

Chapter Seven

Synthesis, Recommendations and Conclusion

7.1. Orientation to the Chapter

The foregoing voyage of exploration into the scientific and technological literacy of the cohort of first year physics students and the effects of a traditional school curriculum yielded a sea of data. This chapter crystallizes the principal findings with reference to the critical questions that were pursued in this study, and then discusses each set of findings. Further, the chapter will provide recommendations related to these principal findings, and address limitations of this study by offering suggestions as to how the study could be replicated and/or taken to scale. The novelty of this chapter lies in its integration of elements of the literature reviews, statistical analyses, and revelations of the focus group interviews, which will be used to compare, corroborate and/or contest the principal findings of the foregoing analysis.

7.2. Synthesis of Results Related to Critical Question One

The first critical question had two distinct foci. First, an examination of the nature of the traditional science syllabi and teaching practices that the selected undergraduate physics students experienced at school. Second, a comparison of the traditional science curriculum with transformational OBE in science and technology.

Accordingly, most of the findings related to the first critical question can be separated into two categories. The findings that are informed by empirical data, i.e. findings derived from the questionnaire administered to the students (see Appendix 1), are called essential findings. The other findings, which have a theoretical underpinning, and are derived from the comparison of the traditional and transformational OBE curricula, will be classified as supplementary findings.

The essential findings associated with the nature of the teaching and learning experiences of the students will be presented collectively so as to constitute a direct response to the first critical question. Thereafter, a discussion will follow, which will be informed by supplementary findings that are distilled from the comparison of the traditional and transformational OBE paradigms.

7.2.1 Findings Related to Critical Question One

The five essential findings related to critical question one were:

Finding One:

The teaching methods of students who experienced traditional science curricula at school were largely conventional. Chalk and talk was the most popular method of teaching. The second most popular teaching method was the use of questions and answers.

Finding Two:

Science experiments and group work, were the least popular of the teaching methods.

Finding Three:

The learning experiences of the students were not consistent with traditional teaching methods. The most common learning method amongst the students was more progressive in that it focused on the use of numbers, concepts, and principles to solve problems. The use of concepts and principles to solve problems was the second most popular learning method.

Finding Four:

Although the learning methods experienced most frequently by the students were not a mirror image of the most frequent teaching methods, the influence of traditional teaching practices on learning methods could not be ignored. Many students were still inclined to pursue traditional learning methods like memorization (rote learning) and use numbers exclusively to solve problems.

Finding Five:

There is dependence, at a five and ten percent level, between some of the teaching and learning experiences of the students. The strongest dependence at the five-percent level using the chi-square test statistic is between the science experiments teaching method and relating physics to real life as a learning method.

7.2.2. Discussion of Findings Related to Critical Question One

According to the first essential finding, the most frequent teaching methods experienced by the students resonated strongly with the traditional science curriculum. Chalk and talk was the most frequent kind of teaching experienced by the students. The second most frequent teaching method entailed the use of questions and answers.

Both of the most popular teaching methods are consistent with the supplementary theoretical finding that the learning theory of Behaviourism had a significant influence on the teaching practices of educators. According to the CUMSA Discussion Document (DOE 1992a:30), Natural Sciences “concerns itself with imparting knowledge...” The data implies that chalk and talk, and the use of questions and answers, were the most convenient form of imparting knowledge. Behaviourism, encouraged presenting knowledge “in small, step by step, simple units” (Ornstein & Hunkins 1998:133) like a teacher does when using the chalk and talk teaching method. Behaviourism also encourages observing behaviours to test learning like a teacher does when they solicit answers to test learning. This first essential finding was not surprising because to fulfil the requirements of a curriculum that focused on imparting knowledge necessitated an approach that “...is subject-centred where the teacher is viewed as the authority and the expert in the subject field” (Ornstein & Hunkins 1993:42).

There are striking differences between traditional teaching methods and those proposed within the transformational OBE framework. OBE in South Africa signals a change “from a talk and chalk – rote learning system to being flexible and (adapting) to learner needs and different learning styles and learning preferences” (DOE 1997b:42). In transformational OBE, “...the educators (are) active participants or guides on the side or facilitators of learning, and there is “activity based learning where learners explore ideas and approaches to learning and practice skills” (DOE 1996a:46).

The second essential finding established that science experiments and group work, were the least popular of the teaching methods. The centrality of the teacher was further emphasized in science experiments and group work being the least popular of the teaching methods. Both of these teaching methods are more learner-centred, and the results reveal that they were generally discouraged.

There are two supplementary findings that inform this second essential finding. First, practical work was the stepchild of the traditional science curriculum. There were no deliberate attempts to fully integrate theory and practicals in the traditional curriculum. The examinations for practical work were separated from the theory papers; however, the concepts inherent in the practical work could be examined in the theory papers, as outlined in the Syllabus for Physical Science (DOE 1994). Hence, there was an artificial separation of the theory and practical components of the syllabus. This artificial separation is in direct conflict with the transformational OBE approach, which encourages an “experiential and integrated approach” (Chisholm et al 2000:23) and for learners to “gain skills, knowledge and values” (DOE 1997a:10). Transformational OBE encourages “the setting of tasks that integrate theory and practice, the manual and the mental learning where practicable, and which link the classroom learning to the broader society in which it is located” (DOE 1996a:46).

The other supplementary finding which supports this second essential finding was that the world of science was separate from the world of the students. For the most part, the traditional curriculum ignored the fact that students are sources of subject knowledge, skills and attitudes as group work was the least popular method of teaching. Cooperative and activity based learning contexts were not consistent with the traditional curriculum. The traditional approach suppressed individual expression, and did not see learner contributions as supplementary to the body of knowledge in the syllabus. Also, teachers were not au fait with such a teaching methodology. Hence, it was remarkably unpopular. Textbooks prescribed in a recipe format the ‘experimental method,’ and provided the answers to the so-called discovery questions immediately after the experiment. These are just a few illustrations of how the traditional curriculum perceived the world of science as separate from the world of the student. On the other hand, transformational OBE explicitly endorses group work and appreciates the students as sources of knowledge, skills and values. More specifically, transformational OBE endorses the learning theory of Constructivism in which learners construct new knowledge using their original ideas.

The third essential finding established that the learning experiences of the students were not consistent with teaching methods. One would expect that because chalk and talk was the most popular teaching method, that there would be a corresponding high frequency for associated learning methods like memorization or the exclusive use of numbers to solve problems. Surprisingly, the most common learning method amongst the students was the use of numbers, concepts, and principles to solve problems. The high frequency of the use of numbers, concepts and principles as a method of learning was not an outlier result; it was consistent with other results. This deduction is based on the

fact that the second most popular method of learning was the use of concepts and principles. Hence, it is apparent that this cohort of students was more suited to the conceptual approach to solving problems.

Supplementary findings indicate that the learning methods, which were popular amongst the students, are more consistent with the transformational OBE curriculum. In fact, this essential finding resonates with one of the specific outcomes for the Natural Sciences as outlined in the Discussion Document of C2005, namely: “Demonstrate an understanding of concepts and principles, and acquired knowledge in the Natural Sciences” (DOE 1997a:134). The use of a combination of concepts, principles, and numbers to solve problems is at a higher cognitive order than simply inserting numbers into an equation and then finding the value of the unknown variable. It requires a grasp of concepts and principles, and a skill of relating them to numbers. For example, to understand the concept of kinetic energy goes beyond just memorizing an equation ($\frac{1}{2}mv^2$). It requires an appreciation of the energy changes that occur when the velocity of the object changes, and to be able to operate at an abstract level to understand the principle of conservation of energy because when an object is in free fall it gains kinetic energy while it loses potential energy.

The use of higher order learning methods could also be attributed to the fact that the teaching methods that were experienced by the students were not exclusively traditional. Problem solving, which is a more cognitively challenging approach to teaching, was the third most popular kind of teaching experienced by the students. Problem solving is inconsistent with the traditional science curriculum teaching methodology. All the teachers who taught the traditional science curriculum cannot be painted with the same brush. Some teachers were more learner-centred in their approach and they emphasized problem solving skills and critical thinking. Therefore, the coexistence of such teachers could have led to a high frequency of the higher cognitive order learning methods that entailed the use of numbers, concepts and principles to solve problems.

