same amount of force on each other. According to Newton's Third Law of motion, the force exerted by the truck on the compact car is equal but opposite to the force exerted by the compact car on the truck.

B04: The force exerted by the truck on the compact car is bigger, because the truck has a bigger mass, so it will exert a bigger force.

B05: The compact car was traveling at a higher velocity compared to the truck. The compact car will thus exert a bigger force on the truck.

B06: The compact car does not exert a force on the truck, because during collision the car will bounce back and the truck will move forward until it stops.

B07: The two vehicles are moving towards each other, so they exert equal forces on each other.

(B08): The momentum of both the compact car and the truck before collision will be equal to their momentum after the collision. Thus two vehicles will exert equal forces on each other.

Table 6.1(b) Frequency of the written explanations for item 7 for the combined UL cohorts and UPmaj cohorts.

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
B01	6	2.7	1	3.0
B02	0	0.0	0	0.0
(<u>B03</u>)	40	17.9	18	54.4
B04	137	61.2	12	36.4
B05	7	3.1	1	3.0
B06	6	2.7	0	0.0
B07	11	4.9	0	0.0
(<u>B08</u>)	17	7.6	1	3.0

Explanations B03 and B08 are acceptable scientific explanations for the item. The frequency for explanations B03 and B08, in Table 6.1(b) and that for option E from Table 5.3(b), are almost the same for the UPmaj cohort, and similar for the UL cohorts. In explanation B07 the students have an idea that the forces exerted by the two vehicles on each other will be of the same magnitude, but lack the knowledge and understanding in this regard. This alternative explanation is only present in the UL cohorts. Explanations B05 and B06 are less prominent among the students. Explanation B04 is a classical alternative conception, which is documented in physics education research. This conception is that if two objects of different masses interact with each other, the massive object will exert a bigger force on the smaller object as compared to the force exerted by the smaller object on the massive object (Halloun & Hestenes, 1985a; Maloney, 1984). This alternative conception, which corresponds to distractors A and D from the multiple-choice part, is almost twice as strong in the UL cohorts as in the UPmaj cohort.

The analysis of the students' responses in this item (Tables 5.3(b) and 6.1(b)) suggests that about 57.4% of the UPmaj students and only 25.5% of the UL students have an understanding that the two vehicles would exert forces of equal magnitudes on each other, in accordance with Newton's Third Law of motion. However, the majority of the rest of the students of the two cohorts believe that the large truck would exert a greater amount of force on the small compact car, while the small compact car exerts a smaller amount of force on the large truck. These students believe that the amount of force depends on the mass of the object exerting it, and therefore make a conclusion that the truck exerts a greater amount of force since it has a bigger mass.

6.2.3. Item 8 – Coding of written responses

C01: No response

C02: Uncodable response

C03: There are two forces acting on the ball. The upward force exerted by the hand, which keeps the ball going up, and the downward force of gravity, which is bigger.

(C04): The only force acting on the ball, during its flight, is the force of gravity, since the ball left the hand some time ago and there is no frictional force acting on the ball.

C05: As the steel ball goes up, its velocity decreases. This means that the upward force by the hand decreases as the ball goes up. The velocity of the ball increases as the ball goes down, because the downward force acting on it increases.

C06: The force of gravity only acts when the ball goes down. There is no gravitational force when the ball goes up.

C07: The gravitational force for upward motion is negative and decreases, while for the downward motion it is positive and increasing.

Table 6.1(c) Frequency of written responses to item 8 for the combined UL cohorts and UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
C01	4	1.8	2	6.1
C02	6	2.7	1	3.0
C03	66	29.5	2	6.1
(C04)	39	17.4	13	39.4
C05	80	35.7	15	45.5
C06	17	7.6	0	0.0
C07	13	5.8	0	0.0

The scientifically acceptable explanation for this item is C04. This explanation corresponds to option D on the multiple-choice part of this item. Explanation C03 is based on the reasoning that the force by the hand is able to act on the ball while it is not in contact with the ball. It is well known to the researcher from personal experience that students regard this force as the "force of motion". The students reason that the ball is able to move upwards because there is a "force of motion" exerted on the ball by the hand. This is also a well-known alternative conception that has been documented by Gunstone *et al.* (1981), Halloun & Hestenes (1985a) and Hestenes *et al.* (1992). In fact, the only force that is able to act at a distance is the gravitational force. Unlike the gravitational force, the force by the hand can not act at a distance. For this force to act the hand and the ball have to be in contact with each other. This alternative conception is much more prominent in the UL cohorts than in the UPmaj cohort. Explanation C05 involves the increase in the magnitude of the force due to gravity, as the ball goes down, and the decrease in magnitude by the upward force. This alternative conception is more prominent in the UPmaj than in the UL cohorts. Explanations C06 and C07 are less prominent among students in the UL cohorts and non-existent in the UPmaj cohort.

From Tables 5.3(c) and 6.1(c), it can be deduced that the majority of the students in all the cohorts believe that, other than the force of gravity acting on the ball, there is upward force acting on the ball as it goes up. Some of the reasons they provide is that there is a force by the hand acting on the ball as it goes up. The force by the hand on the ball ended when the ball left the hand, however students believe that the ball goes up because that force is still in action. The students have this understanding that "motion requires force", and believe that "active force wears out" (Hestenes *et al.*, 1992), because the velocity of the ball decreases as it goes up. Both "motion requires force" and "active force wears out" are regarded as common alternative conceptions in mechanics. Of course, there are some students who are able to identify the force acting on the ball correctly as the gravitational force only, when the frictional force is ignored.

6.2.4. Item 9 – Coding of written responses

D01: No response

D02: Uncodable response

D03: There is gravitational force acting on the bowling ball. Since the gravitational force is acting vertically downwards, the bowling ball will fall straight down.

D04: The bowling ball is moved forward by the force of the airliner. While moving forward its velocity decreases, the ball then fall straight downwards because of the gravitational force acting on it.

(D05): Even though there is gravitational force pulling the bowling ball downwards, it will fall forward at an angle because of inertia.

D06: When the bowling ball falls from the airliner, there is gravitational force acting downwards (on the ball) causing it to fall down. There is also frictional force acting in the direction opposite to the direction of the airliner. This force pushes the ball backwards. The combination of the frictional force and the gravitational force thus results in the ball falling backwards at an angle.

Table 6.1(d) Frequency of the written responses to item 9 for the combined UL cohorts and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
D01	5	2.2	2	6.1
D02	3	1.3	1	3.0
D03	36	16.1	1	3.0
D04	29	12.9	3	9.1
(D05)	78	34.8	19	57.6
D06	73	32.6	7	21.2

The scientifically acceptable explanation is D05, which states that the bowling ball will fall forward at an angle because of its inertia and the gravitational force acting on it. This explanation corresponds to option D in the multiple-choice component of this item. In explanation D03 students seem to ignore both the effect of air friction on the ball and the fact that the bowling ball possesses inertia. This alternative conception is more prominent in the UL cohorts than in the UPmaj. Explanation D04 is also more prominent in the UL cohorts than in the UPmaj. The reasoning seems to imply that one force acts on the bowling ball, and the other forces start acting after the first force has ended. This therefore seems to imply that the airliner exerts a force on the bowling ball and then later on gravity starts acting. This is a well known alternative conception that "gravity acts after impetus wears down" (Halloun & Hestenes, 1985b; Jimoyiannis *et al.*, 2001). The frequency from Table 6.1(d) indicates that the alternative conception D06 is most prominent in both the UL and UPmaj cohorts.

From the analysis of Tables 5.3(d) and 6.1(d), it can be realized that the majority of the students in the UP cohorts indicated that the ball would follow a parabolic path forward, because of its inertia. Some students believe that the bowling ball would move forward because of the force of the airliner. The students have this belief that the airliner exerts a force on the ball as it falls, and this force decreases with time. The gravitational force starts acting on the ball once the force by the airliner has stopped. Others believe that the frictional force is the only force acting horizontally on the ball when it falls, and therefore the ball will be pushed backwards. This explanation may be an attempt to explain the backward motion of the bowling ball that would be observed by a person sitting in the airliner. The students may associate this with experiences of passengers in moving vehicles when objects are dropped from windows.

6.2.5. Item 10 – Coding of written responses

E01: No response

E02: Uncodable response

E03: The rope is exerting an upward force on the block. This force must be slightly bigger than the weight of the block; hence the elevator travels upward at constant speed.

