THE EXTENT TO WHICH ACTUAL DEVELOPMENT OF PROPORTIONAL REASONING CREATES CONDITIONS FOR POTENTIAL DEVELOPMENT IN VYGOTSKY'S ZPD

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DECLARATION

I declare that this research report is my own, unaided work. It is being submitted to the School of Education for the Degree of Master of Education in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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9th day of June 2009

ABSTRACT

This study has examined how the attainment of theoretical frameworks may create the conditions for and support subsequent learning of related material. In this regard, it has investigated a particular conception of Vygotsky's proposal that learning only occurs in the zone of proximal development, which he defined as the gap between what can be performed independently and what can be achieved with assistance. Specifically, it used a multi-pronged, mixed method research approach to probe the relationship between the actual level of development, as reflected by an ability to do proportional reasoning, and potential development, which was measured as the ability to perform certain strategic procedural operations in the molecular biosciences which were underpinned by proportionality. This four phase study which was carried out on a class of 106 second year students registered for Basic Molecular Biosciences II in the School of Molecular and Cell Biology, at the University of the Witwatersrand, Johannesburg, South Africa, initially measured proportional reasoning ability by posing a generative question requiring proportional reasoning to the class during a lecture and established that only 49% of the students who participated were able to answer the question. It could be shown statistically that these students were more adept at answering a contextual question based on proportion than those who had answered the generative question incorrectly, which suggested that actual development created the conditions for future learning. A paper and pencil test developed from Fleener (1993) which claimed to measure the hierarchical development of proportional reasoning ability was administered to the class and was used to select two groups for comparative purposes. The first group (group one) was comprised of the 23 students who scored 50 % or less, and the control group (group two) consisted of the 15 students who scored 100 %. Using these two groups, it was shown that the control group performed better than group one on specific questions underpinned by proportion which had been included in pre-laboratory tests and in summative assessments. Moreover, the control group's general performance in the course, as assessed by their marks in the examination at the end of the first semester, was substantially better than that of group one (67 % as opposed to a 51% average mark). These results were supported by findings where conceptual development of proportion had been judged from student's informal written accounts of the concept. Drawing on biological evidence, it was concluded that the actual level produces the structures necessary for further development. The second phase of the study utilized two focus groups constituted from students who had been randomly selected from the two groups compared in phase one of the research. Facilitated guided informal discussions probed which of factors like play and leisure activities, early childhood enrichment, schooling, mathematical ability and practices, instruction in proportional reasoning, and parental involvement, might have augmented the development of proportional reasoning ability. In phase three, the factors which emerged from the discussions were interrogated in a specially designed questionnaire which was administered to a sub-set of students who were concurrently registered for Basic Molecular Biosciences II and Biochemistry and Cell Biology II. Statistical analysis of the questionnaire which occurred in phase four of the research led to the conclusion that enrichment in early childhood, and having learnt proportion at school were the two factors that contributed most to attainment of the actual level of development which would enable subsequent learning of more elaborate procedural knowledge constructs based on the concept of proportion. These results supported the view that mediation results in internalisation of the embedded knowledge which can be drawn on for further learning in that domain. Therefore, in the final analysis of the research, it was concluded that actual levels of development create conditions for potential development as conceived by Vygotsky's zone of proximal development.

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1. INTRODUCTION

1.1 Purpose of the study

Effective pedagogy requires an awareness of the types of activities which promote learning especially in light of the premises of constructivist epistemology, which are that knowledge is constructed in the mind, not transmitted and that prior knowledge affects subsequent learning. Elaborating this idea from a *social constructivism* perspective, Vygotsky (1978) proposes that tools, which are externally oriented, and signs, which have become internally positioned in the mind, can be used to orient human behaviour and are therefore necessary for learning. Learning thus takes place in individuals as a result of social interaction between them and the society in which they function, and in relation to the tools they are able to access and the signs they have internalised. Within this framework, Vygotsky (1978) therefore proposes that learning takes place in the '*zone of proximal development*' (ZPD) which he defined as the gap between what task a learner is able to perform independently and what he/she is capable of performing with assistance from, or after mediation by, a more knowledgeable other. Once tasks which fall into the zone of proximal development become familiar, internalised knowledge becomes embodied in the brain, so that the form and content of knowing are no longer the same as they were at the level of mediation. Cognitive development thus occurs between what is 'actual' (has been internalised and can therefore be performed independently) and what may potentially be achieved. Therefore, framed by Vygotsky's conception of the ZPD, the purpose of this research is to investigate the extent to which actual development both constrains and creates the conditions for potential development, and to elucidate some of the factors contributing to actual and/or potential development. In this regard, it is proposed that the research will investigate and focus on a specific area of conceptual understanding, proportional reasoning, which has been deemed an essential basis for acquisition of further knowledge and the ability to perform certain operations in the molecular biosciences.

1.2 Background to the research problem

Notwithstanding constructivist theories, like Vygotsky's conception that learning occurs in the ZPD, which suggests that there are optimal conditions necessary for knowledge acquisition, the reality in higher education is that large numbers of students are simultaneously presented with similar learning challenges, despite the fact that they might be at different stages of cognitive development in a particular area. For example, instructors tend to assume that because they would have completed the prerequisite first year courses before being allowed to register for certain second year courses, all the students in a second year class would have reached a certain level of actual development. Instructive interventions are, in fact, generally designed on this premise.

This situation is far from satisfactory, not least because knowledge in the sciences has been described as a "*vertical hierarchical discourse*" (Bernstein, 2000), which therefore assumes a particular developmental trajectory. Vosniadou (1994) supports this idea with the argument that in the sciences a conceptual framework theory forms the basis for future learning so that '*concepts are embedded into larger theoretical structures which constrain them*'. Conceptual change is said to occur either through enrichment of or through revision of one's mental models. This proposal also lends support to the notion that the effectiveness of instructional mediation would be dependent on the <u>actual</u> level of cognitive development. This suggests that in order to optimize the effect of teaching interventions the instructor would need to know the actual level of conceptual development in individual students and to reconcile the instructional challenges with this.

In the course of their daily activities, molecular bioscientists need, amongst other things, to be able to prepare solutions, calculate concentrations of components in solutions, carry out dilutions of stock solutions, adjust concentrations and volumes to suit experimental conditions, construct and use calibration curves, prepare buffers and interpret differences in the magnitude of spectrophotometric and other measurements. All of these operations require the ability to carry out elementary mathematical operations but are underpinned by the <u>concept of proportionality</u> and an ability to apply proportional reasoning. It has been a consistent observation that despite its inclusion in the school maths curriculum, which gives one reason to believe that the concept of proportion should have been grasped before admission to University, and although these areas are taught in the pre-requisite first year courses, it is apparent that a large percentage of second year students struggle to perform these operations after mediation and teaching interventions during the second year of study when they are introduced. Moreover, it has also been noticed that many science <u>graduates</u> are incapable of carrying out these seemingly basic tasks. This suggests that the problem lies deeper than lack of access to instruction and might in fact be because the actual level of achievement in this area at the time of mediation was not what it was assumed to be, in that students struggling in these areas might not have internalised the theoretical concept of proportion by the time they entered their second year of study. This situation could thus have restricted their potential development in this area.

1.3 Research question and sub-questions

In light of the conceptual underpinning of a number of strategic procedural knowledge constructs used in the molecular biosciences by proportionality, the broad research area of interest was therefore refined to an investigation specific to the subject area of the molecular biosciences and in this regard was embraced by the following research question:

> To what extent does the ability to apply proportional reasoning create the conditions for learning of operations underpinned by the concept of proportion in the molecular biosciences?

This research question was broken down into the following sub-questions which lend themselves to empirical investigation:

- What percentage of a class of second year molecular bioscience students is unable to recognize and solve problems requiring a conceptual understanding of proportion?
- To what extent does an inability to understand proportion impact on subsequent learning of chemical transformations or more specifically, on the ability to perform calculations of concentrations or volumes or equivalents, or which use the [1]Henderson-Hasselbalch equation and dilution factors?
- Does an inability to conceptualize proportion influence general performance and overall results obtained in the Basic Molecular Biosciences II course summative assessments?
- Can one elucidate factors which might have supported and resulted in conceptual understanding of proportion?

[1] The Henderson-Hasselbalch equation describes the relationship between the pH, the pK_a of a weak acid, and the ratio of weak acid to the conjugate base concentration in a solution.

A class of second year students registered for the Basic Molecular Biosciences II course, run by the School of Molecular and Cell Biology, in the Science Faculty, at the University of the Witwatersrand, was chosen as the sample group for this empirical investigation. This is because the operational procedures which are required in the molecular biosciences arena are taught in some depth and are an area of focus in the first semester of this course. Moreover, this course is a co-requisite for all the major courses offered in the school of Molecular and Cell Biology and a pre-requisite course for all the major third year courses offered in the school. Thus it was anticipated that findings from this research might suggest ways to increase the throughput in the school.

1.4 Significance of the study

A study of this nature was designed to provide valuable insight into how the attainment of certain theoretical frameworks may create the conditions for and support subsequent learning of related material and thus to provide empirical support for Vygotsky's proposal that learning only occurs in the zone of proximal development. In this regard, one might hypothesize that if students had not reached the required level of conceptual understanding, further interventions would not bring about the desired level of learning. This study therefore allowed for these conjectures to be tested. It was envisaged that research results would also provide evidence in support of debates about whether the ZPD is socially constructed or whether it is dependent on innate ability or biological structures which have been laid down in the brain. These deliberations also allow one to make suggestions about the appropriate mediation to ensure that the very important concept of proportion has been grasped, understood and internalised by University students. Moreover, in light of the University's quest for increased throughput and the country's need for skilled graduates this study has provided empirical evidence for the notion that instruction in higher education should be based on firmly established conceptual understanding if we are to produce skilled graduates. Results of the study could thus also have implications for assessment practices in that it would be desirable to put in place mechanisms to ensure that certain levels of attainment and conceptual understanding have been achieved before students may progress to the next level; the study could also suggest the types of activities which should be designed for academic support programs.

2. LITERATURE REVIEW

2.1 Introduction

A study of this nature calls for a literature survey of what has been deliberated and established in quite distinct areas which I will outline briefly:

Firstly, one would need to look at interpretations of Vygotsky's constructivist learning theory, particularly when it comes to conceptualizations of his zone of proximal development (ZPD). Following this, one would need to investigate what is known about how knowledge becomes internalised or embodied in the brain as this could have considerable bearing on the actual development in the ZPD so that Vygotsky's learning theory could be explained in biological terms. It would also be advisable to look at the general literature on development of concepts and difficult or threshold concepts before reviewing the literature specific to proportional reasoning, which as has been observed, seems to be a difficult concept to access for a number of students. Finally, the concept of proportion needs to be considered from the theoretical perspective of how it can be explained, what research has been done in the area, connectionist modelling of the concept and its ontological development, and lastly from the methodological or more practical aspect of how to measure or assess proportional reasoning ability. These aspects are elaborated in the literature review which follows.

2.2 A perspective on Vygotsky's Zone of proximal development

In light of constructivist epistemology, the central aim of this research is to investigate the extent to which prior (embedded) knowledge impacts on future learning and creates the conditions for potential cognitive development. This issue is at the core of Vygotsky's proposal that learning takes place in the '*zone of proximal development' (ZPD)* (Vygotsky, 1978) which he defined as the gap between what task a learner is able to perform independently and what he/she is capable of performing with assistance from an instructor or someone who has already mastered the task. '*The zone of proximal development defines those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state*' (Vygotsky, 1978: 86). Vygotsky has been widely recognised for his contribution to social constructivism and therefore much has been written about the impact and contribution of cultural factors to learning. On the other hand, I. Moll (1994) has drawn attention to Vygotsky's recognition '*of natural constraints in cognitive development'* (Moll 1994:333, own emphasis).

> 'Cultural development does not create anything over and above that which potentially exists in the natural development in the child's behavior. Culture, generally speaking does not produce anything over and above that which is given by nature. But it transforms nature to suit the ends of man' (Vygotsky, 1929: 418, cited in I. Moll, 1994).

Karmiloff-Smith (1992) has argued that cognitive developmental theory should therefore encompass both innate predispositions and constructivism, since innate tendencies would impact on potential development. I. Moll's conception of the natural line of development concurs, as it implies that appropriate knowledge structures which would have to have been developed in the brain to account for the actual level of development would thereby delineate potential structures for learning. Future learning would thus be impeded by a lack of the appropriate embedded material and conceptual understanding. Nonetheless, I propose that these structures could be accounted for by biological evidence for learning structures and knowledge organisation in the brain and in this respect that Vygotsky's assertion that "…it (culture) transforms nature….." could be interpreted in terms of the emergence of biological structures which result from learning in a particular domain. At this juncture therefore, it would be useful to review some of the biological evidence which explains how embedded knowledge is encoded and organised in the brain.

2.3 Embedded knowledge

Knowledge could be considered to be laid down and encoded for by brain structures accounting for memory. Kandel (2006) has established that memory is dependent on the establishment of new synapses or from the strengthening of existing neural synapses. From this perspective, mind is little more than an emergent property of the brain's functioning, which raises the question as to whether innate mental functions impose constraints on learning. While much research has concentrated on the neuronal signalling pathways that lead to synaptic strengthening, perhaps the most progressive evidence of how memories are stored in terms of neuronal patterns was recently reported by Tsien (2007), who, together with his colleagues, has developed a method of recording more than 200 neurons simultaneously. When the data were linked with powerful mathematical modelling tools they were able identify and record the temporal dynamics in neural networks as memories were formed and to discern the organising principles of memory formation. By evoking emotionally charged, episodic events in rats, and visualising the distinct pattern of neural activity in the CA1 region of the hippocampus, they were able to establish how the animals laid down memories of each event as it happened. It was also evident that the patterns produced after the startling events recurred spontaneously, but with smaller amplitudes, at intervals ranging from seconds to minutes after the original event. Tsien postulates that these mind replays are evidence of memory recall of the event.