The fourth essential finding confirms that despite the tendency of the students to favour conceptual approaches to problem solving, traditional learning methods like memorization and the use of numbers exclusively to solve problems were still very popular. In fact, they were almost equivalent to learning methods like relating physics to real life and the use of one’s own ideas to understand physics. Therefore, the influence of the traditional curriculum cannot be ignored. The supplementary finding pertaining to the significant effect of Behaviourism on the traditional curriculum applies to this essential finding. Additionally, the underlying educational philosophies of Essentialism and

Perennialism also impacted the learning methods embraced by the students as they underpinned the traditional curriculum. Perennialism is rooted in the acceptance of generally agreed-upon knowledge of the past. Such an approach leaves little opportunity for students to create their own meanings of content, and to use students' ideas as a point of departure when designing a learning session. Essentialism focused on cognitive and intellectual essentials, but encouraged a passivity of students and the centrality of the teacher.

Another supplementary finding pointed to the assessment system of the traditional curriculum encouraging traditional learning methods like memorization and the use of numbers exclusively to solve problems. In any educational setting, the assessment method has a profound influence on the nature of the learning methods pursued. The traditional assessment system was designed to test mastery of knowledge. Two factors adversely affected students' success with such an assessment system. First, the huge volume of information and second, the summative nature of the testing. Students were confronted with a syllabus that was content laden, and in which application of knowledge was not important. Moreover, students were confronted with summative assessments in the form of mid-year and final examinations. This meant that huge volumes of information had to be retained by students to be restated in the examinations. The examinations were also high stakes as they determined progression to the next grade.

In contrast to the traditional curriculum, the shift to OBE requires a formative and summative approach to assessment, as teachers must assess learners' progress continually. Assessment in an OBE system enables both learners and teachers to determine whether learners are achieving the agreed outcomes or not. A variety of strategies are used to measure the process and product of learning, namely, "tests, essays, projects, and portfolios" as outlined in *Outcomes-Based Education in South Africa, Background Information for Educators - Draft (DOE 1997b:41)*. Self or peer assessment may also be administered.

Fifth and finally, the chi-square test statistic and the Pearson Correlation Coefficient confirm that there is dependence at a five and ten percent level between some of the teaching and learning experiences of the students. The strongest dependence at the five-percent level using the chi-square test statistic is between the science experiments teaching method and relating physics to real life as a learning method. There are implications of this finding for the implementation of the transformational OBE. You have to tailor the course offerings so that the teaching method induces the desired learning method. For example, if you wanted students to use numbers, concepts and

principles to solve problems, then Table 4.2. states that you should engage Science Experiments and Group work as teaching methodologies. Similarly, for those dependencies that exist at the five and ten percent level, corresponding teaching methods should be applied to achieve a desired learning strategy in students.

This concludes the discussion on essential findings related to critical question one.

7.3. Synthesis of Results Related to Critical Question Two

The first innovation of this study was to develop new insights and methods to evaluate science and technology literacy levels of learners in South Africa. This study adds a new dimension to previous similar studies in South Africa (Laugksch 1994) in that it resonated with the OBE paradigm that is currently in vogue in South Africa. The transformational OBE framework manifests itself explicitly in the second and third critical questions of this study.

The second critical question in this study examined the levels of scientific literacy in the selected cohort of undergraduate science students. The primary source of data for critical question two were twenty multiple-choice questions that were linked to four science themes (Earth & Beyond, Matter & Materials, Life and Living, and Energy and Change) from the Natural Science learning area of C2005. For example, a question that was linked to the theme Energy and Change follows:

The energy changes which take place when a light is switched on:

Choices

Electrical to heat	Electrical to light	Electrical to heat to light	heat to light
1	2	3	4

The twenty questions were part of the all-inclusive questionnaire that was administered to the students. The number of correct responses to these twenty questions determined the scientific literacy category into which a student was placed. The categories of students are outlined in Table 7.1. below.

Ranges of Scores out of 20	Category
Less than or equal to 8	Scientifically Illiterate
9 to 11	Mediocre Scientific Literacy
12 to 15	Good Scientific Literacy
16 to 20	Excellent Scientific Literacy

Table 7.1. The Scientific Literacy Categories of Students

The above scores for scientific literacy were then examined to determine which questions were answered correctly in each of the categories of scientifically literate students. Such an analysis revealed patterns with regard to the nature of questions correctly answered by each of the groups. This was a new dimension in the analysis of the scientific literacy levels of the students. The analysis entailed an examination of the questions with the most, moderate and least number of correct responses by concept, theme, discipline, and an explanation of the patterns that emerged. Additionally, data derived from focus group interviews were used to analyze students' conceptions of scientific literacy. Moreover, biographical data derived from the questionnaire was used to establish which of the teaching and learning methods were the most influential in determining scientific literacy levels, and which factor was the best predictor of scientific literacy. The findings of this analysis are presented below.

7.3.1. Findings Related to Critical Question Two

The findings that are presented below are of two distinct types. Those findings that are a direct response to the second critical question are essential findings. Findings one and two below are essential findings. Those findings that are not a direct response to the second critical question, but do inform the understanding of the scientific literacy levels of the students, are supplementary findings. Findings three to six below are supplementary findings.

For critical question one, the essential findings were derived exclusively from empirical methods; i.e. data generated from the questionnaire yielded the essential findings. The same applies for essential findings related to critical question two. For critical question one, the supplementary findings were derived from a theoretical comparison of the traditional and transformational OBE paradigms. However, the supplementary findings for critical question two are not derived theoretically. Rather, they are derived from a quantitative analysis of data from the questionnaire and qualitative analysis of

Finding Three (Supplementary Finding):

The analysis of the questions that were answered correctly in each of the categories of scientifically literate students (see Table 7.1. p.179) by theme and concept yielded the following preferences for disciplines in science:

Scientific Literacy Level	Most Popular Discipline in Sciences
Scientifically Illiterate	Life Sciences
Mediocre Scientific Literacy	Life Sciences
Good Scientific Literacy	Life and Earth Sciences
Excellent Scientific Literacy	Life, Earth and Physical Sciences

Table 7.4. Most Popular Science Disciplines for Students with Different Scientific Literacy Levels

Finding Four (Supplementary Finding):

The students' conceptions of scientific literacy were consistent with their categorization according to performance on the scientific literacy test.

Finding Five (Supplementary Finding):

Of all the teaching and learning methods, the most influential in determining scientific literacy levels is working in small groups.

Finding Six (Supplementary Finding):

The best predictor of scientific literacy is the former department of education that a student's school was affiliated to.

7.3.2. Discussion of Findings Related to Critical Question Two

The discussion of the scientific literacy levels of the students is guided by the working definition of scientific literacy that was distilled from the literature. Accordingly, scientific literacy entails having a knowledge that would enable citizens to become more aware of science-related issues, so that the quality of their lives would improve by them applying scientific principles and they would have the power to affect public and technological policy (Adapted from Shen 1975, cited in Shamos 1995).

This working definition of scientific literacy is aligned to the scientific literacy test in this study for two principal reasons. First, by and large, the questions in the scientific literacy test attempt to transcend the assessment of scientific vocabulary (the so-called lexical knowledge of science). Some of the scientific literacy questions are aimed at increasing awareness of science-related issues, and the application of that knowledge in real life situations. For example, one question explores the influence of the force of inertia on a passenger travelling in a car when the car changes direction. The second reason why this working definition is chosen for scientific literacy is that the scientific literacy questions in this study are designed to test whether students have the ability to affect public and technological policy. For example, the question on global warming tests if students know whether carbon dioxide gas is responsible for this phenomenon. Thus, if students are in the know, they can affect public and technological policy on reducing the emission of carbon dioxide gas.

The content of twenty multiple-choice questions on scientific literacy resonated with the traditional matric science syllabus. But, the twenty questions were also aligned to C2005 themes in the Natural Sciences as illustrated above. Additionally, science concepts that were receiving attention in the media at the time of development of the questionnaire were also included. The justification for using the old syllabus as a source of content lies in the fact that “content was initially de-emphasized in the new curriculum” (Chisholm et al 2000:22). There was a deliberate silence in the C2005 documents on the nature of the content that must be pursued. This silence was intentional as the specification of content was seen as prescriptive within the OBE paradigm.

The above introduction related to the rationale for a focus on knowledge as per the working definition of scientific literacy, and the sources of content for the twenty questions on scientific literacy, was important as it contextualizes the discussion of the findings which follows.

This study focused on the scientific and technological literacy levels of the first year physics students and the effects of a traditional science curriculum. This discussion pertains to the scientific literacy component of this study. In the discussion of findings that related to critical question one, the teaching experiences of the students were largely traditional, and although the learning methods of the students were more progressive, the effects of traditional teaching experiences could not be ignored. Even though this situation prevailed, the scientific literacy levels of the students were impressive.