E04: According to Newton's Second Law of motion, the force exerted on the block, making the elevator to travel upwards, is given by F = ma. The acceleration of the block upwards is 2 m/s and the mass of the block is 1.0 kg, therefore the force exerted on the block by the rope will be 2 N.

E05: Block II together with the rope are exerting forces on block I, and the collective force by the rope and block II is twice as much as the weight of block I, the elevator travels upwards at constant speed.

(E06): For the block to travel upwards at constant speed, the resultant force on it must be zero. The forces acting on block I, are the force of gravity on the block and the force by the rope on the block. Since the weight of the block is 10 N, then rope I exerts an equal but opposite force on block I.

Table 6.1(e) Frequency of written responses to item 10 for the combined UL and the UPmaj cohorts.

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
E01	16	7.1	4	12.1
E02	4	1.8	0	0.0
E03	8	3.6	2	6.1
E04	77	34.4	3	9.1
E05	18	8.0	3	9.1
(E06)	101	45.1	21	63.6

Newton's First law of motion implies that for an object to be at rest or move at constant velocity, the forces acting on it must balance each other. Explanation E06 seems to concur with Newton's first law of motion, and corresponds to option B from the multiple-choice part of this item, in Table 5.3(e) from the previous chapter. Explanation E04 is more prominent in the UL cohorts than in the UPmaj cohort. This is a well documented alternative conception in which the students use acceleration and velocity interchangeably, instead of using the correct formula $F = m \times a$, the students use the incorrect formula $F = m \times v$ (Clement, 1982; Halloun & Hestenes, 1985a; Hestenes *et al.*, 1992). Explanations E03 and E05 imply that motion is always in the direction of the bigger force. This is regarded as an alternative conception according to Halloun & Hestenes (1985a), Hestenes *et al.* (1992) and Maloney (1984) but does not feature prominently in both the UL and the UPmaj cohorts.

A high percentage of students in this item were able to indicate correctly that for the block to travel at constant velocity upwards, the forces acting on it must balance each other. The students were able to identify the forces acting on the block as the gravitational force directed down, with a magnitude of 10 N, and the force exerted by rope 1 directed upwards. According to Newton's first law of motion, for the state of motion of the block not to change, the forces acting on the block must balance each other. Therefore the force by the rope must have a magnitude of 10 N for the block to travel at constant speed, or remain at rest. However, there are those students who believe that a constant resultant force produces a constant velocity, and the expression given as: $F = m \times v = 2$ N, where $v = 2$ m/s and $m = 1$ kg (Clement, 1982). These students were unable to differentiate between velocity and acceleration (Halloun & Hestenes, 1985a; Hestenes *et al.*, 1992).

6.2.6. Item 11 – Coding of written responses

F01: No response

F02: Uncodable response

F03: Force on block II is equal to the tension in rope I minus the weight of block II, i.e. F = T – W.

F04: The force by rope I on block II is given by F = m x g

F05: According to Newton's Second law of motion, when a block is stationary there are no other forces acting on it, except the gravitational force.

(F06): As the blocks are in equilibrium, the tension in rope 1 must be equal to the weight of block I, therefore rope 1 exerts 10 N downwards on block II.

F07: The gravitational force acting on block II is equal to 10N, and the gravitational force on block I is also 10 N. The tension in the rope is thus the sum of gravitational forces on the two blocks, hence T = 20 N.

Table 6.1(f) Frequency of written responses to item 11 for the UL and UPmaj cohorts

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
F01	7	3.1	5	15.2
F02	1	0.5	0	0.0
F03	10	4.5	2	6.1
F04	61	27.2	1	3.0
F05	11	4.9	2	6.1
(F06)	112	50.0	21	63.6
F07	22	9.8	2	6.2

F06 is the scientifically acceptable explanation as the blocks are in equilibrium. The explanation corresponds to option B in the multiple-choice part of this item in Table 5.3(f). Explanation F03 is less prominent in all the UL and UPmaj cohorts. This explanation is not common among students. Explanations F04 and F05 assume that the resultant force is the force due to gravity on the block. Explanation F04 is the most prominent alternative conception in the UL cohorts, but it is almost absent amongst UPmaj students. This conception, F07, is less prominent in both the UL and UPmaj cohorts. The implication of these results for teaching is that the misconception evident in explanation F04 requires serious attention in groups of weaker students.

6.2.7. Item 12 – Coding of written responses

G01: No response

G02: Uncodable response

(G03): The car is now towing a car twice its mass, the implication is that the mass of the car is increased three times. According to Newton's Second law of motion the mass of an object is inversely proportional to the acceleration produced, provided the same amount of force is applied. If the mass of an object is increased three times, then its acceleration will be ⅓ its original values.

G04: The mass of the car is doubled. If the mass of the car is doubled, then its acceleration will be halved.

G05: According to Newton's Second Law, the acceleration of the car is inversely proportional to the mass of the car. If the mass of the car is increased, then its acceleration decreases.

Table 6.1(g) Frequency for the written responses to item 12 for UL and UPmaj cohorts

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
G01	10	4.5	2	6.1
G02	6	2.8	2	6.1
(G03)	27	12.1	10	30.3
G04	157	70.1	16	48.5
G05	24	10.7	3	9.1

This item challenges students to use their analytical thinking skills for the interpretation of the relationship between the mass and the acceleration of a car. Explanations G03, G04 and G05 are all about the dependence of acceleration on mass. These explanations assume an inverse relationship between mass and acceleration of the car. The students have some idea that as the mass of the car increases, its acceleration decreases. The question seems to have been properly understood by the students, but they ignored the influence of the mass of the first car. The flaw in the reasoning lead to explanations G04 and G05, which were more prominent in the UL cohorts than in the UPmaj cohort.

The students were able to realize that there exists an inverse relationship between acceleration and mass, i.e. if the mass of a car is increased the acceleration of the car will decrease, on condition that we still have the same applied force. However, students seem to forget that the changes between mass and acceleration have to be inversely proportional, if the mass is increased three times, then the acceleration will decrease and become ⅓ of its original value. Otherwise the relationship will no longer be inversely proportional, a fact that would violate Newton's second law of motion. Alternatively, students may not have analysed the problem carefully and neglected to take the mass of the first car into consideration because of oversight.

6.2.8. Item 13 – Coding of written responses

H01: No response

H02: Uncodable response

H03: The gravitational force is greater than the upward force by the cable, because the cable is thin and has less mass and will thus exert less force.

H04: Motion is always in the direction of the bigger force. The upward force by the cable is greater than the gravitational force, thus the upward motion.

H05: As the cable is shortened, the elevator automatically goes up. The cable does not exert a force on the elevator.

(H06): According to the first law of Newton, if the elevator travels at constant speed, then the forces acting on it must balance each other.

Table 6.1(h) Frequency for the written responses to item 13 for the UL and UPmaj cohorts.

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
H01	8	3.6	1	3.0
H02	4	1.8	1	3.0
H03	22	9.8	0	0.0
H04	112	50.0	11	33.3
H05	10	4.5	0	0.0
(H06)	68	30.4	20	60.6

H06 is the scientifically acceptable explanation for this item, explaining that a constant velocity implies balanced forces acting on the object. Explanation H03 and H05 correspond to the alternative conception that the cable exerts less or no force at all; the cable is thin or automatically shortens as the elevator goes up. This alternative conception is only present in the UL cohorts. Explanation H04 corresponds to the alternative conception that motion is always in the direction of the bigger force, therefore for the elevator to move upwards the force upward, by the cable, must be greater than the downward force, by gravity. This is the most prominent alternative conception which is evident from the written responses of both cohorts, but it is more prominent for the UL cohorts than the UPmaj cohorts.

The majority of the students responded to this item by indicating that if the elevator goes up then the upward force on the elevator must be greater than the gravitational force on the elevator. They reasoned that "otherwise the elevator will not move up". The implication is that motion is always in the direction of the bigger force. There were some of the students who believed that since the cable is less massive and thin, it applied a smaller amount of force on the elevator as compared to gravity.

6.2.9. Item 14 – Coding of written responses

I01: No response

I02: Uncodable response

I03: The man and the boy are pulling the crate at the same time and at the same angle, the resultant path will be the path midway the two of them.