Tsien's research next tried to elucidate how different, but related, memories work together in the brain. He and his co-workers found that '*overall network-level patterns are generated by distinct subsets of neural populations*' that they called '*neural cliques'* (p38). These are probably analogous to the postulations by Grossberg (1982) that concepts are recorded in the brain by '*chunking*' since a '*neural clique'* was defined as: '*a group of neurons that respond similarly to a select event and thus operate collectively as a robust coding unit*' (Tsien, 2007: 38). These investigations also revealed that the set of neural cliques coding for different features associated with a particular event, was organised hierarchically from the general to the specific. Moreover, this organising principle was found to be invariant through all the events recorded. In light of this, Tsien concludes that functional coding units giving rise to memories are the neural cliques. Furthermore, '*the brain relies on memory-coding cliques to record and extract different features of the same event, and it essentially arranges the information into a pyramid whose levels are arranged hierarchically, from the most general abstract features to the most specific*' (p39). He proposes that the pyramids could be part of a polyhedron representing all previously recorded events falling into a shared general category. This would allow new memories with the same general categories but with specific differences to use the existing patterns and substitute the upper level in the hierarchical structure. Other observations led Tsien to conclude that this is probably the organising principle of knowledge recorded throughout other areas of the brain which suggests that it comprises the biological basis of concept formation.

From this account, one could therefore explain the zone of proximal development on a particular task from a biological perspective if one were to assume that previous learning experiences would have formed the neural connections, established hierarchical neural cliques, and strengthened the synapses, which together would have given the individual the relevant long-term memory (signs) to access and the neural (and /or glial) circuitry to facilitate fast connections between that, sensory input and accessible working memory. This would explain Vygotsky's notion that "*nature is* *transformed* *to suit the ends of man* (Vygotsky, 1929: 418, cited in I. Moll, 1994, own emphasis)". The assumption is supported by Raichle's investigations on the performance of word tasks (Raichle, 1994) where it was established that practice resulted in remodelling of brain organisation, so that operations which previously needed to recruit many areas, could be performed in areas denoted to the performance of tasks that did not require conscious thought. Vygotsky's zone of proximal development would therefore imply the existence of the relevant structures needed to perform the task, which were available for recruitment via mediation. Once the task had been practiced however, brain re-organisation would enable the individual to perform the task without assistance and apparently almost automatically.

2.4 Development of Concepts

Although biological evidence may explain how concepts are embedded and recorded in the brain, there is still debate on how concepts develop from a psychological perspective. This obviously has implications for pedagogy and instruction and is particularly relevant in this research project.

Based on experimental studies, Vygotsky (1986) proposes mechanisms for the development of concepts and contrasts the developmental path of general and scientific concepts. With respect to general concept development he refers to Ach (1921, cited in Vygotsky, 1986) whose experiments suggested that *'Concept formation is a creative, not a mechanical passive, process; that a concept emerges and takes shape in the course of a complex operation aimed at the solution of some problem; and that the mere presence of external conditions favoring a mechanical linking of word and object does not suffice to produce a concept'* (Vygotsky, 1986: 99). Ach also considered that concepts developed from expansion of specific entities to general ideas, which was the accepted view at the time, and proposed that, rather than resulting from an associative chain of ideas and words, concepts form as a result of an aim directed process, so that the '*decisive factor in concept formation is the so-called determining tendency.*'(Ibid: 99). While agreeing with Ach that concept formation is not a mechanistic process, Vygotsky nevertheless criticises the notion that problem solving alone would lead to concept formation, particularly since it had been observed that children and adults solve the same problem in very different ways using dissimilar thought processes. His own experiments therefore led him to postulate that '*the development of the processes that eventually result in concept formation begins in earliest childhood, but the intellectual functions that in a combination form the psychological basis of the process of concept formation ripen, take shape, and develop only at puberty. Before that age, we find certain intellectual formations that perform functions similar to those of the genuine concepts to come*' (Vygotsky, 1986: 106, own emphasis), but that these are not equivalent to those of the adult because concepts go through a lengthy process of development. Signs, or the functional use of words, are said to be essential to the process, as they direct attention to the complex activity involving imagery, judgement, as well as a '*determining tendency*'. In this respect, Vygotsky postulates that '*real concepts are impossible without words*', and emphasizes the role of society in providing the intellectual stimulation and demands which enhance cognitive ability resulting in higher order thinking in adolescents, in whom concept formation is first possible. Moreover, concepts are not formed by adding quantitatively to existing thought structures but involve qualitatively new thought processes. He thus proposes that concepts develop in three phases, each made up of several stages.

The first phase evolves through trial and error and culminates when a child is able to put together specific elements from different groups. The next phase, basically involves '*thinking in complexes*', initially concrete, where factual linkages between complexes are discovered, and chain associations between complexes may be made. The third and final phase is the jump from complex thinking through the formation of '*pseudoconcepts*' to the abstraction and generalisation so that they may be viewed apart from the '*totality of the concrete experience in which they are embedded*' (Ibid: 135). That aspect may in fact, be considered the characteristic of concept formation. Vygotsky's theory that concepts develop from abstraction (which is imperative for the process of generalisation) is supported by biological evidence, where it was observed that the underlying organisational principle in the brain appeared to be from the general to the specific (Tsien, 2007).

In contrast to his postulations on the mechanisms of development of general concepts, Vygotsky (1986) proposes that scientific concepts are formed as a result of systematic instruction. Notwithstanding that his experimental observations were made in the area of the social sciences, he explored areas like causality which render his conclusions equally applicable to the biological, chemical and physical sciences. Analysis of his data showed that '*the development of scientific concepts runs ahead of the development of spontaneous concepts*' (p147), with the proviso that the curriculum had covered the necessary material. It was also established that '*accumulation of knowledge supports a steady growth of scientific reasoning, which in its turn favourably influences the development of spontaneous thinking*' (p148). However, although instructive mediation was found to be crucial for maturation of higher mental functions, concept formation cannot be accomplished by drilling and rote learning, since '*a concept is more than the sum of certain associative bonds formed by memory, more than a mere mental habit*' (p149). Thus, even contextualized scientific concepts cannot be imposed on a student from without. It is still necessary for individual internalisation or development to take place before the concept can be considered to be 'embedded knowledge'. This implies that despite societal influences and explicit instruction, understanding of scientific concepts will only be accomplished when the appropriate level of mental development or a certain level of maturity has been attained. The implications in terms of this research project are that one might hypothesize that potential development will be constrained by the actual developmental level, particularly if one accepts that scientific learning follows a specific developmental trajectory as elaborated by Bernstein's (2000) description of a 'vertical hierarchical discourse'.

2.5 Threshold concepts

Instructors in various disciplines would not dispute the idea that certain concepts are less accessible to their students than others. The idea of '*threshold concepts*' was developed by the collaborative research of the group involved in the 'Enhancing Teaching and Learning Environments' project (ETL, 2005), which, between 2001 and 2005, investigated how the quality of students' learning was influenced by the whole teaching-learning environment. It has been proposed that threshold concepts exist in many disciplines (Meyer & Land, 2003). These are believed to initiate a new way of thinking and understanding of certain phenomena. Davies (2003) proposes that the notion of a threshold concept '*redefines the familiar idea of a 'powerful concept' in a social constructivist context, providing a penetrating tool for the analysis of the development of discipline specific learning*' (p1). The conception of a threshold concept envisages that a new concept emerges from reworking of prior knowledge which, in the process, may have encompassed two or more concepts. Furthermore, a threshold concept may have arisen as a transformation of something which was defined in terms of properties, to one which has now been defined in terms of relationships. From this perspective a threshold concept has been defined as '*transformative, irreversible, integrative, bounded and potentially troublesome*' (Davies & Mangan, 2005: 2). Threshold concepts may be considered potentially troublesome as they often contradict the ways in which everyday knowledge and experience has previously been applied to make sense of certain areas, so that they are in effect, counter-intuitive. Therefore, a deep, as opposed to a surface, learning approach is required to make sense of and be able to use a threshold concept. Moreover, threshold concepts are those which can be used in many areas of a discipline.

Pursuing a similar line of reasoning, Kitchener (1983) discusses the role of metacognition in solving what she refers to as 'ill-structured' problems. She accepts the definition of metacognition as: '*self-monitoring of one's own cognitive processes and influences on them when they are focused on a specific task or goal'* (p222). She proposes that metacognition involves three sequential procedures. The first of these is an awareness of self as a cognitive processor in terms of the task. Drawing on biological evidence it appears that the prefrontal cortex would be active at this stage of metacognition. Secondly, one would have to possess knowledge about the tasks. This would require the brain to activate the area in which it had 'stored' memories of these types of tasks. It would therefore require areas in the hippocampus to be activated. The final stage involves knowledge of whether a particular strategy is appropriate for the particular task one is engaged in. This would require activation of the areas in the brain involved in planning, reflection, and long-term memory and would draw on organisational areas (like neural cliques) or what may be described in broader terms as "embedded concepts". These problem types require evaluation of alternative strategies, and an initial reflection of whether the problem is solvable in any form. I feel that this is a form of constructivism similar to that described by Lawson (2003) as requiring an if/then/therefore type of reasoning to attempt a solution which would draw more on internalised conceptual understanding than memorized knowledge. In a similar vein, Hatano (1996:199, own emphasis) points out that "*knowledge becomes useable in a variety of problem solving-solving situations only after it has been reconstructed – that is, interpreted, enriched, and connected to the prior knowledge of the learner*".

2.6 Conceptual change

An investigation by Vosniadou (1994) describes a theoretical framework that has attempted to '*capture and model the process of conceptual change*' and emphases the importance of conceptual structures in the learning of science. As mentioned previously, conceptual change is said to occur gradually either through enrichment or revision of existing structures. Understandably, learning would be more difficult to achieve when revision of existing structures becomes necessary. From this point of view, it is proposed that this situation could lead to classroom observations of inconsistency, inert knowledge and the creation of misconceptions. The construct of a mental model has been used in this research to '*refer to a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning, and which has the special characteristic that it preserves the structure of the thing it is supposed to represent*' (Vosniadou, 1994:48, own emphasis). In light of this it was proposed that mental models are used to problem solve, are retrieved and altered during this process and during cognitive functioning, and as such may constrain the knowledge acquisition process. From this theoretical perspective Vosniadou argues that mental models can therefore be used to provide information about the underlying knowledge structures. In studying conceptual change the methodology has consisted of the asking of many questions about the concept under observation. Some of the questions in her research required a verbal response, some were designed to elicit drawings and others required the construction of models. Responses were used to try and describe the mental models students had used to generate the mental model which allowed them to answer the questions. The researcher draws particular attention to the kinds of questions that were used, distinguishing between those that could be answered from rote learning and those questions that required generation of mental models.

Generative questions have been defined as those which '*confront children with phenomena about which they do not have any direct experience and about which they have not yet received any explicit instruction*' (p 50) and it is this type of question which holds the potential for unravelling the mental models used to answer them. The methodology used in this research, which was carried out on young children, was designed to extract internal inconsistencies in order to validate conclusions drawn about each student's conceptual structures. Specific areas investigated were mental models of the earth from a study conducted in the United

States of America. These were linked to explanations of the day-night cycle. It was evident that mental models used by the children to explain the day-night cycle were constrained by their theoretical beliefs about the structure of the earth. Other related areas, such as the concepts of force and heat were investigated and leant support to the argument. Surprisingly, it was evident that instruction does not succeed in making children revise their original conceptual suppositions, thus once again supporting the claim that concepts develop as a result of internalisation and maturation. In this regard, it seems that the process of conceptual change requires internalisation so that restructuring of knowledge occurs. This may involve differentiation of one piece of knowledge, amalgamation of others, and or may require a change of relationships between various bits of knowledge in a particular domain (Hatano, 1996).

Situating this argument in the context of instruction in the molecular biosciences, one might assume that many undergraduate students arrive in one's class with ill conceived theoretical frames, underdeveloped conceptual knowledge and conceptual misunderstanding. Furthermore, one might hypothesize that if this was the case so that some of the students had not reached the required level of conceptual understanding, or mastered and internalised the 'threshold concepts' as embedded knowledge, further instruction based on these concepts would not bring about the desired level of achievement or understanding. This hypothesis therefore presumes that the effectiveness of instructional mediation would be dependent on the actual level of cognitive development at the beginning of an instructional process, which suggests that in order to optimize the effect of teaching interventions the instructor would need to base instruction and instructive challenges on the actual level of conceptual development in the individual students. From a methodological point of view, generative questions seem a good way of elucidating mental models and for eliciting evidence for conceptual misunderstanding. Because so many of the procedural operations in the molecular biosciences and in the Basic Molecular Biosciences II course in particular, are based on the concept of proportionality, proportional reasoning was chosen as the specific concept worthy of investigation in the context of this research, in that a measurement of the ability to apply proportional reasoning could be taken to be indicative of the actual level of development in this domain.

2.7 Proportional reasoning

Lesh *et al* (1988) (who have been members of a United States federally funded 'Rational Number Project', which ran from 1979 until 2002) offer a description of proportional reasoning as '*a form of mathematical reasoning that involves a sense of co-variation and of multiple comparisons, and the ability to mentally store and process several pieces of information. Proportional reasoning is very much concerned with inference and prediction and involves both qualitative and quantitative methods of thought'*. (p1). In this regard, one might draw parallels between problems involving proportional reasoning and Kitchener's ill-structured problems.

The essence of proportional reasoning is that it must define the '*relationship between two relationships*' rather than a relationship between two concrete objects. This description has been extended by Karplus *et al.* (1983 a, 1983b) who consider that it should '*involve a linear relationship between two variables.*' After reviewing the most recent research in the area, Lamon (2007: 638) has defined proportional reasoning as '*supplying reasons in support of claims made about the structural relationships among four quantities in a context simultaneously involving covariance of quantities and invariance of ratios or products; this would consist of the ability to discern a multiplicative relationship between two quantities as well as the ability to extend the same relationship to other pairs of quantities.'* She also emphasises the distinction between proportional reasoning and proportionality, although these terms appear to have been used interchangeably in much of the literature. In light of her definition, proportional reasoning may be assessed according to ability to '*understand the structural relationships in comparison and missing-value problems*' (Ibid: 637). Proportionality, on the other hand, involves an understanding of the constant relationship between two linked quantities which change together. It is therefore necessary to be able to apply proportional reasoning when calculating the constant of proportionality, although one cannot presume that an ability to do proportional reasoning presupposes the capacity to understand proportionality.