The first essential finding for critical question two categorized the students according to their scientific literacy levels. It can be discerned from Table 7.2. that most of the scores for scientific literacy were clustered between 9 and 16 with some of the scores being distributed on the extremes. Thus, the majority of the students (approximately 75,4 %) were of mediocre or good scientific literacy. A limited number (7,6 %) of students were scientifically illiterate, and a reasonable number (17 %) of the students had an excellent scientific literacy. Considering that these students were taught most frequently with the chalk and talk method or through the use of questions and answers, this distribution of scores is good.

One could also argue that the students were products of a traditional curriculum; hence they could have acquired this scientific literacy by rote learning the structured body of knowledge, and the concepts, principles, and ideas that defined traditional science. However, as mentioned in chapter five, the questions on scientific literacy lent themselves largely to the “comprehension and application” which are the second and third levels in Bloom’s taxonomy of educational objectives: cognitive domain (Ornstein & Hunkins 1998:280). There were also questions that were more suited to Bloom’s first level of educational objectives, namely: knowledge. Even so, these knowledge questions did not entail a recall of facts; they required a sound knowledge of science concepts and principles. Therefore, it was unlikely that the responses to the scientific literacy test were a result of rote learning.

Nonetheless, the high scientific literacy levels of the students were predictable. As mentioned in chapter three, the schools that this cohort of students came from were generally well resourced, and the performance of these students in the matriculation examinations was very impressive. In the six core subjects pursued by these students there was a negligible percentage of under performing students (those with ‘f’ and ‘g’ symbols). Some of the students even scored distinctions in the six core subjects. For example, 12 percent of the students scored distinctions in physics (see Figure 3.6.

p.64). Based on these two factors, one would expect high levels of scientific literacy amongst this cohort of students with a negligible amount of under performance. This prediction actually held true.

The second essential finding that related to critical question two provided a statistical overview of the scientific literacy levels of the students. According to Table 7.3, the lowest score was 6 with three students achieving this score, and the highest score was 18 with four students achieving this score. Table 7.3. also reveals that there were no absolute scores for scientific literacy, i.e. none of the students achieved a score of 20 out of 20. Also, none of the students scored 0 to 5 which means that those in the scientifically illiterate range (0 to 8 out of 20) were clustered on upper end of the scientifically illiterate continuum.

Moreover, Table 7.3. shows that the mean (average score), median (middle score), and mode (most frequent score) were 12, 13 and 13 respectively. There are two deductions that one can make from these scores. First, the closeness of these scores reflects the near normal distribution of the scientific literacy levels of the students as demonstrated in the frequency plots in chapter five. Second, as all these scores are above 50 percent, this implies that generally the students' scientific literacy levels were above average. In fact, the mean, median and mode were above average by at least 10 percent.

The third finding that related to critical question two was a supplementary finding, and it yielded the preferences for disciplines in science for each category of scientifically literate students (see Table 7.4. p.181). Note that the Natural Science Learning Area consists of the following disciplines: Life Sciences, Earth Sciences, and the Physical Sciences. Table 7.4. is suggestive of an evolution of the students' abilities and understandings of science concepts and application thereof as one progresses from the scientifically illiterate students through to the students with excellent scientific literacy.

According to Table 7.4. the scientifically illiterate students and students with mediocre scientific literacy had a penchant for the simpler Life Science concepts. Students with good scientific literacy had evolved to a higher level with a good grasp of both the simple Life Sciences and the more challenging Earth Sciences. Students with excellent scientific literacy had reached the ultimate level with equivalence in understandings across all three disciplines. The rationale behind this set of findings will be discussed for each group of students.

The students who were classified as scientifically illiterate displayed the following tendencies: the questions that were answered correctly most frequently were from the Life Sciences (e.g. questions on cellular respiration and genetics); the questions with a reasonable number of correct answers reflected a balance between the Life and Physical Sciences; the questions with the least correct answers pertained to the Earth and Physical Sciences. Additionally, the Earth Science questions were poorly answered. Therefore, one can infer that the order of popularity of disciplines for the scientifically illiterate students decreases in the following sequence: Life Sciences, Physical Sciences, and Earth Sciences.

The students who were classified as having a mediocre scientific literacy displayed the following tendencies: the questions with the most frequently correct answers suggested an affinity for both the Life and Physical Sciences; the questions with a moderate number of correct answers also suggests an affinity for both the Life and Physical Sciences. However, the least correctly answered questions pertained to the Earth and Physical Sciences. Additionally, the Earth Sciences were not as popular as the Life Sciences (see Figure 5.4. p.123). Once again, the Life Sciences emerged as the most popular of the disciplines.

With regard to the type of questions that were most popular amongst students with a good scientific literacy, one could assume that there was no preference as there was almost a similar kind of scoring for Earth Sciences, Physical Sciences and Life Sciences. This equivalence was suggested by the almost linear distribution of high scores across a combination of disciplines. However, with the low scoring variables 5 (seasonal change), 7 (density), 9 (vector sum of forces), 19 (conduction) and 20 (colour of light), there was an overall weakness related to the Physical Sciences. Variables 7, 9, 19, and 20 were part of the Physical sciences, and the variable 7 part of the Earth Sciences. Therefore, one can conclude that the students with a good scientific literacy were more favourably disposed to questions on the Life and the Earth Sciences. Interestingly, there was a distinct shift from the first two groups (scientifically illiterate and those with mediocre scientific literacy) who were more favourably disposed to the Life Sciences.

For students with excellent scientific literacy, the consistency in the distribution of correct responses, is suggestive of a uniform understanding of science concepts, and the application thereof, across the domain of science, i.e. these students had almost equal abilities and understandings in the Natural, Physical, and Earth Sciences. This equivalence in knowledge is manifested by equivalence in scores. The lowest scoring variables for students with excellent scientific literacy were 9 (vector sum of

forces) and 19 (conduction), with an average performance on variable 20 (colour of light). As variables 9 and 19 are essentially Physical Science questions, one is inclined to believe that there is a weakness in this group of students in the Physical Sciences. However, their almost perfect scoring for other Physical Science questions, as expressed in the linear distribution of correct responses in Figure 5.7, eclipses their poor performance on these two questions. Thus, the core distillation from the above analysis of the students with excellent scientific literacy is that there is equivalence in the abilities and understandings of these students in all three disciplines, namely, the Physical, Life and Earth Sciences.

What is clearly discernible from the above analysis of scientific literacy levels of a cohort of students is that there will always be a variety of abilities and understandings of scientific phenomena within any cohort of students. This variety in abilities and understandings may be due to variations in teaching, to curriculum content, to student interests, or to a host of other reasons. In the above analysis, it is fairly obvious that the variety is due, in part, to preference or popularity of different disciplines in the Natural Sciences. This differentiation of students by discipline and level of scientific literacy could influence pedagogy and curriculum content in an attempt to improve the scientific abilities and understanding of the selected cohort of students.

The fourth finding that related to critical question two was a supplementary finding, and it pertained to the fact that the students' conceptions of scientific literacy were consistent with their categorization according to performance on the scientific literacy test. The fourth finding is derived directly from the focus group interviews that were administered to homogenous groups of students; i.e. students with similar scientific and technological literacy levels were grouped together. The analysis of the focus group interviews is presented in Appendix 3. The fourth finding corroborated the categorization of students based on their scientific literacy levels. Students in each of these categories offered conceptions of scientific literacy which were consistent with their categorization.

The students who were scientifically illiterate provided acceptable definitions of scientific literacy: "(It) is the understanding of science and its application on a daily basis." However, the shallowness of their understanding of scientific literacy was revealed in responses to a question that enquired how they would test if a person were scientifically literate. Their responses were similar to a conception of scientific literacy known as cultural literacy, advocated by Hirsch (1987, cited in Zuzovsky 1997). He defined the concept as a grasp of basic information needed to thrive in the modern world, something that was then translated into possession of a lexicon of scientific terms.

The scientifically illiterate students' shallow responses related to testing for scientific literacy included: "The way he looks at things and if the person has an enquiring mind" or "By asking...how does it come about to rain?" These students also provided inadequate responses to the question that enquired as to how they use scientific principles in their everyday lives. Their responses included: "Putting a plug into a socket to use electricity. Switching a light on/off." Such responses did not even include an explanation of the scientific concepts and principles at play.