(I04): The man is pulling with a greater force as compared to the boy; the crate will thus follow a path closer to the man's pull.

I05: The man is much stronger than the boy. The man is pulling the crate with a greater force while the force by the boy is negligibly small. The crate will thus move in the direction of the man's pull.

I06: The boy is younger and has more strength than the man, who is old. The boy will thus pull with a greater force than the man, and the resultant path will be closer to the boy's pull.

Table 6.1(i) Frequency for the written responses to item 14 for the UL and the UPmaj cohort.

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
I01	7	3.1	2	6.1
I02	3	1.3	0	0.0
I03	101	45.1	12	36.4
(I04)	78	34.8	19	57.6
I05	29	13.0	0	0.0
I06	6	2.7	0	0.0

The scientifically accepted explanation for this item is I04, that the force by the man is greater than the force by the boy. Explanation I03 is prominent in both cohorts.

The students reason that since both the man and the boy are pulling at the same time and at the same angle, the crate will follow a path midway the man's and the boy's pull. The length of the strings in the diagram could have lead to this flaw in the reasoning, because students may have interpreted the drawing to be a vector diagram. Explanations I05 and I06 are less prominent in the UL cohorts and do not exist in the UPmaj cohort. The frequencies for the multiple-choice options D and E in Table 5.3(i) corresponds to explanations I05 and I06 of the written responses in Table 6.1(i).

From the analysis of Tables 5.3(i) and 6.1(i), it can be deduced that some of the students were able to recognize that a large man will be able to exert a greater amount of force on the crate than the boy, and that the resultant force on the crate would be in the direction closer to the man's pulling path than the boy's. However, there are those students who believe that, since the man and the boy are pulling simultaneously on the crate, therefore they are pulling the crate with forces of equal magnitudes. The crate would therefore move in the path that is directed midway the man's and the boy's pulling paths.

6.2.10. Item 15 – Coding of written responses

J01: No response

J02: Uncodable response

J03: The two blocks are placed directly opposite/parallel to each other at point 2 and point 5, indicating that they have the same speed at these points.

J04: The intervals between the points are not equal; one block moves at constant speed while the other block is accelerating. They will thus never have the same speed.

(J05): The spaces between points 3 and 4 are equal. During this interval they cover the same distance in the same period of time. Therefore somewhere between point 3 and 4 the two blocks will have the same speed.

Table 6.1(j) Frequency of the written responses to item 15 for the UL and UPmaj cohorts

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
J01	10	4.5	4	12.1
J02	5	2.2	2	6.1
J03	101	45.1	3	9.1
J04	82	36.6	6	18.2
(J05)	26	11.6	18	54.5

Explanation J05 is scientifically accepted for this item. This explanation often accompanied option E, from Table 5.3(j) in the multiple-choice component of the item. Explanation J03 corresponds to the alternative conception of same position implying same speed (Clement, 1982; Halloun & Hestenes, 1985b; Hestenes *et al.*, 1992). This alternative conception is more prominent in the UL cohorts than in the UPmaj cohort. Explanation J04 corresponds to option A in Table 5.3(j). It states that the two blocks will never have the same speed, because the spaces between the successive dots are different for the different blocks. This explanation represents a higher level of conceptual thinking than J03, because students were able to interpret the position of the blocks in terms of constant speed versus acceleration. This alternative conception is more prominent in the UL cohorts than in the UPmaj cohort.

The prevalence of explanation J03 for the weak or under prepared UL students as compared to its near absence for the benchmark group should be noted. The UL students were unable to realise the difference between the rate of change of position and position itself. The students' responses implied that if the two moving objects are at the same position at a particular moment in time, then they are traveling at the same speed. The students are unable to differentiate between position and velocity. Objects that are at the same position at a moment in time are regarded as having the same velocity (Hestenes *et al.*, 1992), according to the students.

6.2.11. Item 16 – Coding of written responses

K01: No response

K02: Uncodable response

K03: The spaces between the numbered squares are larger for block "b" and smaller for block "a". The acceleration of block "b" is thus greater than the acceleration of block "a".

K04: Block "a" is ahead of block "b", because there are more time intervals at the top than at the bottom. This indicates that block "a" is moving faster than block "b". Therefore the acceleration of block "a" is greater than the acceleration of block "b'.

(K05): The spaces between the numbered squares at the top are smaller and equal, while those at the bottom are bigger and also equal. This indicates that both blocks are moving at different but constant speeds. The two blocks thus have zero acceleration.

K06: The two blocks are accelerating at the same rate. The acceleration of block "a" is equal to the acceleration of block "b".

Table 6.1(k) Frequency of the written responses for item 16 for the UL and UPmaj cohorts

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
K01	16	7.1	2	6.1
K02	7	3.1	2	6.1
K03	76	33.9	5	15.2
K04	55	24.6	2	6.1
(K05)	44	19.6	22	66.7
K06	26	11.6	0	0.0

K05 is the scientifically acceptable explanation for this item. This explanation often accompanied option D in Table 5.3(k). The frequency for option D in Table 5.3(k) is almost the same as the frequency for explanation K05 in Table 6.1(k). The students were expected to realize that the numbered squares for both blocks are equal distances apart, an indication that the two blocks are both traveling at constant velocities. The majority of UL students and a small percentage of UP students failed to interpret the visual representation correctly in order to compare the acceleration of the two blocks. Explanations K03, K04 and K06 represent an alternative conception in which velocity and acceleration are indiscriminated. Explanations K04 and K06 are more prominent in the UL cohorts than in the UPmaj cohort. Explanations K03, K04 and K06 reveal a serious lack of understanding and inability to interpret the diagrams. This corresponds to the results obtained in the multiple-choice section of item (Table 5.3(k)) where large differences in the confidence levels associated with correct and incorrect answers were recorded.

The spaces between the numbered squares are equal, for both blocks "a" and "b". The space between the numbered squares is larger for block "b" than for block "a". However some of the students were unable to recognize the equal intervals between the numbered squares in each set. Therefore they failed to realize that equal intervals would mean constant velocity and hence zero acceleration. Students used the fact that the spaces between the numbered squares are larger for block "b" than block "a", to conclude that the acceleration of block "b" must be greater than the acceleration of block "a". They associated the spaces between the numbered squares with acceleration. This implies that larger intervals would represent a higher acceleration, while narrow intervals would therefore represent lower acceleration. This reflects a failure to distinguish between velocity and acceleration as documented by Hestenes *et al.* (1992) and Clement (1982).

6.2.12. Item 17 – Coding of written responses

L01: No response

L02: Uncodable response

L03: The same amount of force is applied simultaneously on the two pucks. The pucks will have the same acceleration, and will thus reach the finish line at the same time.

(L04): Puck I has a smaller mass as compared to puck II. Even though the same amount of force is applied on both pucks, the lighter puck will accelerate more than the heavier puck. Thus puck I will reach the finish line first.

L05: Puck II has more mass than puck I. If the same amount of force is applied on both of them, the heavier puck will reach the finish line first.

Table 6.1(l) Frequency for the written responses to item 17 for the UL and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
L01	9	4.0	0	0.0
L02	5	2.2	1	3.0
L03	44	19.6	2	6.1
(L04)	152	67.9	29	87.9
L05	14	6.3	1	3.0

The scientifically acceptable explanation is L04, which corresponds to option A from Table 5.3(l) in the multiple-choice part of this item. Similar frequencies were obtained for option A in Table 5.3(l) and for explanation L04 in Table 6.1(l). Explanation L03 represents a classical alternative conception that equal forces applied simultaneously produce equal accelerations (Clement, 1982). The effect of mass on acceleration seems to be ignored by students. This alternative conception is more prominent in the UL cohorts than in the UPmaj cohort. Explanation L05 reflects an alternative conception which is less common among the students.

The majority of students in all the cohorts were able to realise that puck I would reach the finish line first, because of its smaller mass as compared to puck II. The students were able to apply the second law of Newton. However, there were also those students who believe that the pucks would reach the finish line at the same time. Their reason was that the pucks were pushed simultaneously with the same amount of force; they would therefore have the same acceleration. These students seemed to ignore the fact that the pucks are of different masses.

6.2.13. Item 18 – Coding of written responses

M01: No response

M02: Uncodable response

M03: The force applied is directly proportional to the speed at which the box is being moved across the floor. If the force is doubled then the speed also doubles.