Proportional reasoning thus has all the tenets of a threshold concept as conceptualized by Meyer and Land (2003), in that the ability to use proportional reasoning is '*transformative, irreversible, integrative'*, and generally exposes some counter-intuitive interrelations. Most importantly, it seems to represent the kind of '*troublesome knowledge*' elaborated on by Davies and Mangan (2005) albeit that their research was in the area of economics, and it conforms to the criteria for threshold concepts outlined by Cousin (2006), particularly in that it is a key area that needs mastery and can thus provide a focus for teaching. The last point is particularly relevant in the molecular biosciences, as proportion underpins so many of the essential operations in this field.

Thorton and Fuller (1981), state that most university instructors assume that all students at second year level would be able to apply proportional reasoning. However, their empirical study covering three sections (west, east and mid-west) of the United States which aimed at establishing how 8000 first year college science students solve proportion problems revealed that many (at least 25%) were unable to use proportional reasoning. Responses to two types of proportion problems were categorized according to the Piagetian labels, '*concrete, transitional or formal operational cognitive levels* '. The formulation of the first problem presented to the students, which involved a calculation of one of the ingredients in a scaled up recipe, made it obvious that some kind of proportional reasoning was required. The second problem (calculating the height of a tree from its shadow in relation to the shadow and height of a person) was presented as a word problem with a graphic illustration. Students tested were registered for the following courses: chemistry, life sciences, mathematics, physical sciences and others. Responses were categorized on the reasoning employed, regardless of whether the answer was correct or not, into the following five point scale: 1 = Intuitive (no response or little evidence of reasoning), 2 = additive (adds or subtracts to obtain an answer), 3 = ratio attempt (attempts a ratio but fails for reasons other than arithmetic errors), 4 = ratio formula (uses proportional reasoning to set up an equation and then solves for the unknown), and 5 = conversion (introduces a new quantity as a conversion factor then multiplies or divides). Responses 1 and 2 were classified as being indicative of a concrete operational cognitive level, response type 3 was labelled transitional, and responses 4 and 5 revealed an understanding of the ratio-concept. The study established that 75% of the responses indicated a good grasp of the concept of proportion when presented with the first problem. However, fewer students (60%) used proportional reasoning when presented with the shadow problem. In both cases a significant percentage (20%) of the students used additive reasoning instead of the multiplicative strategies required for proportional reasoning.

This is somewhat disturbing because higher order problem solving often requires the development of proportional reasoning, to the extent that it has been proposed that it is a pivotal point in the acquisition of higher reasoning ability (Inhelder & Piaget, 1958), and a '*milestone in students' cognitive development'* (Cramer & Post, 1993). Moreover, it has also been considered the capability that brings about a conceptual shift from concrete operational levels to formal operational levels (Piaget & Beth, 1966) which implies that it would have an impact on other learning. For example, it has been shown that there is a direct relationship between proportional thinking and ninth-graders' ability to demonstrate knowledge and understanding of concepts related to simple machines, structure of matter, and equivalent fractions, at the knowledge, comprehension and application levels (McBride & Chiappetta, 1978). However, it has also been demonstrated that this threshold concept is one which is consistently found difficult in the middle school years. In this regard, Norton (2005), confirmed the findings of other authors (Lesh *et al.*, 1988) in that only 18 % of students were able to apply proportional reasoning at this stage, and established that this was due largely to misconceptions resulting from '*inappropriate use of whole number thinking, including not understanding the relationship between the numerator and the denominator '(*Norton, 2005: 4). Other research indicated that students did not understand the part/whole relationships described in fraction notation. In essence, while proportional reasoning involves multiplicative thinking (Cramer & Post, 1993, Lesh *et al.*, 1988, Norton, 2005), it has been established that students exhibiting difficulties often resort to additive strategies (Lawson, 2003) particularly in the more difficult questions.

In 1985, Tourniaire and Pulos published a review of the literature on proportional reasoning. In it they list problems and tasks that have been used in various studies. It is apparent that the methods used to evaluate proportional reasoning ability may affect the results. In general, two types of contrasting methods have been used: comparisons versus missing values, and explanations versus answers only. Although numerous kinds of tasks have been used, they can be categorized into physical tasks, rate problems, mixture problems, and probability tasks. Most frequently used are word problems presented either in written or oral form, with and without illustrations. Some of the studies cited have been criticised for each having used only a single method, which thus brings the generalisation from these findings into question. Several studies have also investigated the strategies used to solve proportional problems, and have also concluded that either multiplicative or additive strategies have been used by the participants of the studies. Errors were found to result from the use of an inappropriate strategy or the misuse of the correct strategy. Variables affecting performance were also examined and it was evident that these could be divided into task centered variables and student-centered variables. It appears therefore that much of the research has focused on the cognitive development of proportional reasoning in children and adolescents in middle school educational systems (Cramer & Post, 1993).

Tourniaire and Pulos (1985) cite another analysis which contends that competence in proportional reasoning is dependent on the individual's capability of accessing a repertoire of strategies, a so-called [2]'*M-capacity'* (p191). An '*M-capacity'* of greater than 6 was necessary to solve the balance scale problem. However, Pulos *et al*. (1981) found that while '*M capacity*' was related to proportional reasoning, experience has also been found to affect performance (Furman, 1981). One thing that emerged from all the studies was that proportional reasoning is not a '*unitary construct'* (Tourniaire & Pulos, 1985:200). Contemplation of these studies from a consideration of the effect of embodied knowledge on problem solving indicates that access to hierarchically organised conceptual knowledge must be available in order to solve problems requiring proportional reasoning. This aspect thus seems to support Tsien's (2007) biological observations of the hierarchical manner in which knowledge is organised and stored in the brain.

Other research suggests that a hierarchy of proportional reasoning exists which may be empirically examined (Fleener, 1993). Fleener proposes that this construct '*must be studied as a dynamic system of complexity relationships'* (p2, own emphasis). She maintains that proportion is often taught in school middle grades as a skill which has to be mastered, which implies that in that situation, instruction was geared towards teaching the selection and application of a particular algorithm, rather than an emphasis on the general reasoning construct. Basing her formulation on Kieren's (1988: 165) model of rational number building, Vergnaud's (1988) notion of a conceptual field, and the general reasoning constructs postulated by Piaget (1969), she has developed a six level model for a proportional reasoning construct, the lowest level of which requires the ability to order number magnitude, while the highest requires the inverse/compensatory proportional reasoning which needs to be

[2] The notion of M-capacity is derived from Pascual-Leone's neo-Piagetian theory and refers to the "number of schemes one can attend to at one time" (Tourniaire and Pulos, 1985: 191)

applied to solving a balance scale problem. The model, named the Qualitative and Quantitative Test of Proportional Reasoning (QQTPR), was empirically tested in a study involving 18 (17 female and 1 male) elementary major education students in their final semester before student teaching. Participants also took the 'Test of Logical Thinking' (TOLT) designed by Tobin and Capie (1981) to determine developmental levels, and were interviewed individually 3 to 4 weeks post testing to rank the QQTPR test items in order of perceived difficulty, and to account for their choice. Regression analysis showed that students' perceptions of difficulty levels matched their actual performance on the test.

A series of developmental stages from the way in which children predict the movement of a balance scale which has equally heavy weights which can be placed in various combinations at equally spaced distances on the arms was proposed in 1958 by Inhelder and Piaget. These stages were characterized by '*several qualitatively distinct, increasingly complex stages*' (Van der Maas *et al*., 2003:2). Interestingly, results from research into proportionality have been supported and supplemented by connectionist modelling of problems requiring proportional reasoning.

In this regard, connectionist models have been used to mimic the way in which children solve the 'balance scale problem' and to provide insight into how learning in general occurs in the brain. A given node in a connectionist system may receive input from a number of sources, which in light of the previous accounts, seems to mirror what happens in the brain. Early networks were 'hand wired' to set inputs and outputs of nodes to be relevant to some behaviour. However, Elman *et al.* (1996) suggest that an ideal would be to use networks in a way that would allow them to configure themselves so that they can be used to develop a theory, which might be considered analogous to development of a concept in human learning, particularly because they can thus be assumed to mimic what happens when knowledge is internalised. In fact, learning networks have been designed, which are not only trainable, but which are able to learn. Moreover, these have demonstrated that in the early stages of learning (when they have just been set-up) the weights will be most malleable, whereas, as learning continues, the impact of any particular error declines. From a developmental point of view this suggests that '*the ability to learn may change over time – not as a function of any explicit change in the mechanism, but rather as an intrinsic consequence of learning itself. The network learns to learn* *just as children do*' (Elman, 1996:70, own emphasis). One might extrapolate this observation to surmise that in the developing brain, as certain connections become strengthened in specific areas; neural circuitry becomes developed to the extent that it forms a structure available for knowledge construction, so that the chance of making a false deduction (or mistake) from the relevant input is reduced.

Connectionism has also been used to model ontological development and a network simulation, designed to explore the developmental stages in learning in the balance scale problem, produced some surprising results. While Piaget's (1964) description of developmental stages might have suggested that they proceed in a series of discrete stages, '*involving qualitative change at the representational level*' (Elman *et al*., 1996: 159) the simulations have shown that '*abrupt behavioural change is not necessarily accompanied by abrupt representational change*' (Ibid: 159, own emphasis). What was a particularly noteworthy finding was that, although outputs could remain unchanged, there was ongoing change with respect to the internal representation. Extrapolating the finding to children's development, this implies that although children may not show any outward signs of having reached the next developmental stage, there could nevertheless be developmental or structural changes occurring in the brain. This is a slightly different representation from Piaget's conception of stage manifestation in his theory of development, but it does endorse the notion that conceptual knowledge is internalised before it manifests in enhanced performance. Moreover, the finding also highlights the importance of being aware of a general distinction in the way in which research in the field of proportional reasoning has been conducted.

One school proposes a 'judgement-only view', which maintains that one can formulate a set of rules for the various developmental stages from observations of children's performance when presented with a problem. In opposition to this viewpoint is the school that maintains that a '*clearer picture of children's true knowledge is derived from children's explanations of their responses.*' (Van der Maas, 2003:3). This is an important distinction to be aware of, as it should inform the methodology in future research. Both points of view are under debate, and each has its advantages. For example, nonverbal versions of Piagetian tasks are less time-consuming, and the effects of interaction between the researcher and the child are negated. Following a nonverbal approach, Siegler (1981) has designed a Rule Assessment Methodology (RAM) to assess performance on the balance scale task, which inspired a number of researchers to study the performance of various populations on the balance scale problem. These have been listed in van der Maas *et al* (2003). Moreover, several computational models based on the balance scale problem have been developed in order to attempt to elucidate the developmental stages in proportional reasoning (Van der Maas *et al.*, 2003, Thomas & Karmiloff-Smith, 2002). Van der Maas *et al.* (2003) have used a '*Piagetian and neo-Piagetian approach*' to assess results and to attempt explanations of cognitive development of proportional reasoning. Their explanations take into account the *'importance of cognitive capacity, perceptual clues and processing speed of mental procedure*' (p49) which I consider to be consistent with a biological framework for cognition. These researchers conceded however, that in order to test their explanations, more empirical research needs to be undertaken. For example, their focus to date has been on the balance scale problem. Other tasks requiring proportional reasoning might yield different perceptions of cognitive development of proportional reasoning. However, in terms of Fleener's hierarchical arrangement of proportional reasoning problems, the balance scale problem is indicative of one at the highest level of proportional reasoning. In order to provide the same type of theoretical conclusions one would have to design problems with an equivalent rating, which means that they should be designed to involve compensatory or inverse relationships.

2.8 Conclusion of the literature review

A review of the literature has revealed that empirical research on the ability of students studying science in tertiary institutions to use proportional reasoning has been limited, which means that my research will provide valuable insight into this group, especially in a South African context, particularly as to date we have no evidence of how many students at Universities are able to understand and apply the concept. Drawing from the theoretical standpoint that proportional reasoning is a cornerstone of cognitive development and that it represents a threshold concept and troublesome knowledge, it is felt that it is a suitable concept for investigations of whether its acquisition would be a predictor of success in other areas in a molecular biosciences course. Moreover, it is a concept and ability which underpins many of the activities required of molecular bioscientists, and most importantly has been cited as an indicator of the transition from concrete operational to formal operational level thinking (Piaget & Beth, 1966), which makes it a particularly interesting concept to investigate if one is to use the findings to corroborate existing constructivist learning theories. Therefore from a purely learning theory perspective, one might conclude that an investigation of this nature, could provide empirical evidence for the specific conceptualization of Vygotsky's '*zone of proximal development'* along a natural line of development elaborated by I. Moll (1994), in that one would be able to draw conclusions about the extent to which actual development creates conditions for potential development and thus be able to make generalisations about learning *per se*. From a more pragmatic standpoint, the literature survey has revealed that there is sufficient research in the field of proportional reasoning from which to draw, both from a methodological and a theoretical standpoint. In this regard, it has informed the proposed methodology and design of the research.