The students with a mediocre scientific literacy provided a set of responses to the concept scientific literacy that were largely related to the lexicon of terms associated with science. There was a specific focus on "understanding of the jargon" or understanding scientific terms and language. Only one response mentioned the application of knowledge, experimentation and observation in real life situations. Their responses on lexical knowledge were also similar to the conception of scientific literacy known as cultural literacy, which was described above.

With regard to the nature of testing for scientific literacy proposed by students with a mediocre scientific literacy, the same kind of lexical thinking prevailed where students wanted to enquire whether or not scientific meanings were understood or do people have "the basic understanding about science". Some responses were tangential like: "Take their lifestyle into consideration – what do they do, read – how do they interpret things in life." One response was quite realistic: "If the person is able to figure out any problem without a solution by himself using his common sense e.g. throwing grass in the air to determine the direction of the wind."

As for the application of science in everyday life, the responses provided by students with a mediocre scientific literacy were rather disappointing as students simply listed examples without elaborating on scientific principles e.g. use of electrical appliances, computers and the Internet. One group of students did attempt to elaborate by stating that a focal point is created when taking photographs.

The students with a good scientific literacy offered responses that combined the foci of the two foregoing groups of students. They offered definitions that combined "the knowledge and understanding of scientific terminologies and theories and the application thereof" or the application of mathematical principles to the real world, towards benefit of mankind. Their conception of science seems to fit best with Shen's (1975, cited in Shamos 1995) practical scientific literacy concept which included the kind of scientific and technical knowledge that can immediately be put to use to help to solve practical problems. They also offered interesting responses as to how they would

test for scientific literacy including: “If they can help with your physics homework.” Others wanted scientifically literate people to know basic scientific knowledge, and have conversations about science.

As for the use of science in their everyday lives, some students were rather arrogant and stated that “Most principles are instinctive (and) in our subconscious (sic). We don’t feel we actually benefit from our studies in physics...” Others listed the example of Crossing a road – you judge the speed and distance, time, of the car approaching, if you’ll be able to cross safely.

The fifth finding that related to critical question two was also a supplementary finding, and it pertained to the fact that of all the teaching and learning methods, the most influential in determining scientific literacy levels is working in small groups. An analysis of variance test was administered to establish which of the teaching and learning methods were mostly influential on the scientific literacy levels of the students. At the 10 percent significance, working in small groups emerged as the most influential factor on scientific literacy level. Note that according to chapter three, working in small groups was the least popular of all methods of teaching. 7 % of the students declared that they always used group work as a method of teaching, 17 % experienced it most times, 51 % a few times and 24 % were never exposed to this kind of teaching. Interestingly, the OBE paradigm emphasizes working in small groups as a teaching method and according to this study that should improve the quality of scientific literacy levels.

The sixth finding that related to critical question two was also a supplementary finding, and it pertained to the former department of education that a student’s school was affiliated to. This was the best predictor of scientific literacy. A multiple analysis of variance (MANOVA) test was administered to establish which of the following contextual factors was the best predictor of scientific literacy:

- a) the first language of the student,
- b) the location of school,
- c) the former department that the learner’s school was affiliated to,
- d) the number of learners in the matric science class,
- e) the medium of instruction in the matric science class, and
- f) the performance of the student in matric.

The MANOVA proved that performance in matric and number of learners in the matric science class had a partial influence on the scientific literacy level at a 10 percent significance level. However, the only factor which influences the scientific literacy level at a 5 percent significance level was the former department that the learner's school was affiliated to. Hence, it was the best predictor of scientific literacy levels. Scheffe's pair wise comparison was used to determine which categories of former departments differ. The pair wise comparison revealed that comparisons were significant between groups 5 (House of Assembly-HOA) and 4 (Department of Education and Culture), 5 (HOA) and 3 (House of Representatives), 6 (Other – Mostly Private Schools) and 3 (HOR), 5 (HOA) and 1 (Department of Education and Training).

This concludes the discussion related to findings associated with critical question two and the focus now shifts to critical question three.

7.4. Synthesis of Results Related to Critical Question Three

The second innovation in this study was the use of the Strategic Objectives Learning Outcomes (SOLO) Taxonomy to arrive at qualitative judgments about responses to questions that tested the technological literacy levels of the students. These qualitative judgements were then quantified using the SOLO taxonomy categories.

The third critical question in this study focused on the levels of technological literacy in the selected cohort of undergraduate physics students. To determine the levels of technological literacy of the students, six open-ended questions were administered to the students as part of the all-inclusive questionnaire. The six questions were based on each of the specific outcomes for technology as envisaged in C2005. Some of these questions consisted of sub-questions. A total of eleven sub-questions on technological literacy corresponded to eleven variables. Each student scored between 1 and 5 points for each of the eleven variables. For example, if a student's response was incorrect, inadequate, or a restatement of the question then that response was coded as prestructural according to the SOLO taxonomy and given a score of 1. Similarly, unistructural responses, which provided one correct response to the question, were scored 2. Multistructural responses were scored 3 as they included many correct aspects of the work but did not integrate them together. In relational responses, which were scored 4, the learner integrated the parts with each other so that the whole had a coherent structure and meaning. Extended abstract responses were scored 5 as the learner focused on more abstract features representing a higher mode of operation.

For each student, the mean of these 11 scores was calculated, and the students were classified as follows:

X	=	1	Technologically Illiterate or Prestructural
X	=	2	Unistructural Technological Literacy
X	=	3	Multistructural Technological Literacy
X	=	4	Relational Technological Literacy
X	=	5	Extended Abstract Technological Literacy

(X represents the mean of the scores for the 11 variables, and each of the above classifications is consistent with the SOLO Taxonomy as described in chapter three.)

The categorization of students using prestructural, unistructural, and multistructural labels led to the identification of the students in each of these groups. The three groups of students' scores were compared with their scientific literacy scores. For example, to what extent were students who were scientifically illiterate also exhibiting a prestructural technological literacy? Similarly, mediocre scientific literacy was combined with unistructural technological literacy, good scientific literacy was combined with multistructural technological literacy, and excellent scientific literacy was also combined with multistructural technological literacy because there were no students with relational technological literacy or with extended abstract technological literacy. As there was significant overlap between these two sets of scores, the combined categories were used to perform a qualitative analysis of the six questions on technological literacy. For all six questions on technological literacy, the responses of each category of students were dissected to develop a portrait of the patterns and qualitative differences in the responses of the different combined categories of students.

The foregoing discussion was provided to orient the reader to the process that led to the major findings associated with critical question three.

7.4.1. Findings Related to Critical Question Three

The findings that are presented below are of two distinct types. Those findings that are a direct response to the third critical question are essential findings. Findings one and two below are essential findings. Those findings that are not a direct response to the third critical question, but do inform the understanding of the technological literacy levels of the students, are supplementary findings. Findings three to eight below are supplementary findings.

For critical question one and two, the essential findings were derived exclusively from empirical methods, i.e. data generated from the questionnaire yielded the essential findings. The same applies for essential findings related to critical question three. For critical question two, the supplementary findings derived from a quantitative analysis of data from the questionnaire and qualitative analysis of student responses. The same applies to the supplementary findings for critical question three. Once again, the supplementary findings combine qualitative and quantitative research methods.

Finding One (Essential Finding):

The distribution of students per technological literacy score were as follows:

Technological Literacy Score	Frequency	Percent
1	22	12.9
2	107	62.6
3	42	24.5
	N = 171	100

Table 7.5. The Distribution of Students Per Technological Literacy Score

Finding Two (Essential Finding):

The statistical overview of technological literacy levels of the students yielded the following results:

LOWEST SCORE		HIGHEST SCORE		MEAN	MEDIAN	MODE
Value	Frequency	Value	Frequency			
1.18	7	3.45	2	2.13	2.09	2.18

Table 7.6. Statistical Overview of Technological Literacy Levels of the Students

Finding Three (Supplementary Finding):

There was considerable overlap between the corresponding scientific and technological literacy levels of the students as revealed in Table 7.7. below.

Category	Scientific Literacy Level	Technological Literacy Level	Number of Students
1	Illiterate	Prestructural	5
2	Mediocre	Unistructural	32
3	Good	Multistructural	20
4	Excellent	Multistructural	14
			N =71

Table 7.7. Combined Scientific and Technology Literacy Levels of Students

For each of the combined categories, the responses to all six questions on technological literacy were analyzed qualitatively. This qualitative analysis generated finding four.