M04: The applied force must be more than the frictional force between the floor and the box, otherwise the box will not move. Since the applied force is bigger, then the motion is in the direction of the bigger force.

(M05): For the box to move at constant speed the forces exerted on the box must balance each other. The applied force must be equal in magnitude to the frictional force on the box.

M06: The magnitude of the applied force must be greater than the magnitude of the gravitational force on the box, otherwise the box will not move.

M07: The external forces acting on the box are very weak forces. The applied force must be greater than the external forces for the box to move.

Table 6.1(m) Frequency of the written responses for item 18 for the combined UL cohorts and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
M01	8	3.6	5	15.2
M02	2	0.9	1	3.0
M03	52	23.2	1	3.0
M04	64	28.6	6	18.2
(M05)	49	21.9	16	48.5
M06	31	13.8	3	9.1
M07	18	8.0	1	3.0

The scientifically acceptable explanation is M05, which corresponds to option C in Table 5.3(m) in the multiple-choice component of this item. However, not all students who chose option C gave the acceptable explanation. Explanation M03 is a classical alternative conception, in which students mistook force and velocity as being proportional to each other (Hestenes *et al.*, 1992). A higher velocity is taken as a result of a bigger applied force on an object. The alternative conception is more prominent in the UL cohorts than in the UPmaj cohorts. Explanations M04 and M07 represent the alternative conception which states that motion occurs when force overcomes friction (Clement, 1982; Hestenes & Wells, 1992; Minstrell, 1982). The alternative conception seems to be more prominent in the UL cohorts than in the UPmaj cohort. Explanation M06 is a known alternative conception that "a force cannot move an object unless it is greater than the object's weight (Gunstone *et al.*, 1981). Explanation M06 corresponds to option B in Table 5.3(m) and similar frequencies are reported for them.

The students were able to recognize the forces acting on the box as the applied force and the frictional force. However, some of the students believe that for a box to move at constant speed over a rough surface the applied force must be greater than the frictional force, otherwise the box will not move. The applied force must be greater so as to overcome the frictional force. Other students believe that for an object to move at constant speed the applied force must be constant as well, i.e. constant force produces constant speed, expressed as $F = m \times v$ (Hestenes *et al.*, 1992). Almost half of UPmaj students and only about 22% of the UL students correctly believe that the box move at constant speed because the frictional force has the same magnitude as the applied force, but is directed opposite.

6.2.14. Item 19 – Coding of written responses

N01: No response

N02: Uncodable response

N03: The velocity of the object increases, and then the object stops, after which its velocity decreases and later on the objects stops at a different position.

(N04): The object accelerates uniformly from rest for a longer period of time, moves at constant velocity for some time, and then decelerates for a short period of time, in the same direction.

N05: The object accelerates for a short period of time, moves at constant velocity and then decelerates for a longer period of time, in the same direction.

N06: The object starts from rest, moves at a certain speed, and later stops, change direction and decelerates to a stop.

N07: The object accelerates slowly, then moves at constant speed, and then accelerates faster.

Table 6.1(n) Frequency of the written responses to item 19 for the UL and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
N01	11	4.9	3	9.1
N02	7	3.1	1	3.0
N03	39	17.4	5	15.2
(N04)	76	33.9	15	45.5
N05	52	23.2	5	15.2
N06	19	8.5	3	9.1
N07	33	14.7	1	3.0

N04 is the scientifically acceptable explanation for this item. This explanation corresponds to option B from Table 5.3(n) in the multiple-choice component of this item. However, the frequency for option B in Table 5.3(n) is different to the frequency for explanation N04 for the UPmaj cohort. The students were expected to match the multiflash, for the motion of an object, and the velocity-time graphs. The object had undergone three different types of motion. First the object accelerated from rest, moved at constant velocity, and then decelerated. However, they failed to realize that the first part of motion took place for a longer period of time and the last part of motion took a shorter period of time, and that all three different types of motion took place in the same direction. A more subtle interpretation of the diagram is required to distinguish between options A and B in the multiple-choice component of the answer and between explanations N04 and N05. Explanations N03, N06 and N07 are a clear indication of serious flaws in the reasoning and interpretation of the representation of the motion of an object by a multiflash diagram.

The students were unable to recognise, that unlike the speed the velocity is a vector quantity, and thus the direction of motion also plays a role in the representation of velocity. The students failed to realize that the acceleration of an object depends on the rate of change in velocity, and not on the velocity itself. A higher velocity does not mean a higher acceleration, but rather a higher rate of change of velocity implies a higher acceleration. The other problem in this item is that students were unable to interpret the diagrammatical representation of motion.

6.2.15. Item 20 – Coding of written responses

O01: No response

O02: Uncodable response

(O03): The object accelerates for a longer period, moves at constant motion, and then decelerates for a short period of time. The acceleration is positive, then zero, and later on becomes negative.

O04: The object accelerates uniformly but slowly, moves at constant velocity, and then accelerates uniformly and faster.

O05: The object accelerates faster, moves at constant velocity, and then accelerates slowly.

O06: the object accelerates for a short period of time, moves at constant velocity, and then decelerates for a longer period of time.

O07: The object accelerates slowly, decelerates, and then accelerates faster.

Table 6.1(o) Frequency of the written responses to item 20 for the combined UL cohorts and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
O01	7	3.1	4	12.1
O02	3	1.3	2	6.1
(O03)	89	39.7	18	54.6
O04	38	17.0	1	3.0
O05	22	9.8	2	6.1
O06	29	13.0	5	15.2
O07	36	16.1	1	3.0

Item 19 and 20 require the students to interpret the motion of an object using graphs. In Item 19 the students were supposed to interpret the motion using the velocity-time graph. In item 20 they are to interpret the same motion using the acceleration-time graph. The correct explanation in this item is O03, which corresponds to explanation N04 from the previous item (in Table 6.1(n)), and also corresponds to option D in Table 5.3(o) in the multiple-choice component of this item. Explanation O06 is similar to explanation

O03. It suggests a proper understanding of the principles involved, except that the distance between dots was not interpreted accurately. However, the frequency of the correct explanation in item 19 is lower than the frequency of the correct explanation in item 20.

6.2.16. Item 21 – Coding of written responses

P01: No response

P02: Uncodable response

P03: The intervals get shorter from left to right. This indicates that the speed of the car decreases. The motion is thus a decelerated motion. The acceleration is directed to the left. The car is still moving to the right, therefore the net force is in the direction of motion.

(P04): The intervals get shorter from left to right. This indicates that the speed of the car decreases. The motion is thus decelerated. Therefore the acceleration is directed to the left. The net force, which is the frictional force and opposes motion, is also directed to the left.

(P05): The car is pulling the tape as it moves to the right. The intervals get bigger as motion proceeds. The motion is thus an accelerated motion to the right. For an accelerated motion the direction of acceleration and the direction of the net force are the same as the direction of motion. Therefore the acceleration and the net force are both directed to the right.

P06: The car is moving to the right, this means that the speed of the car is to the right. Therefore the acceleration is also directed to the right. However, the frictional force acting on the car is directed opposite to the direction of motion of the car. Therefore the direction of the net force is directed to the left.

Table 6.1(p) Frequency of the written responses to item 21 for the combined UL cohorts and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
P01	15	6.7	3	9.1
P02	8	3.6	2	6.1
P03	57	25.5	9	27.3
(P04)	15	6.7	11	33.3
(P05)	79	35.3	8	24.2
P06	50	22.32	0	0.00

The frequency distribution for this item could not be interpreted because of flaws in the item presentation. If one studies the tape carefully, it is possible that the motion of the car could have been accelerated, and it is also possible that the motion could have been decelerated. If the tape was attached to the car with the ticker stationary, then the motion would be accelerated. In this case the direction of the net force and the direction of the acceleration would be to the right. In the case where the ticker was attached to the car, with the tape stationary, the motion would be decelerated. Therefore the direction of the net force and the direction of the acceleration would be to the left.

In this item the majority of students were able to realize that the net force and the acceleration have the same direction. The problem with this item was that the problem statement did not specify where the first dot was made. Therefore it is possible that both the acceleration and the net force could be directed to the left, in this case the motion would be decelerated. It is also possible that the net force and the acceleration could be directed to the right, and the motion would be accelerated.

6.2.17. Item 22 – Coding of written responses

Q01: No response

Q02: Uncodable response

Q03: The block does not accelerate up or down, therefore N = W. The horizontal component of force F must be equal to force k; therefore force F must be greater than force k.