3. RESEARCH DESIGN AND METHODOLOGY

3.1 Justification for the research design

With reference to Vygotsky's conception of the zone of proximal development, the aim of this research was to investigate the extent to which actual development creates conditions for, or constrains, potential development, and to elucidate some of the factors contributing to actual development which, in this project, was reflected by the ability to apply proportional reasoning. The specific research sub-questions asked in this context, focussed around establishing the extent to which a general inability to use proportional reasoning impacts on performance in specific key areas like subsequent learning of chemical transformations or more specifically, on the ability to perform calculations using the Henderson Hasselbalch equation and dilution factors, as well on general performance in the Basic Molecular Biosciences II course. Theoretically, the notion proposed by Vygotsky's famous concept is that an established general cognitive capacity – such as proportional reasoning - enables the mediated development of more powerful forms of related reasoning 'under the guidance' of more capable others. Another question at hand therefore was to determine *ex post facto*, what factors may have led to the establishment of such a general cognitive capacity in the first place. Further research therefore attempted to elucidate the factors that contributed to the students' conceptual understanding or the lack thereof. The ultimate purpose of this section of the study was, therefore, to produce a set of hypotheses for subsequent investigation, which could thus generate a deeper range of factors considered to be important for the development of proportional reasoning. After reviewing the literature, it was decided that the most appropriate research paradigm would be a 4 phase mixed method research design involving quantitative and qualitative research as elaborated below. The underlying reason for the choice of this research approach lies in the advantages offered in terms of testing the validity of and verifying the findings.

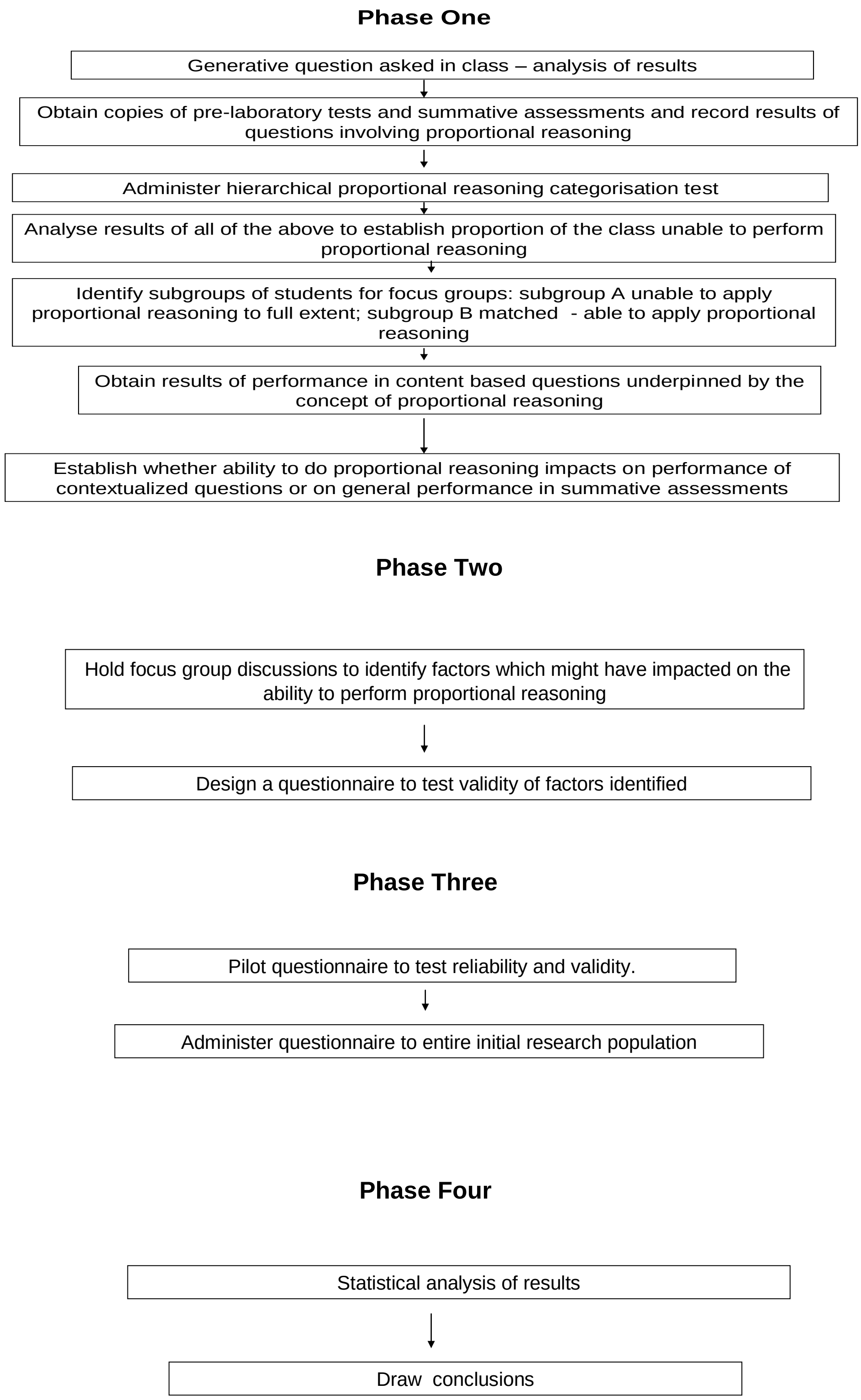

Figure 3.1: Flow chart showing research design

3.2 Overview of the research design

Phase 1: Quantitative phase

During the first phase, the primary aim was to establish what proportion of the second year Basic Molecular Biosciences II class is able to apply proportional reasoning. This was gauged initially from responses to a generative question requiring proportional reasoning asked during class, but the predominating or over-riding assessment was taken from the scores obtained from results of the paper and pencil test which was based on the QQTPR model developed by Fleener (1973) which claims to rank proportional reasoning ability on a hierarchical scale. This strategy enabled selection of two groups of students: one that was constituted of those students who had scored ≤3/6 on the test and the other of students who had scored 6/6 on the paper and pencil test.

Proportional reasoning ability was then compared with performances on contextualized questions, using proportion as the underpinning concept, which are specific to the Basic Molecular Biosciences II course, in these two groups of students who had been identified from the first part of the research as having either a highly developed conceptual understanding of proportion or limited conceptual development in this domain. Ability to apply proportional reasoning was also compared with <u>general</u> performance in the first semester of the course. In studies contrasting the general performances of the two groups, and the performance on questions included in summative assessments, statistical analysis using a two-sample, one-tailed t-test, assuming unequal variances was carried out in order to examine if the results obtained for the two groups were significantly different. Fischer's exact test and a chi-squared test were also used to determine whether differences in performance of the two groups on specific questions based on the concept of proportion were statistically significant.

Students' informal WebCT discussions on proportion were also appraised and assigned Piagetian based ratings of proportional reasoning ability. These ratings were correlated with scores from the paper and pencil test and were used to establish whether an association between the rating assigned on the basis of the written accounts in the discussions thread and the performance on questions included in the first summative assessment in the course, as well as on general performance, was evident. These findings were used to substantiate the previous results.

Phase 2: Qualitative phase

As explained above, results of the first part of phase 1 allowed identification of two sub-populations of the Basic Molecular Bioscience II students: The first group comprised the 23 students who performed at a low level on the hierarchical proportional reasoning ability scale devised by Fleener (1993) i.e. they obtained a score of ≤3/6. The second group was comprised of the 15 students who scored 6/6 on the paper and pencil test and thus demonstrated a high level of conceptual understanding of proportion Ideally the two groups should have been matched with respect to sex, age, and race, as well as economic and academic backgrounds with the first group but this was not possible as there were so few students who qualified for the second group. For this reason, all students who scored 6/6 were included in group two, while group one consisted of all the students who scored ≤3/6. Students were randomly selected from these two sub-populations of the Basic Molecular Biosciences class to form focus groups which, through guided discussions, attempted to establish which of factors like: gender tasks, play and leisure activities, early childhood enrichment, schooling, mathematical ability, instruction in proportional reasoning, parental involvement and mathematical practices might have augmented the development of proportional reasoning ability.

Phase 3: Quantitative phase

Factors identified in phase 2 as promoting development of proportional reasoning were incorporated into a questionnaire which was administered to a sub-set of the students who had participated in phase 1. The specific aim of this phase in the research was to establish the validity of the impact of the factors, which had been identified from the focus group discussions, as affecting the development of proportional reasoning and the understanding of proportion. The sub-set of 33 students who completed the questionnaire consisted of the Basic Molecular Science II students who were majoring in Biochemistry and Cell Biology.

Phase 4: Quantitative phase

The questionnaire findings on each factor investigated were graphed in order to visually inspect the link between the number of students who answered yes to whether they had been exposed to each of the factors and their score on the paper and pencil test. Thus students were divided into groups who had scored, 6, 5, 4, or ≤3 on the test. The relationship between each factor and the score on the test was probed using a chi-squared test to determine statistical significance.

3.3 Research population

The empirical investigation to establish what proportion of second year molecular bioscience students is able to apply proportional reasoning and the impact of this ability or the lack thereof on performance in other areas in the course was carried out on those of the second year students registered in 2008 for the *Basic Molecular Biosciences II* course at the University of the Witwatersrand who gave consent to participate in the study. None of the students in the class objected to me using the results of pre-laboratory tests and summative assessments for my research. Some however, were not willing to participate in focus group discussions. This class was chosen for investigation because the course (which runs for the entire year) is a co-requisite for the second year major courses and a pre-requisite for the major courses offered at third year level in the three teaching programs in the School of Molecular and Cell Biology (MCB) which is situated in the Faculty of Science: *Biochemistry and Cell Biology, Genetics and Development* and *Microbiology and Biotechnology*. This means, therefore, that the sample under investigation included virtually all of the current second year students registered in MCB. (It excluded students who had passed the Basic Molecular Biosciences II course the previous year, and who, during the period when the study was undertaken, were only registered for one of the major courses offered in the school). The mandate of the course is both to cover the background content knowledge to support the material covered in the major courses offered in MCB, and more importantly, concurrently to develop the skills required of molecular bioscientists. As stated previously, essential practical skills required of biomolecular scientists include, amongst others, the ability to 'scale up or down' experimental quantities, prepare solutions, calculate concentrations of components in solutions, carry out dilutions of stock solutions, construct and use calibration curves, use dilution to determine numbers of bacteria in growth media, and to prepare buffers. It has been noticed since the inception of the course in 2003 that these are abilities that many students struggle to attain, with the result that there is a relatively high failure rate in the course, and that even at third year and honours level, many students, who despite their shortcomings might have managed to pass the course, have still not mastered these skills. Because all of these operations are based on an underpinning conceptual understanding of proportion it was felt that it would be desirable to establish what percentage of the current Basic Molecular Biosciences II class is able to perform operations involving proportion and to use proportional reasoning, and furthermore to investigate whether there is any correlation between this ability and the ability to perform operations which are underpinned by a conceptual understanding of proportion as well as to general performance in the course.

3.4 Methodology

3.4.1 Estimation of Proportional Reasoning Ability

In an initial pilot study to establish how many of the class were able to think proportionally, a generative question, identical to the one used by Lawson (2003) was posed to the class during a lecture period. Lawson has proposed that this question can also be used to indicate the strategies used by students to solve the problem. The question has a similar formulation to one of those administered to college students in the 1970s, the results of which were published by Thorton and Fuller (1981). In their study, student responses were categorized on a five point scale according to the reasoning employed rather than on whether the answer was correct or not. In this respect performance was thus not the criterion used for judgement of ability. The scale used is shown below:

1. Intuitive
2. Additive
3. Ratio attempted but fails for reasons other than arithmetical reasons
4. Ratio formula where an equation is set up and the unknown solved for
5. Conversion implies that a factor is introduced which can be used to multiply or divide as appropriate

Piagetian labels were assigned to the various levels on the grading scale. In this regard, responses 1 and 2 were graded at a concrete operational level as there was little evidence of reasoning in these types of responses. For example, addition is used in situations in which counting and correspondence are appropriate and objects can be represented physically. The notion of ratios involves a conceptual leap to "*quantities that defy physical representation*" (Lamon, 2007: 630), and therefore are a result of abstract thought processes. Thus, response 3 in which a ratio was attempted, was rated at a transitional operational level, and responses 4 and 5, which successfully used ratios and demonstrated an understanding of rational numbers thereby revealing an ability to use abstract thought, were classified at a formal operational level. In my study, individual responses to the generative question were analysed to determine the number of students in the class that used an additive strategy rather than the multiplicative strategy required for proportional reasoning, so that I was able to establish what percentage of the study population was at a concrete operational level in this domain.

A second, and what was deemed a more valid, estimation of proportional reasoning ability involved the development of a paper and pencil test, consisting of six questions, that was based on the "Qualitative and Quantitative Test of Proportional Reasoning" (QQTPR) test developed by Fleener (1993). The rationale behind Fleener's test was her proposition that a hierarchical arrangement of questions of increasing difficulty can be used to determine the level of conceptual development and to ascertain whether students are able to use proportional reasoning as opposed to just possessing an algorithmic skill which has been accessed through teaching interventions. The test developed for the Basic Molecular Biosciences II class, retained the same hierarchical configuration of questions, left some questions unchanged and altered some to be more contextual. All retained the same structural design however. The actual test is included in the appendix and the individual questions will be discussed in more detail in the results section.

In light of the ongoing debate about whether judgement of proportional reasoning ability, or in a more general sense conceptual development, should be judged by performance or should rather be based on verbal explanations, informal written discussions between a small group of students were analysed and used to assign the Piagetian labels employed by Thorton and Fuller (1981) to the various students who participated in the discussion. Written discussions rather than verbal accounts were chosen for my study in order to prevent a possible influence between the researcher (as I was also the lecturer of the course) and the students, and for ethical reasons as I did not want my students to feel the possibility of being compromised in any way. The labels which I assigned to the students on this basis were compared with their scores on the paper and pencil test, and found to compare well.

3.4.2 Methodology used to answer the research sub-questions

The paper and pencil test which was developed for the Basic Molecular Biosciences II class was used to identify two groups of students: the first group consisted of students who scored ≤3 /6 for the test and were thus deemed to be a low stage in their conceptual development; the second group which served as a control, consisted of students who had scored 6/6 on the test and had thus demonstrated that they were able to apply proportional reasoning. These two groups were used for comparative purposes in order to answer the research question of whether an inability to apply proportional reasoning impedes ability to perform certain operations in the course which are underpinned by the concept of proportion.