Finding Four (Supplementary Finding):

For all six questions, the characteristics associated with each SOLO Taxonomy level were generally mirrored by the corresponding category of students. Thus, confirming that the SOLO Taxonomy is a reliable assessment method of quantifying qualitative responses and using them as a baseline for improvement.

Finding Five (Supplementary Finding):

The students' conceptions of technological literacy were consistent with their categorization as outlined in Table 7.7. Their definitions were confined to interpretations of technological literacy that placed emphasis on conceptual material and technological skill.

Finding Six (Supplementary Finding):

Cooperative learning environments did have a significant effect on the quality of responses to technological literacy questions.

Finding Seven (Supplementary Finding):

There is no relationship between the teaching and learning methods experienced by the students and their technological literacy levels.

Finding Eight (Supplementary Finding):

The first language of a student is the best predictor of technological literacy.

7.4.2. Discussion of Findings Related to Critical Question Three

There is a fundamental difference in the examination of scientific and technological literacy levels of students in this study. Physical Science, Biology, and General Science were subjects that were offered at schools and as such each of them had a structured domain of scientific knowledge. On the other hand, technology has never been successfully mainstreamed in South Africa. A structured domain of knowledge associated with technology has not been defined in South Africa. Therefore, while it is possible to measure scientific literacy because students had exposure to science (Physical, Biological and General Science) education, it is not possible to do the same for technological literacy, as the students were not exposed to technology education. If anything, technology was an afterthought, especially in light of the central focus of the content that even eclipsed practical work. Therefore it is the firm belief of the author that this study does not measure technological literacy, but rather it measures intuitive technological literacy. This is a novel concept that emerged during this study.

Regardless of the status of technology in the traditional science curriculum, the technological literacy levels of the students were acceptable. The first finding of this study, which was an essential finding and therefore a direct response to the third critical question, related to the distribution of students per technological literacy score. The rounded technological literacy scores were from one to three. These rounded technological literacy scores were actually the rounded means of eleven variables

related to technological literacy. It is imperative to understand that if a student had a rounded technological literacy score of 2 that this did not mean that s/he scored 2 for all the variables. Indeed, a student with a rounded technological literacy of 2 could have scored 1, 3, 4, or even 5 for some of the eleven variables. Nonetheless, the distribution of students per rounded technological literacy score is reasonable.

A small proportion of the students was in the prestructural category (12.9 %) which implied that on the whole their responses were inadequate, irrelevant or simply a restatement of the question. Most of the students (62.6 %) were in the unistructural technological literacy score. A fair proportion of students (24,5 %) was in the multistructural technological literacy score. Because there were no rounded technological literacy scores in the relational and extended abstract categories of 4 and 5 respectively, it does not mean that there were no individual scores of 4 and 5 for any of the variables. There were indeed technological literacy scores of 4 and 5 for some of the variables but the rounded mean of the eleven variables (rounded technological literacy level) never exceeded 3.

The second finding that related to critical question three, was also an essential finding and it provided a statistical overview of the technological literacy levels of the students. There are three important features of the statistical overview which distinguish technological literacy scores from the scientific literacy scores. First, the range of scores was much smaller for technological literacy as compared to scientific literacy scores. The technological scores ranged from 1.18 through to 3.45 out of a maximum of 5. The scientific literacy scores ranged from 6 to 18. Second, the technological literacy scores were not whole or natural numbers as they represented the mean score for eleven questions on technological literacy. Third, the corresponding mean, median and mode for technological literacy were much smaller and not natural numbers.

Table 7.6. shows that the mean (average score), median (middle score), and mode (most frequent score) were 2.13, 2.09 and 2.18 respectively. There are two deductions that one can make from these scores. First, the closeness of these scores reflects the near normal distribution of the technological literacy levels of the students as demonstrated in the frequency plots in chapter five. Second, as all these scores are close to 2, this implies that the technological literacy levels of the students were largely at the unistructural level of the SOLO Taxonomy.

The third finding that was related to critical question three, was a supplementary finding, and it showed that there was a high level of overlap between the technological and scientific literacy scores. 42 % of the students had corresponding scientific and technological literacy levels as revealed in Table 7.7. What this implies is that one can predict a student's technological literacy with 42 percent confidence if the scientific literacy level is known and vice versa. The level of confidence with which such a prediction can be made is high considering that the scientific levels were informed by a structured domain of knowledge and a set of teaching experiences while the technological literacy levels are based largely on intuition as described above. The combination of corresponding scientific and technological literacy levels of the students was the basis of categorization of students for the qualitative analysis of responses to the six open-ended technological literacy questions.

The fourth finding that related to critical question three, also a supplementary finding, confirmed that for all six questions, the characteristics associated with each SOLO Taxonomy level were generally mirrored by the corresponding category of students. Thus, confirming that SOLO Taxonomy is a reliable assessment method of quantifying qualitative responses and using them as a baseline for improvement.

The qualitative analysis revealed that for each of the six technology related questions, there was generally a spread of responses from inadequate to superior, and the quality of the responses were generally aligned to the categories of students. For example, consider the responses to the question on selecting and evaluating products and systems, which required students to describe the technological features of a cell phone. The responses progressed from category 1 students who were either incorrect, avoided answering the questions, focused on irrelevant information, or incoherent; to category 2 students' responses which were a combination of mediocre and poor responses. Mediocre responses included a list of technological factors like good reception and network coverage but did not attempt to integrate the list of factors and bring any coherence to the response. Lower order responses were commercial in nature or contained irrelevant information. Category 3 offered more refined responses than their counterparts in categories 1 and 2. Category 3 students still provided a list of technological factors but enhanced the list with the use of labels like ergonomics. Category 4 students' responses were similar to those of category 3 students.

One can conclude from this illustrated analysis of the question related to a cell phone, that in order to successfully demonstrate the associated outcome of selecting and evaluating products and systems, there are different levels through which learners must progress. Sure, some learners may be able to automatically qualify at the SOLO taxonomy level of multistructural or even extended abstract level. However, there are other students who will be confined to pre- and unistructural levels when they first encounter the challenges presented in demonstrating an outcome. These students will have to be guided through processes that will elevate their understandings to reach higher SOLO Taxonomic levels.

The fifth finding that related to critical question three, was a supplementary finding, and it stated that the students' conceptions of technological literacy were consistent with their categorization as outlined in Table 7.7. Their definitions were confined to interpretations of technological literacy that placed emphasis on conceptual material and technological skill. This finding was informed by the analysis of responses provided by students during the focus group interviews (see Appendices 2 and 3 for the focus group schedule and analysis respectively).

The literature showed the evolution of the concept of technological literacy from an emphasis on conceptual material; to an emphasis on technological skills; and finally into a multidimensional concept which included applications of technology in new situations, an appreciation of societal issues and values, and the use of research skills to arrive at technological solutions.

Category one students' definitions of technological literacy were more inclined towards the first phase in the evolution of the concept as there was an emphasis on conceptual material. The emphasis on conceptual material was evident in definitions like: "It's the understanding of technology like electricity and its understanding by the ordinary people..." There was also a focus technological skills, albeit less conspicuous in the definitions provided by category one students, but more so in the tests for technological literacy proposed by the same students. The emphasis on technological skills was displayed in recommendations of technological literacy tests like: "If a person is exposed to technological appliances and knows how to use them in a daily basis."

Category two students were almost exclusively focused on technological skills. Their responses related largely to the use technological devices in everyday life and being computer literate. For example, one group of students stated that technological literacy meant to "be able to use and feel comfortable with technological equipment and able to adapt to advancements thereof". The ways in

which these students in category two proposed to test the technological literacy of the students was also focused on technological skills. There were also some references to conceptual material where students defined technological literacy as a “basic understanding of the jargon”.

Category three students had an equivalent focus on conceptual material and technological skills. The focus on conceptual material was displayed in comments like: “The awareness of Technological advances in the fields of mechanics and electronic advance (sic), and the ability to use, apply and improve on these theories.” The focus on technological skills was evident in tests for technological literacy, which were about operating modern appliances like computers and cell phones.

There was a silence in all these categories of students on the multidimensional concept to technological literacy which included applications of technology in new situations, an appreciation of societal issues and values, and the use of research skills to arrive at technological solutions. This silence was expected of this group of students whose technological literacy levels were mediocre. As one progresses with technological literacy, it is possible for someone who attain the highest level where s/he critically “analyzes the pros and cons of any technological development (using reliable research methods), to examine its potential benefits (and demerits), its potential costs, and to perceive the underlying political and social forces (especially values) driving the development” (Fleming 1987, cited in Saskatchewan Education 2000:1).