(Q04): When the box moves at constant speed, it means that all forces acting on it balance each other.

Q05: The applied force must be greater than the frictional force, since motion is in the direction of a bigger force. The weight of an object is always greater than the upward force by the surface on an object.

Table 6.1(q) Frequency of the written responses to item 22 for the combined UL cohorts and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
Q01	19	8.5	1	3.0
Q02	6	2.7	2	6.1
Q03	118	52.7	25	75.8
(Q04)	36	16.1	4	12.1
Q05	45	20.1	2	6.1

Explanation Q04 corresponds to option C in Table 5.3(q) in the multiple-choice component of this item. This can be seen from a comparison of the frequency obtained for Q04 in Table 6.1(q) with the frequency obtained for option C in Table 5.3(q). This indicates the mistake that the students are making in the interpretation of the forces acting on the box. Balanced forces in the students' reasoning, would mean equal magnitude and opposite directions. However, in this item the components of forces have to be taken into account when a balance of forces is considered. Therefore force N plus the component of force F (in the vertical direction) must be equal in magnitude to force W, while force k equals the magnitude of the component of force F (in the horizontal direction). Explanation Q03 is the most prevalent alternative conception of "canceling forces" (Clement, 1982; Halloun & Hestenes, 1985a; Maloney, 1984; Minstrell, 1982).

Students believe that a crate can move at constant speed only when the forces acting on it are of equal magnitudes, and are directed opposite each other, this is corresponds to option A from the multiple-choice component of this item. There are also cases when the forces are directed oppositely and have equal magnitudes that the object moves at constant speed. There are also cases where the forces have equal magnitudes but are directed at angles to each other; in this situation the object would not move at constant speed. In such a situation the components of forces are the ones to balance each other, and not the forces themselves.

6.2.18. Item 23 – Coding of written responses

R01: No response

R02: Uncodable response

R03: The rocket will go straight up at right angles, because there are no forces acting on it.

R04: There are no forces acting on the rocket, and the rocket possesses inertia. Therefore the horizontal component of its motion will remain the same.

(R05): Even though the rocket engine is turned off, the rocket possesses inertia, and will follow path "E" until it reaches c.

Table 6.1(r) Frequency of the written responses to item 23 for the combined UL cohorts and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
R01	16	7.1	11	33.3
R02	8	3.6	3	9.1
R03	72	32.1	4	12.1
R04	92	41.1	4	12.1
(R05)	36	16.1	11	33.3

The correct explanation is R05, which often accompanied option E from the multiple-choice component of this item. This appears to have been a difficult item, even the best performing cohort performed poorly here. A third of the UPmaj students did not provide any explanation for their multiple-choice answer. The item required higher order thinking and imagination for the interpretation of the problem. The setting of the rocket in outer space seems to be an unfamiliar situation to the students. From the explanations given by the students, one would realize that the two disconnected diagrams in the problem statement also lead to difficulty in the understanding of the problem.

In this item the students were unable to visualize the situation in the first place, and were therefore unable to imagine what would happen from point b to point c. This is the item that most of the students admitted to guessing their answers. However, some of the students indicated that because the rocket possesses inertia it will follow a parabolic path since the engine would be switched off.

6.2.19. Item 24 – Coding of written responses

S01: No response

S02: Uncodable response

(S03): The centripetal force that was originally exerted on the ball is removed when the string breaks. The ball moves because it possesses momentum, and therefore will proceed in the same direction it was moving when the string breaks. The ball will thus follow path "B".

S04: The original motion of the ball was circular in shape. Even when the string breaks the ball would still maintain its original circular motion, because of inertia.

S05: The ball will follow path "C" because of the momentum it possesses, and also because the centripetal force is removed when the string breaks.

S06: When the string breaks, the ball looses balance and heads straight downwards because gravity is the only force exerted on it.

Table 6.1(s) Frequency of the written responses to item 24 for the combined UL cohorts and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
S01	21	9.4	7	21.2
S02	7	3.1	3	9.1
(S03)	60	26.8	11	33.3
S04	65	29.2	7	21.2
S05	24	10.7	3	9.1
S06	47	21.0	2	6.1

The correct explanation is S03, which corresponds to the correct option B in the multiple-choice component of this item. The majority of students were able to recognize that once the ball exits the track or the string breaks, the ball would want to continue in the same direction, because it possesses momentum. However, the frequency of explanation S03 obtained for UPmaj, in Table 6.1(s), is lower than the frequency obtained for option B, in Table 5.3(s). The larger percentage of "no responses" to this item recorded for UPmaj may be the reason for the discrepancy. Explanation S04 indicates that the students believe that even if the string breaks the ball will continue motion in the same circular path because it possesses momentum. The students believe that the ball will continue to do what it was doing before, that is continue to move in a circular path. This is the most prominent alternative conception for both groups of students. Explanations S05 and S06 is based on the thinking that there is no longer a centripetal force exerted by the string, and the only force acting on the ball is the force of gravity, therefore the ball will fall down. This alternative conception is only prominent in the UL cohorts.

6.2.20. Item 25 – Coding of written responses

T01: No response

T02: Uncodable response

(T03): According to Newton's First Law of motion, the ball will continue to move with the same speed in the same direction, unless an external unbalanced force is exerted on it. The direction of the ball's speed when it leaves the channel is path "B", and it will continue in the same direction.

T04: Originally the ball moved in a circular path; because of its inertia it would still follow a circular path even after leaving the channel.

T05: When the ball leaves the channel, the only force acting on it is the gravitational force directed downwards. Therefore the ball will move straight downwards when it leaves the channel.

Table 6.1(t) Frequency of the written responses to item 25 for the combined UL cohorts and the UPmaj cohort

Code	UL		UP	
	Number of Students	Number of Students (%)	Number of Students	Number of Students (%)
T01	12	5.4	5	15.2
T02	5	2.2	2	6.1
(<u>T03</u>)	88	39.3	16	48.5
T04	37	16.5	9	27.3
T05	82	36.6	1	3.0

The conceptual content in this item is the same as that of item 24, but students have shown a better performance in this item. The scientifically acceptable explanation for item 25 is T03, which frequently accompanied option B in the multiple-choice component of this item. Explanation T04 is about the ball possessing inertia, and because of its inertia it continues moving in the same circular path even if the force by the string has ended. It is similar to explanation S04 in the previous item. This is the strongest alternative conception in the UPmaj cohort. Explanation T05 is based on the thinking that gravitational force is the only one acting on the ball, thus making the ball to go straight downwards, even if it possesses inertia. This alternative conception is also present in item 24 as explanation S06. It is almost completely absent in the UPmaj cohort, but it is very prominent in the UL cohorts.

6.3. Summary

The analysis of the written responses for the strongest cohort (UPmaj) and the combined UL cohorts, which include some of the weakest students, allows the identification of the most important alternative conceptions and the relative difficulty of addressing these conceptions. The UPmaj cohort has had the benefit of better quality teaching in physics than the UL cohorts, as observed from Appendix E. The prevalent alternative conceptions, which were recorded for UPmaj, can therefore be viewed as resistant to change. This result has important implications for teaching as will be discussed in the next chapter.

The next table (Table 6.2) provides a summary of the prevalence of the most important alternative conceptions observed for the two groups, UPmaj and the combined UL cohorts. A number of faulty explanations with frequencies above 10% listed in Tables 6.1(a) to 6.1(t) above are not included in Table 6.2. These faulty explanations are interpreted to reflect lack of analytical accuracy or inadequacy in the accurate interpretation of diagrams. These are the incorrect explanations for items 12, 14, 19 and 20. The deficiencies in the problem statement for item 21 and the unfamiliar setting for item 23 prevented meaningful interpretation of written responses, and are therefore also not reflected in Table 6.2.