The paper and pencil test was also an end in itself, in that it allowed one to answer the first sub-question which asked what percentage of a class of second year molecular bioscience students is unable to recognize and solve problems requiring a conceptual understanding of proportion, or as it turned out to rather establish what percentage of the class was able to apply proportional reasoning and could thus be considered to have highly developed conceptual understanding.

The next sub-question asks to what extent an inability to understand proportion impacts on subsequent learning of procedural knowledge operations in the molecular biosciences, and specifically on the ability to perform calculations of concentrations or volumes or equivalents, or which use the Henderson Hasselbalch equation and dilution factors. In this regard, selected contextualized problems which require proportional reasoning, which had been included in pre-laboratory tests and summative assessments, were analysed and a comparison in performance of these was made between the two groups of students that had been identified on the basis of their results in the paper and pencil test. Responses to some of these questions were assigned Piagetian labels in a similar manner to that used by Thorton and Fuller (1981). The grading I used was not identical however, as in my research an algorithmic approach, regardless of whether a ratio was set up was regarded as indicative of a concrete operational level. It is argued that this is because I consider that the inability to apply the formula $C_1V_1 = C_2V_2$ which would enable a student using an algorithmic approach to answer certain questions, is indicative that the student has just applied a rote learning approach to problem solving, has probably not understood that the formula involves ratios, and has not provided evidence of transition to abstract reflective thought. I therefore categorised this approach as concrete operational rather than transitional, which was the label assigned by Thorton and Fuller (1981) to anyone attempting to set up a ratio.

The third sub-question was to investigate whether an inability to conceptualize proportion influences general performance and overall results obtained in the Basic Molecular Biosciences II course summative assessments In order to answer this, the performances of these two groups in the June examination were compared with respect to overall marks obtained and the marks obtained for section B which had included the questions which were based on the concept of proportion. Performance differences between the two groups were analysed for statistical significance.

Results of three individual students who had been classified as having different levels of conceptual development based on their written discussions indicating their understanding of proportion, were used to substantiate those that had been obtained previously based on the comparative performances of the two groups of students in specific questions with a proportional conceptual underpinning and on their general performances in the course as indicated by achievements in the summative assessments. In order to obtain empirical backing of previous results from another perspective, the performances of the three students in the first summative assessment, and the June examination were examined in order to explore two of the research sub-questions.

The final research sub-question probed whether one can elucidate factors which might have supported and resulted in conceptual understanding of proportion. Students from the two groups which had been used for comparative purposes in the earlier parts of the research were randomly invited to take part in focus group discussions. These were held during lunch time, in an informal setting with lunch provided, in the first week of the final teaching block, i.e. in the week that the students returned from their study break. Factors that emerged from the discussions were explored further by inclusion in a questionnaire designed for this purpose. The questionnaire (chapter 7.6) was administered to other students in the Basic Molecular Biosciences II class, i.e. who were concomitantly registered for Biochemistry and Cell Biology II. In this respect it elicited the opinions of a different subset of students which increased the validity of the findings of the focus groups. The questionnaire was piloted to test for comprehension on three students in the Biochemistry and Cell Biology class who were not registered for Basic Molecular Biosciences II.

3.5 Data collection and analysis

3.5.1 The collection of responses to the questions posed in class.

The individual responses to the generative question (after Suarez and Rhonheimer, 1974, cited in Lawson, 2003, p22) which was posed during a lecture period in week three of the course were collected via radio frequency personal response systems linked to a radio receiver on the lecturer's laptop, and data was saved using the *Interwrite* PRS software. Individual numerical responses were analysed to get an estimate of how many students had used an additive strategy to answer the question.

The numerical responses to the second question which was asked during the same lecture period were also collected and saved using the *Interwrite* PRS system.

3.5.2 Statistical analysis to determine whether a correct answer to the generative question would result in increased ability to answer a contextual question correctly.

A hypothesis was proposed that students who got the generative question correct would be more likely to show better performance in a contextual question (based on proportion) than the group of students who failed to answer the generative question. The 79 students who responded to the generative question were assigned to two groups: group one consisted of those who answered the generative question correctly; group two consisted of those who answered the generative incorrectly. In order to test whether a significant difference in performance exists between groups one and two, the data were subjected to the Yates-Corrected Chi- Square test for 2 X 2 Contingency tables as described by Rosner (1990).

A 2 X 2 contingency table, consisting of two rows and two columns can be used to display data that can be classified by two different variables, each of which has only two possible outcomes. “One variable is arbitrarily assigned to the rows and the other to the columns. Each of the four cells represents the number of units with a specific value for each of the two variables”. (p323).
Details of how the test is conducted are shown below (taken from Rosner, 1990):

General contingency table:

a	b	a + b
c	d	c + d
a + c	b + d	n = a + b + c + d

The test statistic was calculated manually as follows:

$$X^2 = n\left(\left|ad-bc\right| - \frac{n}{2}\right)^2 / \left[(a+b)\ (c+d)\ (a+c)\ (b+d)\right]$$

The calculated critical value X^2 was read off statistical tables to determine whether the results were statistically significant. A [3]SAS statistical package was used to confirm results.

3.5.3 Determination of Proportional reasoning ability using a paper and pencil test based on the QQTPR model devised by Fleener (1993)

A specifically designed, contextualized, paper and pencil test based on the series of hierarchical questions used by Fleener (1993) in her QQTPR model was used to determine to what extent all the individuals in the class have internalized the proportionality construct and was used to categorise the conceptual developmental stages of the individuals in the class who were participating in the study. The test

[3] SAS/STAT guide for personal computers, SAS Institute, Inc, Cary, NC

(which is included in the appendix) was administered to the students present (102 out of a total of 106 in the class) at the start of a practical session in the second last week of the first semester. The test papers were collected by the teaching assistants and marked by the researcher. A spreadsheet tracking individual responses to all the questions in the test was subsequently constructed. By visual inspection, the data was grouped into high performers who scored 6/6 and low performers who scored ≤3/6. These two groups were used for comparative purposes in further research. The students scoring 4/6 and 5/6 were not used in this capacity.

3.5.4 Collection and analysis of questions included in pre-laboratory tests and summative assessments.

Copies of all written pre-laboratory tests and summative assessments were obtained for all the students and were photocopied for future inspection. Responses to selected questions on proportion which were included in the formative pre-laboratory tests and summative assessments were subsequently captured into a *Microsoft Excel* spreadsheet and were analysed in all the students in the two groups selected for comparative purposes with respect to their performance on these questions. Responses to questions which required explanations of the strategies used to arrive at the answer were analysed to provide insight into individual understanding of proportion.

The performances of the students in the two groups, on questions like those involving calculations of dilutions, equivalents, or concentrations and the Henderson Hasselbalch equation, were analysed to establish whether there was an observed relationship between the ability to work with problems obviously involving proportion and the ability to apply proportional reasoning in a contextualized scenario to answer questions specific to the molecular biosciences. In instances where only yes-no answers to the questions, indicating whether individual students had or had not answered a specific question correctly, the performance the students in the two groups were compared for statistical significance using a Fischer’s exact test.

The Fischer’s exact test gives exact results for any 2 X 2 table but is only necessary for tables with small expected values, where the standard chi-square test is not applicable. For tables in which the use of the chi-square test is appropriate, the two tests give very similar results. More explicitly, Fischer’s exact test is therefore used to test the hypothesis H_0 : p1 = p2 versus H1: p1 ≠ p2, where the expected value of at least one cell is < 5 when the data are analyzed in the form of a 2 X 2 contingency table (Rosner, 1990). In this research, the null hypothesis (H_0) is that the proportion of correct responses is the same in group one and group two; the alternate hypothesis (H_A) is that the proportion of correct responses in group two is greater than the proportion of correct responses in group one.

Performances, as indicated by the marks obtained in the June examination and in sets of questions examined in the first summative assessment were compared between the two groups. These data sets were subjected to statistical analysis using the one-tailed, two-sample t-test, assuming unequal variances using the *Microsoft Excel* package to ascertain whether any observed relationships were statistically significant.

3.5.5 Written accounts of conceptual understanding of proportion

Informal student discussion threads on WebCT on their understanding of proportion and difficulties experienced in understanding the concept were examined, and Piagetian labels were assigned to the participating students. The label assigned to three of these students was compared with their score on the paper and pencil test, with their performance in the June examination, and with their ability to answer questions in the first summative assessment in March in order to determine if a relationship exists between the ability to understand the concept of proportion and the application of this understanding in a more elaborate construct such as the Henderson Hasselbalch equation, and the calculation of dilutions, concentrations and equivalents, for example. Answers to the individual questions from questions 1 and 2 in the summative assessment held in March were posted into a table and answers were colour coded so that a correct response was highlighted in yellow and an incorrect response was highlighted in red. Visual inspection was then used to ascertain whether there was a relationship between the categorisation based on the written account in the discussion thread, and the ability to apply the concept of proportion in a contextualized more elaborate setting. The small number of students used in this part of the study did not permit statistical analysis of results. However, observed results could be used to substantiate the conclusions drawn from previous findings, especially because the classification of proportional reasoning ability had been made using a completely different strategy.

3.5.6 Focus group discussions

Students from each of the two groups categorised on the basis of their scores on the paper and pencil test were randomly selected to take part in focus group discussions. They were approached individually by their teaching assistants and asked whether they wanted to participate in the focus groups. They were also asked to indicate which days would be most suitable for them to attend. On this basis, two dates were selected. The first was on the first Monday of the fourth teaching block, and the other on Wednesday of the same week. Each group was assigned one of these days and students who had indicated their willingness to participate and availability were given a written invitation (attachment 7.4) to attend a discussion group. These took place in an informal setting over lunch. Teaching assistants had been given all the names of the students in the two groups and they approached those that they happened to see first during a practical session until between them they had found approximately 25 students. They were not aware of which category students fell into. Having established two dates which suited the majority, further selection depended purely on a student's availability on the dates set aside for the focus group discussions. Thus selection was unbiased and could be considered random.

All focus group interactions and findings were recorded, transcribed and analysed by the researcher. In this regard, the focus group content data underwent an objective, detailed and systematic examination in order to identify factors, patterns, themes or biases affecting the development of proportional reasoning.

3.5.7 Administration and analysis of a questionnaire designed to elucidate factors which could have contributed to the development of conceptual understanding of proportion

A questionnaire (attachment 7.6) was designed to interrogate the factors which had been identified from focus group discussions as possessing the potential to enhance development of the conceptual understanding of proportion. The questionnaire was piloted on three repeating second year students who were not registered for Basic Molecular Biosciences II and was found to be satisfactory with respect to design, simplicity and comprehension. The questionnaire was administered at the end of the second semester to 33 Basic Molecular Biosciences II students who were majoring in Biochemistry and Cell Biology. Questionnaire responses were analysed, inserted into a spread sheet, and the positive individual responses for each factor were compared with the score obtained on the paper and pencil test. For the purposes of this aspect of the research, students scoring 4 and 5 were included. The responses of each group of students to each factor were plotted onto bar graphs, appraised by visual inspection, and subjected to statistical analysis for significance.

3.5.8 Statistical analysis of the factors interrogated in the Questionnaire

Each factor (which I've referred to as "x" in the explanation) probed in the questionnaire was subjected to a statistical analysis as outlined below:

The question asked was: Is the proportion of individuals who had experienced factor "x" different across the different groups that consisted of individual students who had demonstrated different proportional reasoning ability on the paper and pencil test? The null hypothesis (H_o) is that the proportion of individuals who experienced "x" is the same across the groups. The alternate hypothesis (H_A) is that at least one of the groups differs in the proportion of individuals that have experienced "x".

A chi squared test for association was run; specifically the test for association between the groups obtaining scores of 6, 5, 4, and ≤3 in the paper and pencil test and "x". A p (probability) value was calculated. A p value ≤ 0.05 indicated that "x" was significant at 5%.

3.6 Internal validity

Internal validity reflects the extent to which the design of a research study and the data obtained permits the researcher to draw accurate conclusions especially when investigating causal relationships. Internal validity thus aims to minimize alternative explanations of the results. In phase 1 of this study since the data has been obtained through *ex post facto* analysis of direct unprompted responses the internal validity can be assumed. Findings of the focus group discussions in phase 2 were interpreted without researcher bias and referred back to the subjects for verification to maximize internal validity.

The phase 3 questionnaire was administered to an unrelated group of students in a pilot study to verify that the research instrument was clear and explicit and that results could be interpreted without bias. Moreover, these findings were plotted onto graphs and were statistically analysed. These measures increased internal validity.

Finally it is felt that because a number of questions requiring proportional reasoning were asked in various formats, settings and at different times throughout the semester, and that these findings were supported by analysis of written accounts and focus group discussion analysis, this research design is more rigorous than others reported in the literature. The rigorous nature of the design has thus ensured internal validity.

3.7 External validity

External validity refers to the "extent to which results apply to situations beyond the study" (Leedy & Ormond, 2001). Findings need to be able to be generalised to ensure external validity. The population used in this study includes almost all the second year students registered in the School of Molecular and Cell Biology (MCB). As almost the entire second year population in MCB will constitute the research population, it is felt that the findings can be extrapolated to other second year molecular bioscience students registered in South African Universities. However, due to the historical and sociological issues unique to South Africa and its education system, it is not envisaged that the quantitative data can be extrapolated to an international setting. However, as this is the first study of this nature carried out in South Africa, it has nevertheless been interesting to compare results with those obtained in a study (Thorton & Fuller, 1981) carried out from 1976 until 1978 on American students.

On the other hand, from a more general perspective, findings which directly addressed the extent to which actual development impacts on potential development <u>can</u> be extrapolated to other populations, settings and knowledge constructs. This is because one of the strengths of this research is the <u>formalization</u> of actual development, which suggests a procedure for extrapolation to other similar circumstances. In this regard, this study has made a unique contribution to social constructivist theory related to Vygotsky's zone of proximal development.