The sixth finding that related to the third critical question was a supplementary finding and it concluded that cooperative learning environments improved the quality of the responses provided by each category of students. This finding was informed by the analysis of responses provided by students during the focus group interviews (see Appendices 2 and 3 for the focus group schedule and analysis respectively). One example related to the technological literacy question on whether the drug AZT should be made available to students, will be used to illustrate this finding.

When a questionnaire was administered individually, category 1 students’ responses were inadequate with students either not responding or admitting to having no understanding of the drug AZT. In the focus group interviews, category 1 students provided very coherent and correct responses to the questions. For example, “Yes, it must be available in order to lower the rate of babies born with HIV virus” thus showing clear evidence of understanding of the inhibition of the mother to child transmission by the drug. This was a significant improvement to the individual responses of the same students.

When the questionnaire was administered individually, category 2 students' responses were of three types: 1) a combination of informed answers which reflected some understanding of the drug and its use; 2) responses which were purely speculative or in which students admitted having no clue about what the drug; and 3) responses which defended the government's standpoint on not making the drug available to pregnant women. In the focus group interviews, once again, students provided very coherent responses to the question. One group stated explicitly, "it lowers the risk of their unborn child contracting AIDS," thus demonstrating clearly that the understanding of mother to child transmission of the virus and the effect of the drug. Once again, there was a significant improvement to the individual responses of the same students.

In the questionnaire, category 3 students were generally able to provide coherent responses to the question on whether AZT should be made available to pregnant women. In the focus group interviews, there was no doubt that the students knew what the drug was used for, but they went a step further. The students took the discussion to new heights by focusing on societal and political issues. This is the highest level of technological literacy and is supported in the working definition of technology provided above. In terms of societal issues, the students enquired about the increase in the number of orphans, as the mother's death would only be prolonged. They also discussed the ongoing debate in South Africa as to whether poverty causes AIDS and contested that viewpoint. Thus, they were truly exhibiting technological literacy as envisaged by the working definition of technological literacy in this study. They were analyzing the pros and cons of any technological development, to examine its potential benefits (and demerits), and exploring the underlying political and social forces. Interestingly, cooperative learning was not a focus of the traditional curriculum. But it is in the new OBE approach to science and technology. What this finding suggests is that we have the potential to improve the quality of technological literacy of the students if we allow them to collaborate on learning activities.

The seventh finding that related to critical question three, also a supplementary finding, confirmed that there is no relationship between the teaching and learning methods experienced by the students and their technological literacy levels. An analysis of variance test was administered to establish which of the teaching and learning methods were mostly influential on the technological literacy levels of the students. At the 5 and 10 percent significance level none of the teaching and learning methods had an influence on the technological literacy levels of the students. This finding is not surprising in the least as it was mentioned above that technology, like practical work, was the stepchild of the traditional science curriculum. Therefore, neither the teaching methods nor the

learning methods were geared towards technology. The learning related to technology was either as a result of limited discussions in the traditional curriculum on the application of scientific knowledge or because of personal interest displayed by the students in technological advancements. The interesting part of this finding lies in the challenge that it presents for the success of technology in the OBE curriculum, as it does not point to a specific learning or teaching method that can be pursued to enable technological literacy.

Finally, the eight finding related to the third critical question, yet another supplementary finding, showed that the first language of a student is the best predictor of technological literacy. A multiple analysis of variance (MANOVA) test was administered to establish which of the following contextual factors was the best predictor of technological literacy:

- a) the first language of the student,
- b) the location of school,
- c) the former department that the learner's school was affiliated to,
- d) the number of learners in the matric science class,
- e) the medium of instruction in the matric science class, and
- f) the performance of the student in matric.

The MANOVA proved that the only factor that influenced the technological literacy level at a 5 percent significance level was the first language of a student. Hence, it was the best predictor of scientific literacy levels. None of the remaining contextual factors were influential on technological literacy levels, even at a 10 percent significance level. Scheffe's pair wise comparison was used to determine which categories of first languages differ. The pair wise comparison revealed that there were no significant differences between the different language groups.

As mentioned in chapter three, the first language of the students was one of the two variables in this study that were used as proxy indicators to determine the racial distribution of the sample. The first language of a student was defined in the questionnaire as the language that was used most often by the student. Nearly half of the students (49 %) in this study used Afrikaans as their first language, and about one quarter (24 %) of them used English as their first language. The remaining students (29 %) listed indigenous languages like IsiZulu, Setswana, IsiXhosa, and Sepedi as their first language.

This concludes the discussion related to the findings associated with critical question three. The focus now shifts to recommendations that emerged in the course of his study.

7.5. Recommendations

There are two sets of recommendations offered below. First, a set of recommendations related to selected findings of the study. Second, a set of recommendations that address the limitations of this study.

7.5.1. Recommendations related to Selected Findings of this Study

There are six principal recommendations. Each of these recommendations are linked to one of more selected findings related to the three critical questions in this study.

It is apparent from the first and second essential findings of critical question one that behaviourist approaches to teaching still fingerprint the educational system in South Africa. This was evident in the high frequencies with which chalk and talk and the use of questions and answers featured as science teaching methods at Grade 12 level. The first recommendation is that deliberate attempts be made, through legislation, to facilitate the execution of more progressive science teaching methodologies in grades 10 to 12. These progressive teaching methods are currently being explored in the lower grades in South African schools but the system cannot afford to delay the same in higher grades because of the sequential manner in which OBE is being introduced into the schooling system. This research (essential finding five of critical question one) also points to specific teaching methodologies that need to be engaged in the higher grades. For example, the strongest dependence between teaching and learning methods at the five percent significance level using the chi-square test statistic was between the science experiments teaching method and relating physics to real life as a learning method. Hence, the mainstreaming of science experiments would enhance the quality of the learning methods embraced by the students as they would begin to relate physics to real life situations. Note that according to essential finding three of critical question one, practical work (science experiments) was the stepchild of the traditional science curriculum. Other teaching methods that this study proposes be focused on in the higher grades, using the Pearson correlation coefficient test results, include working in small groups as it was closely related to the learning method of using numbers, concepts and principles. Further, working in small groups proved to be the most influential learning method on scientific literacy levels of the students according to

supplementary finding five for critical question two. Moreover, supplementary finding six of critical question three showed that cooperative learning environments did have a significant effect on the quality of responses to technological literacy questions.

The second recommendation pertains to uniting the world of the student with the world of science. As mentioned above, the fourth essential finding of critical question one demonstrated how the experiences of the students were ignored in the development of an understanding of science knowledge. Evidence of this finding lay in the fact that the use of student-centred science experiments were unpopular, and group work was the least popular method of teaching. But how does one go about uniting the world of a content-laden syllabus with a high stakes matric (Grade 12) examination, that is also content-oriented, with the variety of ideas with which students arrive at school with. The justification for doing so is even more important than describing the how part because if the learner does not make meaning of the knowledge presented at school by linking it to his own set of ideas, the knowledge will never be assimilated. Nonetheless, I will still provide a process option to blend the world of the student with the world of science. It is clear from the ongoing debates about the implementation of C2005 in the lower grades that there was an overwhelming shift to process and a de-emphasis on content. To successfully link the world of the student with the world of science in the higher grades we need to straddle both content and process equally. The science syllabus for the higher grades in science has remained static for the last fifteen years as discussed in chapter four. The syllabus needs to be redefined in terms of content and processes that incorporate the outcomes related to science and technology as envisaged in C2005. Such an approach must transcend what is available in the Discussion Document of C2005 (DOE 1997a). The essence of the approach would be to identify content, knowledge and skills which are fundamental to learn science, identify ways in which information can be elicited from learners to engage with that knowledge, and then facilitate the exchange of ideas between these two worlds of science and the student.

The third recommendation relates to the first and second essential findings of critical question two, which highlighted the impressive levels of scientific literacy of the students who experienced a traditional science curriculum. Indeed, we need to maintain and improve on these levels of scientific literacy. Very often when there is a change in the government; there is a tendency to replace all that existed under the predecessor. The same holds true for C2005, which has attempted to displace every trace of the traditional system. However, this might not necessarily be the best option in light of the findings, which show impressive scientific literacy levels for products of the traditional curriculum.