Table 6.2 Alternative Conceptions and Incorrect Explanations Revealed by the written responses

			UL cohort	UP cohort
Alternative conception/Incorrect explanation	Item number	Code	Frequency (%)	Frequency (%)
Less friction acting on lighter ball than on heavier ball	6	A04	29.5	0.0
A heavy object falls faster than a light object	6	A06	33.0	18.2
A bigger mass exerts a bigger force	7	B04	61.2	36.4
Continuing action of an applied force after contact stops	8	C03	29.5	6.1
Impetus dissipation followed by increasing gravity as the object falls	8	C05	35.7	45.4
A compromise between the downwards gravitational force and the backwards frictional force determines the direction of motion.	9	D06	32.6	21.2
The applied force is directly proportional to the velocity of the object	10	E04	34.4	9.1
Misapplication of the formula $F = m \times g$	11	F04	27.2	3.0
Motion is in the direction of the bigger force	13	H04	50.0	33.3
Velocity and position undiscriminated	15	J03	45.1	9.1
Acceleration and velocity undiscriminated	16	K03	33.9	15.2

			UL cohort	UP cohort
Alternative conception/Incorrect explanation	Item number	Code	Frequency (%)	Frequency (%)
Equal forces produce equal accelerations	17	L03	19.6	6.1
Motion when force overcomes friction	18	M04	28.6	18.2
Lack of/Incorrect application of components of forces	22	Q03	52.7	75.8
The object moved in a circular path. When the string breaks or when the object leaves the circular channel it would continue on its circular path	24 25	S04 T04	29.2 16.5	21.2 27.3
When the string breaks or the ball leaves the circular channel the only force acting on the ball is the gravitational force which pulls it down	24 25	S06 T05	21.0 36.6	6.1 3.0

The results in Table 6.2 indicate that the alternative conceptions A04, C03, E04, F04, J03, L03 and S06/T05 are more easily uprooted than the others, because they are present to a large extent in the UL cohorts, but almost completely absent in the UPmaj cohort. The prevalence of the alternative conceptions A06, B04, D06, H04, K03, M04 and S04 in the UPmaj cohort is between 15.2% and 36.4%, and between 29.2% and 61.2% in the UL cohorts. This result can be interpreted to indicate that with better quality teaching in physics these alternative conceptions can be addressed, but that they may be more difficult to uproot than in the previous group. However, in the case of alternative conceptions C05, Q03 and T04 their prevalence is higher in the UPmaj cohort than in the UL cohorts. This can be interpreted that these are the most difficult alternative concepts to uproot, because they are much more strongly held by the students, as compared to the other two previous groups of misconceptions.

Faulty explanations G04, I03, N05, O06, P03 and R04, which were also associated with frequencies above 10%, are not reflected in Table 6.2, because they can be interpreted as showing lack of higher order analytical skills or inaccurate interpretation of diagrammatical representations of motion.

CHAPTER 7 DISCUSSION AND CONCLUSION

7.1 Introduction

This study explored the baseline knowledge and understanding of mechanics concepts upon entry to tertiary education of eight cohorts of students enrolled at three universities in South Africa. In this regard the following three research questions were formulated:

1. What are the performance and associated confidence levels of first entering physics students registered at selected South African universities?
2. Is there a correlation between the confidence and performance of students in mechanics?
3. Can the relationship between confidence and performance be used to reliably identify the presence of misconceptions in mechanics?

This chapter will present answers to these questions as revealed in the research report in this dissertation and discuss their implications to teaching physics at tertiary level.

7.2 Discussion

Generally one would expect to find that students showing high confidence levels, in a certain concept, will show evidence of having the necessary skills and understanding of that particular concept, by obtaining high scores in a test that is intended for assessing skills and understanding of the said concept. It is expected that students answering an item correctly would show high levels of confidence, while students responding incorrectly to an item, would show lower levels of confidence. However, that was not necessarily revealed in this study. Students made incorrect judgments about their skills, knowledge and understanding of basic mechanics concepts. Students having high confidence levels do not necessarily score high on the test, and students having low confidence levels do not necessarily score low on the test. From Table 5.2, it is evident that 34.1% of the students having high performance in the test, show high confidence levels. A small percentage, 1.9% of the students scored high on the test but were not confident about their choices, 10.6% of the students scored low on the test and showed low levels of confidence, while 53.4% of the students have scored low on the test but show high confidence levels. According to Hasan *et al.* (1999), 34.1% of the students would be classified as having correct knowledge of concepts, 1.9% of the students classified as having lack of knowledge and understanding of the concepts and happen to have guessed correctly, 10.6% of the students definitely having lack of knowledge of the concepts, while 53.4% of the students have strongly held alternative conceptions. More than 50% of the students are making false judgments about their knowledge and understanding of basics concepts in mechanics. This is in agreement with the study by Ochse (2003), who indicated that students (enrolled for Psychology third year) were unable to make a prediction of their performance. There are those students who are confident that they will obtain high scores, and as it turns out they obtained low scores, and there are those who obtain above average scores but had indicated earlier that they expect to obtain lower scores. The students made inaccurate judgments about their performance. The students' excessively high levels of confidence in their performance in mechanics is in agreement with the findings of Pallier *et al.* (2002), that students tend to be overconfident when assessing themselves on tasks that require higher order analytical skills.

Appendix C indicates the performance of the individual students and their confidence levels. When test performance and confidence levels for the individual students from the eight cohorts were correlated (Research question 1), different degrees of relationships were obtained. A moderate relationship between test performance and confidence level was obtained for the UPmaj cohort, this is indicated by a correlation coefficient of 0.57 (shown in Table 5.1). The trend line in the scatter plot, of Appendix D(d), starts from the bottom left and goes to the top right. This is indicative of the fact that students scoring high on the test are confident about their choices, while students scoring low on the test are less confident about their performance. The students therefore made fairly accurate judgments about their performance. There is, therefore, a relationship between performance and confidence level. Trend lines in the scatter plots of Appendices D(a)-(f) indicate that positive correlations between performance and confidence exist, with the degrees of relationships varying from 0.23 to 0.57 for six of the eight cohorts. Correlation coefficients of 0.23 and 0.25 (for ULfy and CTadp) indicate that the relationship is positive but rather weak as compared to that of 0.57. However, correlation coefficients of 0.07 and 0.05 as found for students from ULsc and ULmaj, respectively, indicate that there exist very little or no relationship between test performance and confidence levels for these cohorts. This is indicated by the almost horizontal trend lines on the scatter plots of Appendix D(g) and Appendix D(h), respectively. For these cohorts, students who scored low on the test did not necessarily show low levels of confidence, while student who scored high on the test did not necessarily show high levels of confidence. This confirms the incorrect judgment students made about their knowledge and understanding of basic concepts in mechanics.

7.2.1 Conceptual Dimensions

The studies by Hasan *et al.* (1999) and Planinic *et al.* (2006) both indicated the presence of alternative conceptions among students. It is also observed in this study that majority of the students do have alternative ideas about certain concepts, they believe that these ideas are correct and they are confident about them. The question then becomes in which of these concepts do student make incorrect judgments and what alternative conceptions do these students have? In order to answer these questions, the performance of the students in the different conceptual dimensions is discussed below. (Refer to Table 4.1, for the different conceptual dimensions, Table 6.2 for the alternative conceptions documented in this study, and Appendix B for the items in the test instrument.)

7.2.1.1 Kinematics

Items in this dimension require the students to differentiate between position, velocity and acceleration. The students were also required to recognize the vector nature of velocity and acceleration. Items 9, 15, 16, 19, 20 and 23 are found in this conceptual dimension. The performance of students in this dimension is, on average, poor, in almost all the cohorts, except for UPmaj. The average confidence levels of students choosing the correct options are above the threshold of 1.5, while the average confidence levels of students choosing the incorrect answers in this dimension are also above the threshold of

1.5. The low item performance coupled with high levels of confidence is an indication of students having either inadequate knowledge or alternative conceptions and being confident about these conceptions. Alternative conceptions D06 and K03 were considered moderately difficult to uproot, whereas alternative conception J03 was almost completely absent in the cohort with better school background. Inadequacy in the interpretation of ticker tape diagrams lead to the problem encountered with items 19 and 20, and item 23 challenged students due to its unfamiliar setting.

It can therefore be deduced that students have inadequate knowledge and understanding of the concepts associated with kinematics. For example students are unable to differentiate between velocity and position. Students regard objects that are at the same position at a particular moment in time as having the same velocity. Students also used the length of the space between successive blocks on a ticker tape, as an indication of the magnitude of acceleration instead of the magnitude of velocity. According to the students, a wider interval between the blocks would represent a higher acceleration, while a narrow interval between the blocks would represent a lower acceleration.