3.8 Reliability

Reliability refers to the extent to which “similar research conducted in the future will result in a similar outcome “(Leedy & Ormond, 2001). This might be conceived in terms of trustworthiness. Research phases involving quantitative research can be repeated on subsequent Basic Molecular Biosciences II classes, and on other science students. However, the factors emerging from the focus group discussions have relied on the interpretation of the researcher and it is therefore possible that bias might have influenced the way in with the data was analyzed. To improve the trustworthiness and to ensure equivalence the researcher facilitated all the focus group discussions personally and made certain that similar issues were discussed. Moreover, the results were described and documented in a way that will enable others to follow the same procedure in different circumstances. Audio recordings of focus group discussions provided a means of reviewing the discussions, and transcriptions were made personally.

3.9 Ethical considerations

Application for ethics clearance was made to the University’s ethics committee and approved by them. All participants in the study were informed of the nature of the study and were asked for written consent to participate. They were given the assurance that their identities would be disguised in any work presented in a public forum or in written format and that if they wished not to participate it would not be held against them. They were also assured that findings would in no way prejudice their final marks in the Basic Molecular Biosciences II course or in subsequent selection procedures for honours or maters programmes for example. Moreover, from a pragmatic perspective, I carried out the research analyses when I was on Sabbatical leave and had thus no longer had any formal contact with the students in the capacity of their lecturer.

4. RESULTS

This chapter starts with a section (4.1) which presents results of a pilot study to determine what percentage of the population of students who were attending a lecture (on solutions) given in the Basic Molecular Biosciences II course was able to apply proportional reasoning to solve a generative question. In light of these findings, the next section (4.2) presents results of a paper and pencil test designed to test proportional reasoning ability on a hierarchical scale which was administered to the whole Basic Molecular Biosciences II class. This accomplished identification of two groups of students, one that had demonstrated proportional reasoning ability and the other with limited ability, which allowed comparison of proportional reasoning ability with general performance in summative assessments. Section 4.3, which follows, reports a comparison of students' performance in specific questions from summative assessments with their Piagetian classification of development of proportional reasoning ability based on written accounts in a WebCT discussion thread which was selected for analysis. The next section (4.4) presents an analysis of focus group discussions held to try to acquire information which would point to the factors which could have contributed to the development of proportional reasoning. The final results section (4.5) presents the analysis of a questionnaire which had been designed in response to information which emerged from the focus group discussions and which had been administered to a sub-population of the Basic Molecular Biosciences II class.

4.1 Analysis of *Interwrite* PRS data on the number of students in the Basic Molecular Biosciences II class who were able to answer a generative question requiring proportional reasoning and a contextualized question underpinned by the concept of proportion

Initial ability to recognize, conceptualize and answer a question requiring proportional reasoning was determined by the response to a generative question (after Suarez & Rhonheimer, 1974, cited in Lawson, 2003, p22) which was posed during a lecture period in week three of the second year Basic Molecular Biosciences course. Answers to the question were collected from each participating student via radio frequency personal response systems (keypads) linked to a radio receiver on the lecturer's laptop using the *Interwrite PRS* software. The problem, When liquid measuring at mark 4 on the wide cylinder (A) is poured into the narrow cylinder (B), it measures at mark 6. If liquid measuring at **mark 6** on the wide cylinder is poured into the narrow cylinder what will it read?

was presented to the class on a power point slide which is shown below:

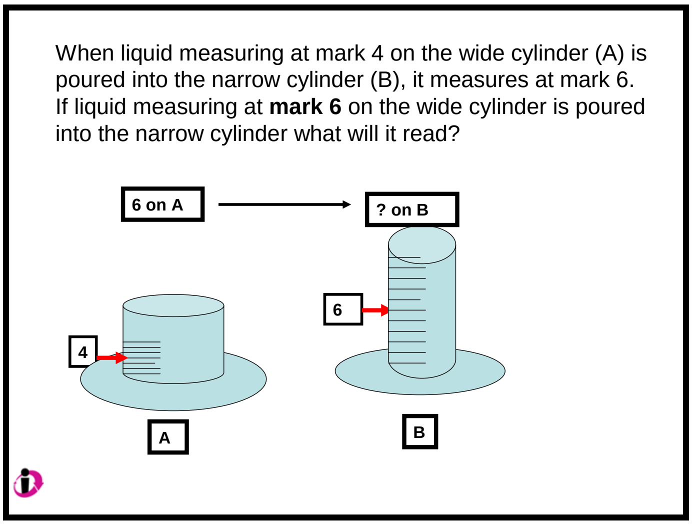

Figure 4.1: Generative question asked during a lecture period to determine students' ability to use proportional thinking (after Lawson, 2003).

Collective responses were displayed on a bar graph and made available to the class by means of a projector. The *Interwrite PRS* software used in this system also allows one to capture the numerical response given by each individual so that this can be analysed in order to postulate reasoning strategies employed to answer the question. The system is useful because saves individual responses which can be used further for correlation with data obtained from tests or with responses to other questions posed in class.

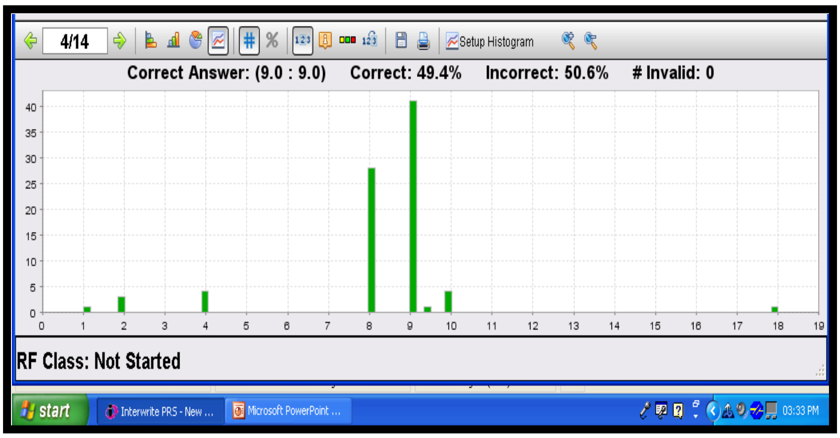

Figure 4.2: Response chart to the generative question posed in class.

Seventy nine responses were received from the class (82 students had registered for the session). The response chart compiled by the *Interwrite* software is shown in Figure 4.2. This chart was projected immediately after the collection of the responses so that the students and lecturer were made aware that this was an area that needed teaching mediation. It was evident from the number line bar graph, which indicated the actual figures calculated by the respondents (shown above), that only 49 % of the 79 students who responded to this question (3 others who were registered for the session did not respond) were able to apply proportional reasoning to obtain the correct answer of 9. This means that over half the respondents (51 %) obtained the incorrect answer, and some did not even attempt an answer, which is quite alarming if one realises that a large part of the work which was to be covered subsequently in this course is based on proportion, and that prior to this investigation, it had been assumed that students entering their second year of study would have mastered the concept which should have been taught at school. Moreover, the percentage of students who got this question incorrect was substantially higher than the 25 % percent shown in the empirical study on 8000 first year college science students, reported by Thorton and Fuller (1981), to be unable to use proportional reasoning in the United States of America.

In the Thorton and Fuller (1981) study, responses to two types of proportion problems were categorized according to the Piagetian labels, '*concrete, transitional or formal*'. The formulation of the first problem presented to the students, which involved a calculation of one of the ingredients in a scaled up recipe, made it obvious that some kind of proportional reasoning was required. However, the problem presented to the Basic Molecular Bioscience II students was similar in concept to their second problem which required calculation of the height of a tree from its shadow in relation to the shadow and height of a person. Their second problem, like the one posed to the Basic Molecular Biosciences class, was presented as a word problem with a graphic illustration. As discussed previously, responses in their study were categorized on the reasoning employed, regardless of whether the answer was correct or not, into a five point scale which was correlated with various Piagetian stages of cognitive development. Responses 1 (intuitive) and 2 (additive strategy) were classified as concrete reasoning, response type 3 (incorrect ratio attempt) was labelled transitional, and responses 4 and 5 revealed an understanding of the ratio-concept so corresponded in terms of classification to Piaget's formal reasoning. Their study established that 75% of the responses indicated a good grasp of the concept of proportion when presented with the first problem. However, fewer students (60 %) were shown to use proportional reasoning (or fitted into their classification of a formal cognitive level) when presented with the shadow problem. This was nevertheless higher than the percentage (49%) of the second year Basic Molecular Biosciences class participants who were able to obtain the correct answer to a structurally similar problem presented to them.

Subsequent analysis of the individual responses obtained from the Basic Molecular Biosciences course showed that 27 (34 % of the total number and 67.5% of those who had calculated incorrectly) of the respondents obtained an answer of 8 which indicated that 34% of the respondents had definitely used an additive strategy to calculate the answer. In terms of Thorton and Fuller's classification they could be considered to be at a concrete operational level. The reasoning applied by these students was that if the reading had risen by 2 in the first instance, it would rise by 2 again, rather than in the same ratio to the numbers supplied in the first scenario in the question, which is indicative of a misconception of proportion. This result therefore established that there was a larger percentage of students in the Basic Molecular Biosciences II class using an additive strategy than that observed by Thorton and Fuller (1981), who found that 20% of the students they tested used an additive strategy (concrete) instead of proportional reasoning in their recipe problem, and that in the second shadow problem 29% used concrete reasoning. One must realise however, that the other responses obtained in my study, shown in figure 4.3 below, might also be indicative of concrete reasoning, rather than having been obtained after reasoning that a ratio needed to be set up to solve the problem. If this was indeed the situation, it would further elevate the percentage of students using concrete reasoning in the Basic Molecular Biosciences class.

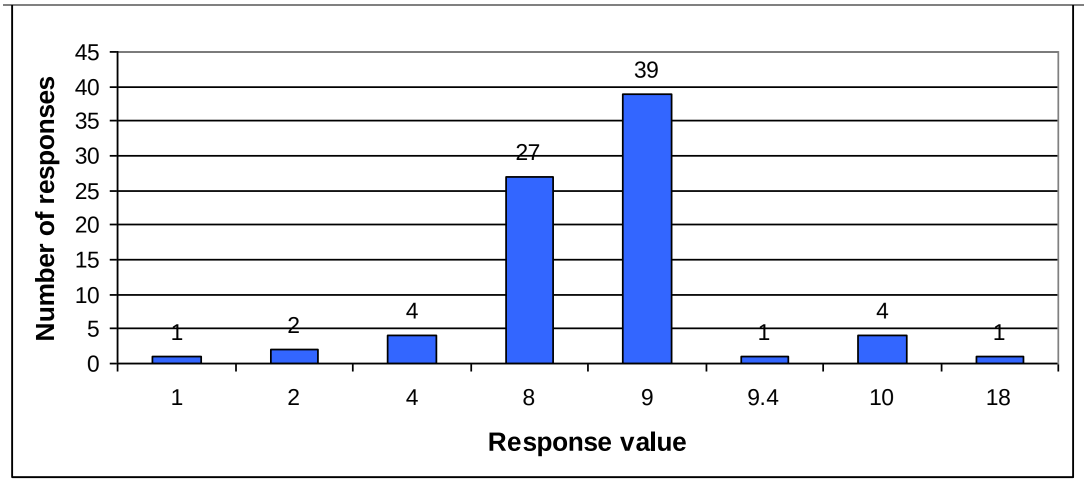

Figure 4.3: Number of students obtaining the various values in response to the generative question. (The correct answer was “9”).

This is somewhat disconcerting if one subscribes to the view that higher order problem solving often requires the development of proportional reasoning; it has been proposed that it is a pivotal point in the acquisition of higher reasoning ability (Inhelder & Piaget, 1958), and a ‘*milestone in students’ cognitive development’* (Cramer & Post, 1993). It has also been claimed that it can predict science achievement (McBride & Chiapetta, 1978). More pragmatically, it is a concept which needs to be applied in order to solve problems involving concentration, dilution factors, and the ratio of protonated to unprotonated weak acids in buffer solutions, in the molecular biosciences. If one therefore considers these results from a Vygotskian perspective, one might postulate that students who are unable to apply proportional reasoning would thus not be able to solve contextualized problems underpinned by proportion in the molecular biosciences, as these would not fall within their zone of proximal development with respect to this concept. I. Moll’s (1994) comment on the natural line of development in the ZPD, and its bearing in limiting potential development, might lead to conjecture that students who have not internalised the theoretical concept of proportion have not developed the biological structures which would allow them to learn to solve contextualized problems which rely on the concept of proportion. Therefore, in order to test this hypothesis, the following problem was presented next to the class during the same lecture. (It must be pointed out that this was after the students had been shown earlier in the lecture how to do similar problems, and after explanations regarding the solution to the generative question posed earlier).

Calculate the final concentration of NaCl (in mM) if you added 1.0 ml of an aqueous solution of 0.4 M NaCl to 9 ml of water.

To solve this problem requires recognition that 0.4 M NaCl has been diluted ten times; this involves proportional reasoning. It also requires students to recognise that 0.04 M is equivalent to 40 mM. Results are shown below in the bar graph compiled by the *Interwrite* software (Figure 4.4). Interestingly, out of the 82 students registered during the lecture, 31 students did not attempt an answer to this question, and only 18 (22 %) obtained the correct answer. Moreover, numerical answers varied from 0.00036 (1 student) to 3600 (4 students).