Hence, an eclectic approach is recommended which embraces the merits of both the traditional and the new OBE approach. This might entail the use of the traditional science curriculum to prioritize the content of science syllabus and the use of the C2005 framework to identify the best processes associated with facilitating an exchange between students' experiences and the content. This melting pot of the traditional and C2005 approaches could improve on the scientific literacy levels.

The fourth recommendation pertains to the preferences of students for the different disciplines (Life, Earth, and Physical Sciences) in the Natural Science learning area. It is evident from supplementary finding three related to critical question two, that students with lower scientific literacy levels prefer the Life and Earth Sciences, while students with higher scientific literacy levels demonstrate an equivalence in understanding across all three disciplines. As mentioned in the discussion, this differentiation of students by discipline and level of scientific literacy could influence pedagogy and curriculum content in an attempt to improve the scientific abilities and understanding of the selected cohort of students. The fourth recommendation echoes the C2005 approach, which eliminates the barriers that exist between these three disciplines. C2005 insists on a co-existence of the three disciplines regardless of the theme (e.g. Life and Living) of Natural Science that is being pursued. The three disciplines are inextricably linked regardless of the theme that is being pursued. For example, by showing the linkages associated with the three disciplines, and using practical demonstrations to show how we engage the Physical Science concepts in our daily lives, students will understand that the Physical Sciences is no different than the Life and Earth Sciences. Of course, more time would be apportioned to the thematic approach.

The fifth recommendation is related to essential findings one and two of the third critical question which highlight acceptable, but not particularly striking, levels of technological literacy of the students. As mentioned in chapter three, technology education does not have a structured body of knowledge, of organizing concepts, of underlying and fundamental principles, ideas that define an academic discipline. Therefore, it follows that there is no valid way of determining curriculum content. Hence, my theory is that this study did not measure technological literacy in the true sense. What was measured in this study is 'intuitive technological literacy' as the students did not take the subject at school level, and if they had exposure to technology education, it had no structured domain of knowledge.

It is therefore recommended that South Africa define a structured body of knowledge with organizing concepts, underlying and fundamental principles, and ideas for technology. Technology has never been successfully mainstreamed in South Africa. There have been attempts at this effort in South Africa as discussed in chapter two. For example, the T2005 Project commenced with a focus on a National Curriculum Framework for Technology Education but ended up focusing on the integration of technology into the life-skills curriculum, which sidelined technology. If the syllabus for technology can be defined, it will help to overcome the confusion that currently prevails about whether technology is deserving of a learning area status.

The sixth and final recommendation is the most important in terms of the future of qualitative assessment practices in South Africa. Supplementary finding four of critical question three revealed that for all six questions on technological literacy, the characteristics associated with each SOLO Taxonomy level were generally mirrored by the corresponding category of students. Thus, confirming that SOLO Taxonomy is a reliable assessment method of quantifying qualitative responses and using them as a baseline for improvement. According to the Centre for Education Policy Development submission to the Review Committee on C2005, C2005 lacks of grade-based benchmarks against which to assess learner performance. Part of the reason for the latter is because “the assessment criteria are broadly stated and do not themselves provide sufficient details of exactly what and how much learning marks an acceptable level of achievement of the outcome” according to the Discussion Document of C2005 (DOE 1997a:12).

The recommendation then is that we begin to explore the implications of the use of the SOLO taxonomy at scale in South Africa. Many educators, education officials and academics are proceeding with the implementation of C2005 without this understanding of how to quantify essentially qualitative outcomes. While Chisholm et al (2000) made several recommendations on the proposed changes to the structure of the curriculum, there was a distinct silence on simplifying the assessment of outcomes as illustrated with the SOLO Taxonomy above. The SOLO Taxonomy will provide South Africa with a simple, yet systematic, method of facilitating learner performance reviews and learner progression.

7.5.2. Recommendations related to the Limitations of this Study

This study was conducted independently by the author, and as such there were human resource limitations. Thus, the scope and depth of the study were informed by these limitations. Consequently, for the sake of convenience, the focus of this study was confined to a single cohort of physics students at one institution, namely the University of Pretoria, who had experienced a traditional science curriculum at school. Indeed, this limits the extent to which the findings of this study can be extrapolated to all students who experienced traditional science curricula at school. Therefore, if this study were to be replicated or taken to scale, it is recommended that the target and sample populations are of greater magnitude and that they be selected from many institutions.

The second limitation of this study pertains to the nature of the questions on scientific and technological literacy. The author and the supervisor made concerted efforts to develop a collection of questions and review them objectively before the final selection was made. It was also the first time that scientific and technological literacy questions were being developed for research purposes within the framework of OBE. The questions were linked directly to the four themes in the Natural Science learning area and they resonated with the specific outcomes of Natural Sciences and Technology.

There is a universe of questions that can be developed for the purpose of testing scientific and technological literacy. Our collection of questions was limited in number and shaped by our own subjective biases. We did validate the questionnaire by piloting it with Technology Education students and incorporated their contributions in the final version of the questionnaire. Nonetheless, it is possible, with more resources and with additional time, to develop a data bank of questions, which are more objective. These questions can then be used to determine with greater accuracy the scientific and technological literacy levels of the students; i.e. the results will be more reliable.

The nature of some of the questions that were used in the test on scientific literacy can definitely be improved:

Question four pertained to seasonal change, and the author believed that this phenomenon was best explained by the tilting of the earth. However, one could also combine the latter with the alternative that related to the position of the earth relative to the sun. This combination could be correct because the word 'position' is an ambiguous one. The word position could have three meanings:

- a) it can be interpreted to mean position of the earth within the solar system but that is not explicit;
- b) it could mean position of the earth during the revolution of the earth but that is not explicit; and
- c) it can also mean tilt of the earth but that is also not explicit.

Because of the lack of explicit detail in the alternative related to the position of the earth, the best answer for this question would be the tilt of the earth. However, if the question is used again, there must be no ambiguity implicit in the words used in the alternatives.

Question five related to the free fall of objects. To make the question more relevant, the author presented a scenario where while making your way to a lecture, three objects (a pen, an eraser and a coin) fall out of a pocket at the same time. The question required the respondents to identify which of the objects would fall the fastest or if they would all fall together. The author listed the fourth alternative; i.e. all objects fall together as the correct option. A point of criticism may be that this is a weak answer because it does not say which object would reach the earth first or last; and if you take air resistance into account the objects would not reach the ground at the same time.

The fundamental concept being tested in this question five is whether students understand that all objects fall towards the earth with the same acceleration due to gravity (approximately 10m/s^2). Of course, the concept of air resistance is important as in the case of a sheet of paper, which has a large surface area. A sheet of paper will experience more air resistance than a pen when falling, and thus reach the ground later. However, if the objects do not have a large surface area, then the effects of air resistance are negligible as in the case of the three objects above and they reach the ground at the same time. In any event, the motion that was being analyzed was the simultaneous free fall. Nonetheless, the effects of air resistance and the sizes of objects must be carefully presented if this question is used again in a scientific literacy test.

Question six focused on the level of water in a container “decreasing” when the ice melts. A possible criticism is that while floating it (ice) displaces the amount of water to which it will melt, so the level of water will remain the same. The author offers the following rationale for stating that the volume of water will decrease when the ice melts:

Consider an ice tray with water before it is placed into a freezer. Suppose that the water level of each cube of water is the same as the height of the side of the tray. The water molecules in this liquid phase are in contact with one another. When the ice begins to freeze the amount of water in the tray does not increase but the volume of the cube expands, and the height of the cube is now higher than the side of the tray, the cube also expands onto the sides of the tray. This happens because as water turns to ice, the distance between the water molecules increases. Hence, its volume increases. The reverse of this process of ice making occurs when the ice melts in water. The volume of the ice in a liquid phase is less than that in a solid phase. Hence, the level of water should decrease when ice melts in water. Incidentally, the author conducted the experiment and confirmed that the level of water decreases when the ice melted. Nonetheless, the stem of this question was contentious as some say the level of water decreases and others say that it remains the same. However, that ice is less dense than water cannot be disputed, and this was the answer required of the students. Therefore, if the same concept is tested in the future, the question must not have a stem, which is so contentious.

Question seven concerned Newton's First Law of Motion; i.e. a body will remain in a state of rest or uniform motion in a straight line unless acted upon by a net or unbalanced force. A situation was presented where you are riding in a car, which swerved to the left and your body moves to the right. The author contended that the reason why the body moved to the right was because it wanted to continue moving in a straight line.