Acceleration is defined as the rate at which the velocity changes, but students regard an object having a high velocity as having a higher acceleration and the one having a lower velocity as having lower acceleration. This therefore indicates the confusion the students have between acceleration and velocity. However, the UPmaj cohort has displayed high average performance and high levels of confidence in almost all the items within this dimension. Unlike the other cohorts, the UPmaj cohort made a fairly accurate judgment about their performance.

7.2.1.2 Newton's First Law of Motion

Items 10, 11, 13, 18, 20, 24 and 25 are located in this conceptual dimension. The average performance of students in this conceptual dimension is poor, but better than the average performance in the kinematics conceptual dimension. Even though the average performance is poor, the average confidence levels of all cohorts in this dimension are above the threshold. In this category students have low average test performance and high average confidence levels. The students were unable to make accurate judgments about their performances. This was found to be an indication of the prevalence of alternative conceptions among students, in the dimension of Newton's first law of motion. The alternative conceptions documented for this conceptual dimension are E04 for item 10 (moderately strong), F04 for item 11 (moderately weak), H04 for item 13 (moderately strong), M04 for item 18 (moderately strong), S04/T04 and S06/T05 for items 24 and 25. The alternative conception associated with items 10 (E04) is present to a limited extend in the UL cohorts and almost absent in the UPmaj, see Table 6.2, which suggests that this alternative conception can be easily uprooted with proper teaching.

Students have this belief that for an object to move there must be a force to cause that motion. Students do not take into consideration the fact that the motion is uniform, i.e. the elevator is moving at constant velocity, and thus are unable to apply the rule of "canceling forces". The belief that objects move because of unbalanced forces, irrespective of the type of motion, is contradictory to Newton's first law of motion, an indication that the first law is not well understood by students. The items in this dimension are associated with smaller differences between average confidence levels associated with correct and incorrect answers, as shown in Table 5.4 in chapter 5. This was confirmed by the analysis of the written explanations, as presented in chapter 6.

7.2.1.3 Newton's Second Law of Motion

Items located in this conceptual dimension are 12, 17, 21 and 23. The performance of students in this conceptual dimension was found to be poor. On average the performance is the lowest as compared to all the other dimensions included in the test. This dimension had two problem items: item 21 (an ambiguous item) and item 23 (an item with an unfamiliar setting). Item 12 was plagued by lack of analytical accuracy while item 17 appeared to be easy and had one weak misconception, L03 (19.6% of UL cohorts in Table 6.2).

A small number of students have the belief that if the same amount of force is exerted on two objects of different masses, then the two objects would have the same acceleration. The concept of acceleration decreasing proportionally with increasing mass for the same applied force, seem to be unnoticed by many students. The students seemed to have difficulties in differentiating between acceleration and velocity. When velocity and acceleration are not differentiated in solving problems on moving objects, the result is the belief that the resultant force and velocity are directly proportional to each other, instead of the resultant force being directly proportional to the acceleration of a moving object. This therefore leads to the incorrect formula $F = m \times v$ instead of the correct formula $F = m \times a$.

The students' average confidence levels, in this dimension, are above the threshold. Therefore the students displayed low test performance and high average confidence levels, which according to Hasan *et al.* (1999) points to the presence of alternative conceptions among students. Noticeably, however, the best performing cohort, UPmaj, also obtained low average scores in this category. However, one can not conclude from this analysis that students have alternative conceptions as far as Newton's Second Law of motion is concerned. Only one item (item 17) seemed to give an indication as to whether alternative conceptions exist or not, while the other items points to the lack of higher order analytical skills. Items in this dimension are not unambiguous enough to allow application of the Hasan *et al.* (1999) model.

7.2.1.4 Newton's Third Law of Motion

Items found in this conceptual dimension are 7 and 11. The performance of students in this dimension is on average better than in all the other dimensions included in the study. The UPmaj cohort is performing well in this dimension and the confidence of these students were justified in this dimension. However, when looking at the other individual cohorts, the UL cohorts are scoring low on the items located in this dimension. Students have the belief that during an interaction between two objects of different masses, the object with a bigger mass will exert a bigger force (item 7), while the object with a smaller mass exerts a smaller force. In the case of the truck and a small compact car, the students believe that the truck will therefore exert a greater amount of force on the car, while the small compact car exerts a smaller amount of force on the truck during the collision. This is an alternative conception that can be corrected, because it is present to a large extent in the weaker cohorts and less so in the best performing cohort. The alternative conception associated with item 11 (F04) is present to a limited extend in the

UL cohorts and almost absent in the UPmaj, see Table 6.2, which suggests that it can be easily uprooted with proper teaching.

7.2.1.5 Superposition Principle

Items 10, 11, 13, 14, 18 and 22 are located in this conceptual dimension. The performance of students in this category is somewhat better than the performance in Newton's second law of motion category. However, the students have shown higher levels of confidence. The students from the best performing cohort have high performance in the test and have shown high levels of confidence. The students are making accurate judgment of their performance; they display the knowledge and understanding of correct concepts. However, the same cannot be said for the other cohorts; they show high levels of confidence but perform poorly, indicating the prevalence of alternative conceptions in the superposition principle category. The presence of weak alternative conceptions E04 and F04, and moderately strong alternative conceptions H04 and M04 were confirmed by the analysis of the students' written responses. For example, the belief that motion is determined by the bigger forces. When the block goes up, it is believed that the force pulling upwards is bigger than the pulling force downwards. The students reason that motion is always in the direction of the bigger force, implying that the upward force must be greater than the downward force by gravity, otherwise the block will not move. The fact that the block travels up at constant velocity, and the forces acting on it must be balanced, seems unnoticed by students, and thus rules out the fact that the resultant force on the block equals to zero. It is worth noting that alternative conception Q03 associated with item 22 had a significantly higher percentage in UPmaj than in the combined UL cohorts (75.8% of UPmaj students versus 52.7% of UL students). This item is rated difficult and also classified as requiring higher order analytical skills from the students. Its high prevalence amongst students from mainly privileged school backgrounds is alarming. Uprooting this alternative conception will be a challenge to even the most skillful physics teacher. In item 22 the block is being pulled by a force at an angle to the horizontal, the students believe that the forces balance each other. This indicates the mistake that the students made in the interpretation of the forces acting on the block. Balanced force in the students' reasoning, would mean equal magnitude and opposite directions. The students failed to consider the components of forces when a balance of forces is considered.

7.2.1.6 Gravitation

Items found in this conceptual dimension are 6, 8 and 9. The performance of students in this dimension is poor in almost all cohorts except UPmaj. However, the average confidence levels of all cohorts are above the threshold. According to Hasan *et al.* (1999), the students can thus be classified as having alternative conceptions as far as the gravitation category is concerned. This conclusion was confirmed by the analysis of the students' written explanations. Five different alternative conceptions were documented ranging from weak (A04 and C03 from items 6 and 8, respectively), moderately strong (D06 from item 9) to very strong (C05 from item 8). For example, students have the valid idea that the two balls, dropped simultaneously from the same height, and having different masses, would reach the ground at the same time. There are those students who believe that the two metal balls will reach the ground at the same time because they experience the same gravitational acceleration downwards. However, some of the reasons for the two balls to reach the ground at the same time are not scientifically correct. Some students believe that the two balls reach the ground at the same time because they are both acted upon the same amount of gravitational force. Even though the masses are different, the students believe that the same downwards pulling force acted upon the two metal balls. These groups of students confuse gravitational force and gravitational acceleration. There are those students who believe that a heavy metal ball would reach the ground first. The alternative conception prevalent in this category is that, heavy objects fall faster than lighter objects.

In the case of a ball that was thrown upwards, the students have the belief that, other than the force of gravity acting on the ball, there is an upward force acting on the ball as it goes. Some of the reasons they provide is that the hand is still acting on the ball as it goes up. The force by the hand on the ball ended when the ball left the hand, however students believe that the ball goes up because that force is still in action. The students have this understanding that there is a force of motion exerted by the hand on the ball, and this force decreases as the ball goes up. Their reason for the force by the hand to decrease was that the velocity decreased as the ball goes up. This is alternative conception C05, which is more prominent in the UPmaj than in the combined UL cohorts (45.4% of UPmaj students expressed this belief compared to 35.7% of UL students). This alternative conception seem to be difficult to uproot, it is more prominent despite better teaching. Of course, there are some students who are able to identify the force acting on the ball correctly as the gravitational force only, since the frictional force was ignored.