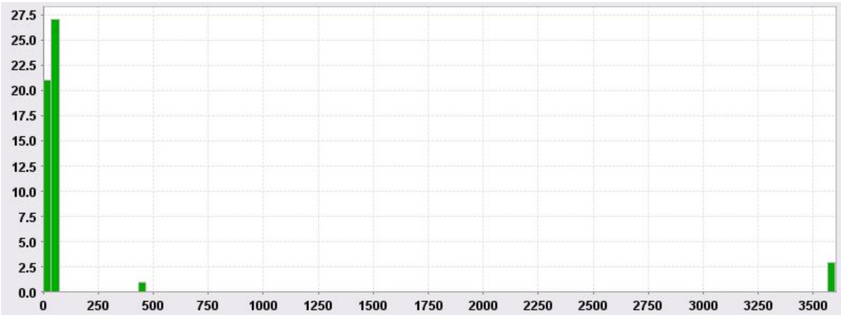

Figure 4.4: Actual response chart to the contextualized question requiring proportional reasoning asked in class after the generative question on proportion

Table 4.1 below shows the varied responses, the number of each, and an attempt to rationalise the strategy used to obtain each answer. Despite their varied responses, it is obvious that several students have tried to fit the values given into the following formula $C_1V_1 = C_2V_2$ (where C_1 = initial concentration, C_2 = final concentration, V_1 = initial volume, and V_2 = final volume), which they would have learnt in first year. However, it is equally obvious that students who do not obtain the correct answer are not aware of <u>how</u> to apply the formula and thus do not appear to have conceptualized what its purpose is. According to the Thorton and Fuller (1981) classification, an attempt to apply the algorithm, thereby setting up a ratio, would be classified in Piagetian terms as transitional rather than concrete reasoning. However, I argue that if a student cannot correctly slot the numbers into such a simple formula, one might surmise that there is no understanding of what the purpose of the formula is and what the resultant ratios (which would have been set up by default) are actually aiming to achieve. Moreover, as this approach has not required a student to rationalise that this type of problem requires proportional reasoning, I would therefore be inclined to categorize this type of thinking as being on a “concrete” operational level. This is because it appears that these responses are indicative of a “rote learning” approach to this type of problem solving which would justify my classification of their approach. However, it is also not possible to determine from the actual values given whether the students who obtained the correct answer did so because they were able to apply the formula correctly or whether they used a proportional reasoning strategy to generate the correct answer. This would require an explanation of the reasoning employed.

Vosniadou (1994) has drawn attention to the importance of obtaining explanations about problem solving methods in order to understand the mental models used to understand scientific concepts. The method of data collection in this initial stage of the research did not allow for this however. Nevertheless, a comparison of responses to both questions allows one to speculate which students used an algorithmic approach to solve the generative question, as they would probably have used the same approach in the contextualized question.

Table 4.1: Number of students obtaining each of the varied responses to the contextualised question posed during a contact period with the Basic Molecular Bioscience II students

Response	Number of students	Strategy used
.00036	1	Tried to apply algorithm
.004	1	? incorrect conversion
.04	7	Diluted 10x but failed to convert to mM
.044	1	algorithmic
.36	4	algorithmic
.4	4	No obvious calculation
3.6	1	algorithmic
4	1	Multiplied by 10
4.4	1	algorithmic
40	18	Diluted 10X and correctly converted to mM
44.4	7	algorithmic
444.4	1	algorithmic
3600	4	algorithmic
No response submitted	31	

A comparison between responses to the two questions is shown in Table 4.2 below. From the data presented in Table 4.2, it would appear that an ability to answer the generative question correctly predisposed a student towards answering the next more contextualized question correctly, whereas an inability to answer the generative question would make it more unlikely that the student would be able to answer the contextualized question correctly. However, there were a number of students (9) who, despite being able to answer the generative question, were unable to reason correctly to enable them to answer the next question. One might thus surmise that they had applied an algorithmic approach to answering the first question and had applied the algorithm incorrectly when attempting the next question. It is also evident that a higher number of students who had answered incorrectly compared with those who had answered correctly (19 versus 12) did not respond to the next question. A small number of students (5) who had answered the generative question incorrectly were able to answer the next question correctly after mediation.

Table 4.2: Comparison of responses obtained from the generative question and a contextualized question requiring proportional reasoning posed to the Basic Molecular Biosciences II class during a contact period

Response to generative and next question	Number of Students	Percentage of those who responded to the first question	Percentage of those who responded to the second question
Generative question correct and next question correct	18 (13 + 5)	23 % (17 % + 6 %)	35 %
Generative question correct and did not answer next question	12	15 %	0 %
Generative question correct and next question incorrect	9	11 %	18 %
Generative question incorrect and then next question correct	7 (5 + 2)	9 % (6 % + 3 %)	14 %
Generative question incorrect and did not answer second question	19	24 %	0 %
Generative question incorrect and next question incorrect	17	22 %	33 %

In order to ascertain whether these impressions were statistically significant, the results presented in table 4.2 were subjected to statistical analysis as follows:

A hypothesis was proposed that students who got the generative question correct would be more likely to show better performance in a contextual question (based on proportion) than the group of students who failed to answer the generative question. The students who responded to the generative question were assigned to two groups: group one consisted of those who answered the generative question correctly; group two consisted of those who answered the generative incorrectly. In order to test whether a significant difference in performance exists between groups one and two, the data were subjected to the Yates-Corrected Chi- Squared test for 2 X 2 Contingency tables as described by Rosner (1990). The results inserted into the 2 X 2 contingency table were as follows:

Group 1 (answered the generative question correctly): 39

Group 2 (answered the generative question incorrectly): 43

a = number of group one students who answered second question correctly

b = number of group one students who answered second question incorrectly

c = number of group two students who answered second question correctly

d = number of group two students who answered second question incorrectly

Contingency table then becomes:

13	26	39
5	38	43
18	64	n = 82

The test statistic was calculated manually using the following formula:

$$X^2 = n\left(|ad-bc| - \frac{n}{2}\right)^2 / [(a+b)\ (c+d)\ (a+c)\ b+d)]$$

$X^2 = 4.42$

The critical value X^2 (4.42) was read off a chi-squared value distribution table and was found to be significant at a 5% significance level. The results were further tested using the SAS statistical package which confirmed the result.

Therefore, based on the samples tested, I have found statistical evidence that the students who answered the generative question correctly showed better performance in the contextual question (based on proportion) than the group of students who failed to answer the generative question. This implies that the application of proportional reasoning to solve other contextual problems did not fall within the zone of proximal development for students who were unable to reason proportionally, and one might conclude that an inability to perform proportional reasoning impedes ability to answer contextual questions based on proportion.

However, it must be emphasized that this conclusion was drawn from a pilot study, so that before one could state this categorically, it was deemed necessary to consider whether there is any correlation between students who answered the generative question correctly and their subsequent performance on other contextualized questions which require either application of proportional reasoning or recognition of the concept of proportion in the question. It was therefore decided to compare performance of questions which obviously involve proportion and others underpinned by the concept which were included in formative or summative assessments in the course. However, it was also felt that one should not base one's assessment of students' ability to use proportional reasoning on only one question presented to the whole class on a power point slide as a criticism of other studies reported in the literature has been that they have relied on performance in only one or two questions in order to determine proportional reasoning ability (Tourniaire & Pulos, 1985). In light of this, a paper and pencil test based on that devised by Fleener (1993), who maintains that it can determine proportional reasoning ability in terms of a hierarchical classification of difficulty, was created and administered to all the Basic Molecular Biosciences II students who were present at the beginning of a practical session towards the end of the semester. The test and its results will be presented in section 4.2, which follows. After students had been categorised in terms of their results of this test as well as taking into account their responses to the generative question asked in class, the impact of actual development on potential development was assessed by a retrospective analysis of ability to answer specific contextual questions underpinned by proportion, as well as by analysis of subsequent general performance in the June examination.

4.2 Assessment of proportional reasoning ability using a paper and pencil test based on Fleener's QQTPR model (1993) for the hierarchical categorisation of proportional reasoning ability and its use for comparison of performance in summative assessments between students scoring 100% (6/6) and those with a low (≤50% i.e. ≤3/6) score.

Fleener (1993) has developed a test which claims to test proportional reasoning ability on a hierarchical scale because questions included in it are scored for complexity in terms of four variables (structure, context, numerical characteristics, and presentation mode).

In light of these variables, Fleener developed a scoring rubric, a summary of which is shown in Table 4.3 below:

Table 4.3: Scoring rubric for assessing difficulty of proportional reasoning questions

	1	2	3	4	5	6
Structure Variables	Relations/ magnitude	Discrete quantity	length	consumption	Speed / density ratio	compensatory
Context variables	Familiar	Context bound				
Presentation mode	qualitative	quantitative				
Numerical characteristics	No computation	instrumental	Procedural = simple proportion	Whole number proportion	Rational number proportion or extraneous information	Requires abstract symbolisation

Fleener's sample tasks (1993, p15) which had been graded in terms of increasing difficulty were either used unchanged or adapted to create a similar more contextualized test consisting of 6 questions for these second year students. The paper and pencil test was administered to 102 Basic Molecular Biosciences II students (i.e. out of the class totalling 106 students) towards the end of the first semester (second last week). During the preceding weeks in the semester, students had been made aware of the relevance of proportional reasoning ability to solve contextual problems and to carry out various operations in the molecular biosciences, and in addition to receiving instruction during practical, tutorial and lecture sessions in how to perform these operations and how to solve contextual and general problems underpinned by the concept of proportion, they had been required to discuss the concept in the groups to which they'd been allocated for practical sessions via some form of written communication – i.e. using email, blogs, or WebCT discussion with one another and with their teaching assistant. This did raise the issue of whether the results in the paper and pencil test would be indicative of the developmental level in terms of conceptual understanding of proportion at the start of the semester. However, it was rationalized that as proportional reasoning is a concept which develops over time and apparently is not something that can be taught but is a concept that must be internalised when the person is ready to do so (Lawson, 2003), there might have been no influence by the interventions which aimed at creating conceptual understanding and internalisation of the concept. Notwithstanding this, I felt it would be helpful, in the first instance, to compare results from the generative question and the paper and pencil test.

The paper and pencil test which was developed for the Basic Molecular Biosciences II class is shown below and the rationale for the categorisation of each question in terms of structure is stated below each one. Questions are graded from the simplest in question 1 and the most difficult in question 6.

1. Place each number below on the number line provided. If a number cannot be placed on a number line, circle it and explain why it cannot be put on the number line.

   0.022, 1.67, -1.5, 7/8, 1.26, 13/7, 0.3, 5/4.

   -2______________-1______________0______________1______________2

This is a problem confirming that <u>magnitude</u>, particularly of fractions and decimals has been understood.

2. Suppose in a large 100 g box of *Smarties* there are the following number of each colour:

   12 red, 24 light brown, 16 yellow, 18 green.

   If you purchased a 40 g box of *Smarties*, how many *Smarties* would you expect to have in the box?

This is a problem indicating ability to calculate a <u>discrete quantity</u>.

3. You have decided to construct a bioreactor in the laboratory that is an exact replica of a commercial bioreactor. Suppose the column length of the commercial bioreactor was 1200 cm and the diameter was 100 cm. What would be the height of your laboratory reactor if the diameter was 5 cm?

This is a problem indicating ability to calculate a <u>continuous quantity</u>.

4. You need to order chemicals for the laboratory out of your research grant. You price chemical X from two sources. The pricing from each is shown in the table below:

Product	Chemical company A weight	Price	Chemical company B weight	Price
Chemical 1	500g	R143.00	400g	R86.00

Which Chemical company would you buy Chemical X from and why?

This is a <u>consumption problem</u> which checks ability to calculate the price per unit from different data sets.

5. The density of substance B is twice that of substance A. If 100 ml of substance A has a mass of 1000g, what mass would 100 ml of substance B have? Why?

This problem assesses ability to work with a <u>measurement involving ratio</u> (since in this example, density = mass/volume)

6. A meter stick is balanced at its natural balance point on a fulcrum. A 100 gram weight is placed 20 cm to the left of the fulcrum. Where would a 200 gram weight be placed if the stick is to be balanced again? Show how you arrive at your answer.

This balance scale problem is indicative of the highest level of proportional reasoning ability since it involves realisation that it is a <u>compensatory problem</u>.

Results of the test are shown in Table 4.4 below:

Table 4.4: Results of the paper and pencil test (adapted from Fleener, 1993) for measuring proportional reasoning ability on a hierarchical scale, which was administered to 102 Basic Molecular Bioscience II students at the end of semester one

Overall Result	Number of students	% (rounded to 1 decimal place) of respondents	Number of students in the category not corresponding to <u>hierarchical</u> classification
1 correct answer	3	2.9	2
2 correct answers	5	4.9	5
3 correct answers	15	14.7	13
4 correct answers	28	27.5	18
5 correct answers	35	34.3	6
6 correct answers	15	14.7	0

It is evident from the results presented in Table 4.4 that only 15 of the 102 students who participated were able to answer all 6 questions. On the other hand, 35 students answered 5 questions, all but 6 of them failing to answer the final balance scale problem. Of the 28 students who obtained 4 correct answers, 10 complied with Fleener's hierarchical grading in that they answered the first 4 questions correctly but could not do the last two. However, 18 of the students in this category were unable to answer one or two of the first four questions but could answer the fifth question and in two cases, both the 5^{th} and 6^{th} question. In the categories where students were only able to answer up to three of the questions, the hierarchical categorisation distinction was less evident. It therefore appeared that certain students found some types of questions easier than anticipated by Fleener's categorisation of difficulty. Nevertheless, none of these students was able to answer the 6^{th} balance scale problem correctly, and only 8 of the 23 students could do the 5^{th} problem. Of the 23 students who answered three or fewer questions correctly, 15 could do 3 of the problems, 5 were able to do 2 of the problems and there were 3 students in the class who only answered one question correctly.

Initially, a comparison was made between ability to answer questions in the paper and pencil test and the ability to answer the initial generative question asked during the lecture at the beginning of the year. It was felt that this was necessary to substantiate the results from the paper and test and that it might possibly also indicate whether any students had increased their actual development during the semester.