A point of criticism is that in the question and answers two systems are mixed up, the one of the passenger in the car and the other of the outside observer. Hence, in the first system the answer 3 (move to the right) will be correct, and in the second system the answer 4 (keep on going in a straight line) will be correct. It is highly possible that the question can be interpreted in these two ways. The author was fixed on the second system response and it seems as though the respondents were as well because 98.24% of the students selected "keep on moving in a straight line" as the correct answer. If the same question is used in the future, the criticism must be addressed.

Question 8 pertained to the pushing and pulling of objects. The author contends that it is easier to pull an object than to push it. Objects exert a downward force equal to their weight onto the ground. In return, the ground exerts a normal force, equal to the weight of the object, in an upward direction. When you push the object, you are exerting a downward and a horizontal force on the object. Thus, you are in fact pushing the object into the ground while trying to move it across the floor. This makes it difficult to push the object. When you pull an object, you are exerting a horizontal and an upward

force on the object. Thus, you are pulling the object off the ground and trying to pull it across the floor. The combined upward force (normal plus the one you exert) makes it easier for you to pull the object across the floor, as there is less resistance with the floor.

Rather than complicate this question with the concept of normal force, the intention was to elicit, in a simple way, the understanding that the upward force is greater when you pull as opposed to when you push objects. The possible criticism is that this question cannot be answered without more information about the situation. For example, the points at which the forces act; the direction of the push and the pull; a drawing; and/or better description of the situation. These considerations must be made and incorporated into the revised question.

Question eleven related to the cellular respiration. The respondents were required to identify the by-products of cellular respiration. The most appropriate answer was CO₂ and energy. A point of criticism is that water should have been included as part of the answer. At another level, we could specify ATP as a product, or add that heat could also be considered as a product of cellular respiration. At yet another extreme, we could consider NADH₂ and FADH₂ as products although they are consumed within the energy carrier system of cellular respiration. The point of the question was not to go into factual detail. Many students often confuse the processes of gaseous exchange with cellular respiration. The rationale for the question was to check whether students know that cellular respiration is similar to gaseous exchange, which releases CO₂, but different to gaseous exchange in that energy is released during cellular respiration. It is apparent that many of the respondents had very little difficulty in figuring out the most correct response as 80.29 % got it right. Regardless, if the question is repeated in a scientific literacy test then water should be part of the answer.

Question eighteen concerned the identification of the best conductor of electricity as Silver not Copper. A possible criticism is that the differences between the electrical resistivity of Copper and Silver are marginal... so the properties of Copper are not far superior to that of Silver.

The question required the respondents to identify the “best conductor” of electricity. Rightly so, even though the difference is marginal, the answer is Silver. The rationale for including the question was not to test the level of detail in terms of electrical resistivity. Rather, the idea was to check the respondents understanding of conductivity of different elements, which is a feature in the General Science syllabus in South Africa. The reason why Silver is not used as extensively as Copper is

simply because of the higher costs and the nature of the material. Nonetheless, the question will not be recommended for future tests of scientific literacy.

Lastly, question nineteen on colour of light is very interesting. It must be noted that these questions were informed largely by the syllabus documents for Science in South Africa. It is clear in the Standard 9 or Grade 11 Physical Science Syllabus that when light passes from one medium to another (of different optical density) then its speed changes but its colour remains constant. This change in speed is brought about by a change in wavelength, not a change in frequency (note $v = fh$, where h represents λ , the symbol for wavelength). Therefore, the colour of light is determined by its frequency not its wavelength. Some critics may argue that both wavelength and frequency determine the colour of light. This criticism must inform similar questions in future tests of scientific literacy.

The third limitation of this study concerned the literature review. There is a dearth of literature available on the technological literacy. There are two main reasons for this limitation. First, more attention has been focused on the concept scientific literacy that spawned the concept of technological literacy. Technological literacy is a relatively new concept compared to scientific literacy. The origins of the concept scientific literacy were traced back to the 1930's and the concept of technological literacy was only alluded to in the 1970's when the concept of practical scientific literacy was presented by Shen (1975, cited in Shamos 1995) [see Table 2.1. pp.29-32]. Second, technological literacy is commonly subsumed within the scientific and technological literacy discourse. Nonetheless, every effort was made to provide an insightful exposition of the different conceptions of technological literacy. This study contributed to the literature with the introduction of a new concept, namely intuitive technological literacy. It was proposed above in the section on recommendations related to the findings of this study that a curriculum be developed for technology so that it can be worthy of learning area status. It is recommended that concomitantly the process of development be documented and published to contribute to the limited literature available on technological literacy.

The fourth limitation is related to the research methodology of this study, which can be described best as the Mixed Methodology Design Model of combining qualitative and quantitative research methods. The mixed methodology method entailed mixing aspects of the qualitative and quantitative paradigm at all or many methodological steps in the design. This research methodology approach required a superior knowledge of both the qualitative and quantitative paradigms of research. However, the author was a novice qualitative and quantitative researcher, and the guidance and

advice of the supervisor and the statisticians from the University of Pretoria proved invaluable. It is recommended that if the study is replicated or taken to scale that the same kind of support be available. It would be even better if expert qualitative and quantitative researchers can be part of the team that conducts the research and the analysis. These recommendations are being made because arriving at the principal findings associated with each question was a complex and onerous task. The process was extremely iterative and involved several consultations. With the involvement of experts at the coalface, the process would not only be more expeditious but the results will also be more reliable.

The fifth limitation of this study relates to the use of the SOLO Taxonomy for the classification of qualitative responses generated by the students. The use of the SOLO Taxonomy is simple and systematic; however, there are moments when you doubt your judgement, not at the first three levels of pre, uni, and multistructural responses, but more so at the fourth and fifth levels of relational and extended abstract responses. Sometimes, you encounter a response that lists a variety of factors extremely coherently and you are tempted to assign a score to that response which goes beyond the relational level. So you search desperately for any link to extended abstract ideas. Sometimes the link to abstract ideas is remote and you are tempted to force the classification at a higher level. Given such challenges associated with the use of the SOLO Taxonomy, it is recommended that for future studies, as we did for this one, that the researcher and supervisor agree on some common approach to classifying these higher level responses. What this limitation highlights is that the SOLO Taxonomy like other assessment models, is not a flawless approach. It is not immune to the subjective biases that one encounters when exercising qualitative judgements in other contexts where it is difficult to distinguish between two groups. Nonetheless, these are the exceptions and not the norm with the SOLO Taxonomy. By and large, it is a reliable method of systematically assessing qualitative responses.

It is unequivocal that there were many other limitations of this study; but the discussion was confined to the above five limitations, as they were the most challenging to the author.

7.6. Conclusion

As stated at the outset, South Africa is a fledgling democracy and needs to assert itself on many fronts. This study provided us with an opportunity to explore developments in the spheres of scientific and technological advancement, and in curriculum transformation. The implications of this study for each of these spheres will be elaborated.

With regard to scientific and technological advancement, my thesis is that to progress in this sphere, we need to assess where we are and use that result as a basis of making improvements. The methods used in this study to measure scientific and technological literacy levels have proved successful. We can now embrace these methods, revise them according to scale and need, and assess scientific and technological abilities. Once we establish where we feature as a nation on the barometer of scientific and technological literacy it will help us in two ways. First, it will explain our limitations as a nation to advance scientifically and technologically. Second, it will provide us with an opportunity to review our weaknesses as illustrated in the scientific and technological literacy tests, develop strategies to address the weaknesses, and evolve scientifically and technologically as a nation. The immediate benefit of this scientific and technological evolution lies in the empowerment of the general public to understand events and ideas related to scientific discovery and technological development, and thereby to exercise the rights and responsibilities of citizenship in a democratic society. At a stretch, I might add that economic prosperity will also follow but that hinges on other factors as well like a diligent and industrious society.

With regard to curriculum transformation, my thesis is that we need to explore all viable options in the pursuit of a successful educational system. The transition from a traditional behaviorist curriculum to a progressive outcomes-based education paradigm has been a difficult process in South Africa. This study showcased how traditional practices still dominate the teaching and many learning practices associated with science in our schools. Curriculum transformation will continue to throw many curved balls our way in our pursuit of a perfect educational system for South Africa. As we are in the throes of reforming C2005, and because the SOLO taxonomy has proved successful in this study, it could provide South Africa with a simple method of facilitating learner performance reviews and learner progression as recommended above. The SOLO Taxonomy is an alternative worth pursuing in light of the lack of grade-based benchmarks against which to assess learner performance in South Africa.