7.2.2 Confidence level

Students from each of the eight cohorts have shown that they are confident about their chosen options in all the items. They show high levels of confidence; this is evident from average confidence levels from Tables 5.3(a) to 5.3(t). The average confidence levels of those students who have chosen the correct options and those choosing the incorrect options are both high. In general the students who have chosen the correct options have shown high levels of confidence. This according to Hasan *et al.* (1999) is evident that the students have knowledge and understanding of concepts in basic mechanics. However, the students who have chosen the incorrect options have also shown high levels of confidence. It is only in item 23 that students admitted to guessing in the choices they made. It is in this item that on average the students, who have chosen the correct options and those choosing the incorrect options, are not confident about their choices. This was interpreted to be due to the unfamiliar setting of the item.

Hasan *et al.* (1999) used a certainty of response index to distinguish between students' strongly held alternative conceptions and the students' lack of knowledge, while Planinic *et al.* (2006) have postulated that the degree to which students are confident in their answers can be used to rank the students' alternative conceptions and identify those alternative conceptions that are significant, are firmly held by students and are therefore resistant to change. Hasan *et al.* (1999) has made the point that one can use the difference in confidences associated with correct and incorrect answers to distinguish between alternative conceptions and lack of knowledge. However, they did not have the means of checking their hypothesis. From the analysis of the results of the students' written explanations, it becomes evident that there are those alternative conceptions that are easy to uproot and there are those that difficult to uproot. Alternative conceptions that are difficult to uproot are present in all the groups including the UPmaj, while alternative conceptions that are easy to uproot are only prevalent in the weakest groups, all the UL, the UPteach and UPadp groups.

7.3 Alternative Conceptions or Lack of Knowledge

The study by Hasan *et al.* (1999) used the test performance and certainty of response to identify the presence of misconceptions. If test performance is low and the average confidence level is high, then it signifies the presence of misconceptions. From the analysis of the written responses done in chapter 6, it can be noted that low test performance coupled with high average confidence levels does not always signify the presence of alternative conceptions.

Items 12, 14, 19, 20, 21 and 22 are associated with low performance and high confidence levels among students. However one can not apply the Hasan *et al.* (1999) model and classify students as having alternative conceptions in these items. The analysis from the study has indicated that despite the difference in their difficulty levels, it is possible that the items did not assess the depth of the conceptual understanding. The students may have understood the concept but made simple errors due to lack of higher order analytical and interpretation skills. Item 12 has proved to be one such a case. In this item, students are to use the relationship between mass and acceleration as an application of Newton's second law of motion. The students were able to realize the inverse relationship, but failed in the analysis of the problem, thus end up ignoring the influence of the first car on the new acceleration. This could not be classified as misconception, but rather lack of critical analysis of the situation at hand. The same problem could also be observed in Item 19, where the students were able to recognize the three different types of motion. The students identified the motions as i) the first type to be accelerated motion starting from rest, ii) the second type to be motion with constant velocity, and lastly iii) the third type to be decelerated motion. However, the students failed to critically analyze how long each of these motions lasted, i.e. which one took longer than the others. The analysis of the responses indicated the lack of analytical skills in the interpretation of motion. The students have shown to be lacking in the interpretation of the diagrammatical representation of motion. This information could not be obtained while applying the four possible combinations in the Hasan *et al.* (1999) model, shown in Table 3.1. These limitations of the Hasan *et al.* (1999) model became evident during the analysis of the students' written explanations.

7.4 Conclusion

The study was aimed at investigating the presence of alternative conceptions, performance and confidence levels of students entering physics at the three universities (Research question 1). Students entering physics at the universities have different academic backgrounds. The students from UPsc and UPmaj have a higher average performance in the test than the rest of the groups. This then implies that the students from the latter six groups have limited knowledge and understanding of basic mechanics concept, hence their lower performance in the test. However, the results of the study indicate that all the students have high levels of confidence. The groups of student whose average performance is low and those having high average performance in the test all have high confidence levels. The analysis of the students' confidence levels in the test as a whole suggests that the students were confident about their knowledge and understanding of concepts in mechanics. The item-by-item analysis of students' confidence in incorrect responses suggests that they have alternative conceptions, which they acquired from past experiences, and are confident about these ideas they have. However, it also points to a lack of analytical accuracy and inadequacy in the interpretation of diagrams.

Some of the students' strongly held alternative conceptions found in this study are: (a) a heavier object falls faster than a lighter object; (b) motion take place because of a constant applied force, the students belief in the notion of "force implies motion" i.e. every motion has a cause. An object only moves because there exist an external force exerted on it; (c) acceleration and velocity are used interchangeably, i.e. the velocity of an object is directly proportional to the force applied, and this statement then leads to the conclusion that constant force implies constant velocity; (d) the students also believe that a bigger object exerts a bigger force, and hence the third law of Newton is violated, and (e) that moving objects at the same position in a given time have the same speed.

The study was also aimed at investigating whether a relationship exists between the students' confidence levels and test performance (Research question 2). Do students make accurate judgments about their knowledge and understanding of the basic mechanics concepts? The study has shown that in most cases the best performing students make quality judgment about their performance, while poor performing students always make inaccurate judgments about their performance. The study also investigated whether the relationship between confidence and performance can be used to reliably identify the presence of misconceptions in mechanics (Research question 3). The analysis of the students' written explanations and the item difficulty revealed that the Hasan *et al.* (1999) study is lacking in the differentiation between lack of analytical skills and the presence of alternative conceptions. Lack of analytical or interpretation skills cannot be classified as evidence of the presence of alternative conceptions. The respondent may be having knowledge of the necessary concepts, but lack higher order analytical skills to be able to interpret the situation presented.

Misinterpretation of diagrams was evident from the analysis of the students' written explanations. However, this is beyond the scope of the study, and probably may be revisited for future work.

7.5 Limitations to the Study

- The study is confined to the three South African universities for students registered for physics. The sample used therefore represents only a subset of the first entering physics student population at all South African universities.
- The students entering the universities have changing profiles based on the changing landscapes in the South African Education Systems. The results of the study might not be the same after maybe a decade or so from now.
- The interpretation of the students' written explanations is picking up on some lack of knowledge and understanding; however one could not ask follow-up questions on these explanations. An interview would have provided an opportunity to be able to ask follow-up questions and get clarity on some explanations given.

- There are interesting issues like gender, cultural background and language, but these were not investigated in this study.

7.6 Implications to Teaching

Every first entering physics student brings to class a system of belief about the physical process. These systems of belief are acquired through interactions with the environment and also from past personal experiences. Physics education research has, over a number of years, indicated that these systems of belief play an important role in introductory physics and thus form the basis for learning. The knowledge and understanding of concepts the students bring along to class impacts on teaching and learning. It is important for educators to know which alternative concepts students have in physics, and in particular about forces and motion. The laws of Newton may seem straightforward to understand, but students find difficulty in applying them to everyday situations. Knowledge of how the students think is important in the planning and structuring of lessons.

Three types of alternative conceptions exist among the students. There are those alternative conceptions that are easier to correct because they are present to a large extend in the weaker performing cohorts and are almost absent in the best performing cohorts. The alternative conceptions are: (a) Less friction acts on lighter than on heavier objects. (b) Force of motion continues even when contact has stopped. (c) The applied force is directly proportional to the velocity of the object. (d) The use of velocity and acceleration indiscriminately. (e) The use of velocity and position indiscriminately. (f) Equal forces produce equal accelerations. (g) When an object moves in a circular path it will continue to move in a circular path even when the centripetal force stops. There are those alternative conceptions that are present in the poor performing cohorts but moderately so in the best performing cohorts. This can be interpreted to indicate that with better quality teaching in physics these alternative conceptions can be addressed, but they may be more difficult to uproot than the previous group. The alternative conceptions are: a) A heavier object falls faster than a lighter object. b) A bigger mass exerts a bigger force. c) Motion is in the direction of a bigger force. d) Motion takes place when force overcomes friction. There are those alternative conceptions that are present in the best performing cohorts. This can be interpreted as the alternative conceptions that strongly held by the student and can be difficult to uproot despite better quality teaching in physics. The alternative conceptions are: a) Contact force by hand decreases as the ball goes vertically up followed by gravity increasing as objects fall down. b) Incorrect application of vector addition when dealing with components of forces in two dimensions.