Table 4.5 shows numbers of students in each category who answered the generative question correctly, numbers of those who answered incorrectly and numbers of those who did not send a response to the generative question. It must be pointed out that this was not necessarily because they were not present during that lecture or that they did not know how to answer the generative question but might have been because they had not yet hired a personal response system ('clicker'). Although caution needs to be exercised when drawing conclusions from the findings, it was felt that an inspection of the number of incorrect answers to the generative question in the students answering 5 or 6 questions of the paper and pencil test correctly would provide a greater basis for comparison particularly if one is trying to ascertain whether the semester's activities have brought about a change in conceptual understanding in any of the students. It was established that 49% of the respondents to the generative question obtained the correct answer, and 50 % of the students who took the pencil and paper test scored at least 5/6. In this respect, the results from two independent tests to measure proportional reasoning ability in the class supported each other. However, as reported in Table 4.4, only 15 of the students who took the paper and pencil test had achieved the highest level of actual development in proportional reasoning ability as indicated by their score of 100%. Surprisingly, one of these students had used an additive strategy in the generative question, so it is possible that this particular student had increased her actual level of development in response to mediation during the semester. Within the group scoring 5 out of 6, 14 students had answered the generative question incorrectly. If one were to grade this question according to Fleener's rubric it would be on a similar level to question 5 on the pencil and paper test. This therefore raised the possibility that at least 14 other students might have increased their actual level of development during the semester in response to mediation but there are no grounds for stating this categorically. On the other hand, it was rationalised that two groups of students, with very different abilities, could be created based on their scores in the paper and pencil test: a group of students who scored ≤3/6, and a control group who scored 6/6. These groups were then used for comparative purposes with respect to their ability to answer questions underpinned by proportion which form part of the necessary operations required of molecular bioscientists, after they had received instruction about these. These operations were therefore taken to be indicative of potential development in a Vygotskian schema.

Table 4.5: Comparison of answers given to the generative question and the paper and pencil test of proportional reasoning ability

Pencil and paper test categories	Number of students in the category	Number of correct answers to the generative question	Number of incorrect answers to the generative question	Number of students who did not send an answer to the question
1 correct answer	3	0	1	2
2 correct answers	5	1	4	0
3 correct answers	15	3	12	0
4 correct answers	28	13	10	5
5 correct answers	35	12	14	8
6 correct answers	15	8	1	6

There were 23 students who had scored ≤3/6 on the paper and pencil test designed to test proportional reasoning ability. Although not all of these students had been in possession of a PRS 'clicker' which would have allowed them to transmit a response to the generative question on proportion asked in class, the ratio of students who had answered the question correctly to the number who had answered incorrectly in this group was calculated to be 1:4 (correct : incorrect). On the other hand, there were 15 students who had answered all of the questions in the pencil and paper test correctly. The ratio of students who had answered the generative question correctly to those who had answered incorrectly among these students was 8:1 (correct: incorrect). I concluded that these ratios confirmed that it would therefore be reasonable to base the composition of the two groups on their paper and pencil test scores.

Therefore, based on the results of the paper and pencil test, the two selected groups were used for comparative purposes: Students who answered three or fewer questions correctly formed the first group (subsequently referred to as group 1), that was used to investigate whether an inability to do proportional reasoning would constrain potential development, and those who answered all six questions correctly formed the control group (subsequently referred to as group 2). These two groups were thus used for comparative purposes for further investigation into the effect of proportional reasoning ability on the ability to answer contextual problems in the Basic Molecular Biosciences II course and on general performance in the course, and thus to investigate to what extent actual development affects potential development. Students with higher levels of conceptual understanding of proportion who had scored 4 or 5 in the paper and pencil test were excluded from this aspect of the study, as it was felt that that in attempting to answer the research question, it would be better to use the students with obviously low proportional reasoning ability as indicated by a score of ≤ 3/6 and to use the students who had scored 6/6 as a control group for comparison when measuring the effect of actual development on potential development.

So, in order to answer the research question of whether ability to do proportional reasoning creates the conditions necessary for learning of operations underpinned by the concept of proportion, I decided that I would initially compare ability of the two groups of students to solve specific problems underpinned by proportion which had been included in the weekly practical tests, and to follow their progress up until the first summative test which was held at the end of March 2008.

Questions included in the first pre-laboratory test held on the 21st February were chosen for the initial analysis, as it was felt that an ability to answer these a few days

after first encountering them in lectures, would be indicative of inherent ability to learn in this area as the students would not have had much time to practice yet, since they would only recently have learnt how to perform the operations. On this account, one might postulate that this would imply that the students who were able to perform these operations at this early stage had displayed the actual level of development which would have facilitated potential development, as demonstrated by their ability to perform the operations chosen for analysis unaided after mediation. Moreover, it was considered that if one could demonstrate this with empirical data, one could conclude that in these students, learning would have occurred in the ZPD, especially since as L. C. Moll (1990) in his interpretation of Vygotsky's statement that '….*what the child is able to do in collaboration today he will be able to do independently tomorrow*" (Vygotsky, 1987: 211), points out that "*change within a zone of proximal development is usually characterized as individual change*" (L. C. Moll, 1990:12). Furthermore, one could thus make the assumption that students who were able to solve the two questions in the pre-laboratory test must have possessed the facility to learn this material quickly and with relative ease. Pursuing the interpretation of a natural line of development within the zone of proximal development (I. Moll, 1994), one could therefore postulate that it had occurred because the internal structures promoting this ability would have been sufficiently developed for mediation to have facilitated the learning of these operations.
The two questions chosen for analysis were the following:

1. If the concentration of acetic acid was 0.2 M, calculate the volume of 1 M NaOH in 0.5 equivalents for 200 ml of acetic acid.
2. Use the Henderson-Hasselbalch equation to calculate the volume of sodium acetate required to make up 100 ml of a 0.1 M acetate buffer, pH 4.50. The pK_a of acetic acid is 4.67.

The first question is based on a concept which all students in previous years have found very difficult to understand and to master. This question is based on the concept of equivalence which is underpinned by the concept of proportion. It has usually taken some time for past students to understand the concept and several students who have graduated, and have gone on to do post-graduate degrees, have demonstrated that they have still not been capable of performing this type of calculation.

The second question requires students to apply the Henderson Hasselbalch equation which describes the relationship between pH, pK_a and the ratio of unprotonated to protonated species in a buffer solution, which consists of a weak acid and its conjugate base. As this type of question had been done during a tutorial session in class, it was decided to ascertain which students had understood the concept and thus, subsequently (i.e. after mediation), been able to perform this type of operation unaided. This would indicate that students who could do so would have been at a developmental stage which allowed them to learn to do this during the tutorial period. According to Vygotsky's theory of social constructivism, one could hypothesize that in these students, learning would have occurred because the constructs lay within their "zone of proximal development".

From the results which are shown on the graph in Figure 4.5 below, it is evident that the percentage of students in group one who had answered the first question on equivalence correctly was 0 %, while in group two it was 13 %. Following the same trend, the percentage of students in group one who had answered the second question on the Henderson Hasselbalch correctly was 13 %, while in group two it was 33.33 %.

The chi-squared test for association requires that the expected cell frequencies are not too small. For the data analysed here, some expected frequencies were less than five and consequently Fisher's exact test is appropriate (Rosner, 1990). A one-sided Fisher's exact test has a p-value of 0.1494 for the equivalence question and a p-value of 0.1378 for the Henderson-Hasselbalch question and therefore one is unable to detect a statistically significant better performance by Group 2 as compared to the performance of Group 1 in these two questions.

However, even although unable to show that the results were statistically different, the overall impression created from the differences observed on the graph was that ability to learn in these areas was facilitated if the underlying concepts had been internalised.

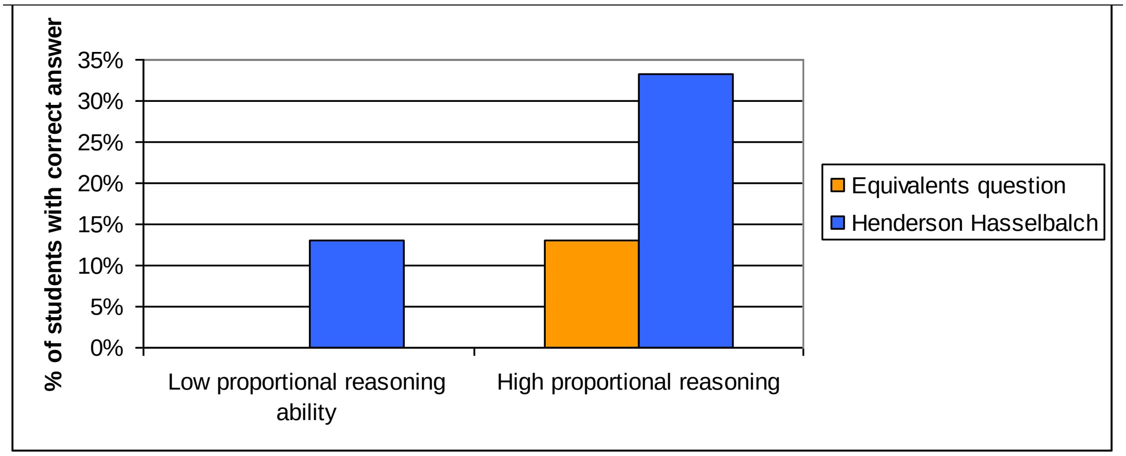

Figure 4.5: Relationship between proportional reasoning ability and capacity to learn to solve two specific problems, one requiring calculation of equivalents and the other the application of the Henderson Hasselbalch equation, which are both underpinned by the concept of proportion.

In order to follow the <u>progress</u> of these students as the semester progressed, individual responses of students in each of the two groups to a question underpinned by proportion which was included in the pre-laboratory test held on 20 March 2008 were analysed. Students were also asked to <u>explain</u> how they arrived at their answer. The question chosen for analysis, which is typical of the type of operation required for everyday laboratory practice in the biomolecular sciences, is shown below:

1 ml of NaOH was added to 3 ml of a 20 mg/ml casein solution. 1 ml was withdrawn and treated with 5 ml Biuret reagent. What is the final concentration of casein in the mixture?

The solution to this problem (when solved using proportion) is as follows:
Dilution factor = 4/3 X6 = 8; so 20 mg/ml divided by 8 is <u>2.5 mg/ ml</u>

The problem can also be solved <u>algorithmically</u> by applying the formula $C_1V_1 = C_2V_2$ twice – once for each dilution. It was anticipated that students with low proportional reasoning ability would attempt this approach.

It is evident from the results shown in Figure 4.6 that 43% of the group with high proportional reasoning ability (group two) were able to answer the question, while only 10% of the group with low proportional reasoning ability (group one) obtained the correct answer.

The Fischer exact test was used to test these results for statistical significance: The null hypothesis (H_0) was that the proportion of correct responses in the question analysed from the March 20 test is the same in Group 1 and Group 2. The alternate hypothesis (H_A) was that the proportion of correct responses in the question analysed from the March 20 test in Group 2 is greater Group 1. A one-sided Fisher's exact test has a p-value of 0.0354 and therefore one is able to detect statistically significant evidence of better performance by Group 2 compared to the performance of Group 1 in the March 20 test.

These results therefore provide clear evidence in support of the notion that potential development in a particular area is affected by actual development. In this respect they support what was suggested previously from the analysis reported in the previous section and thus the tentative claims that were made there.

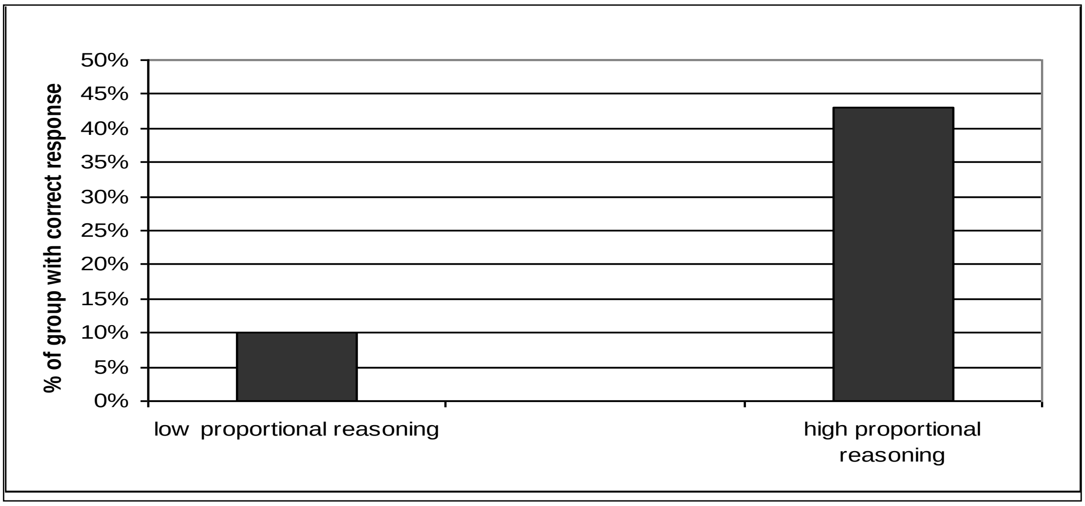

Figure 4.6: Comparison between responses from the group with low proportional reasoning ability and the group with high proportional reasoning ability to a question in the pre-laboratory test held on 20 March 2008

Also interesting was the analysis of the strategies used by each student to answer the question. There were 20 responses received from group one, of which there were only 2 correct answers. Only one of the students from this group, who had obtained low scores on the paper and pencil test, had used proportional reasoning to answer the question; this student was one of the two in the group who arrived at the correct answer. The other student from this group who had obtained the correct answer had used the $C_1V_1 = C_2V_2$ formula twice, in what one might describe as a more algorithmic approach, as described above.

By comparison, there were 14 responses received from the group of students who had obtained 100% on the paper and pencil test. Of these, 6 responses (43%) were correct. Strategies used by students in this group to solve the problem included both proportional reasoning (50 % of the group and 66.67% of those who obtained the correct answer) and algorithmic approaches (50 % and 33.33% of those who obtained the correct answer). Results of this analysis therefore support those previously reported in section 4.1 which demonstrated that an ability to do proportional reasoning enhances learning of specific operations in the biomolecular sciences which are underpinned by the concept of proportion, or conversely, that if the required level of actual development had not been achieved, potential development would be impeded.

To follow the progress of students in each of these two groups further, an analysis of the first summative assessment (March test) results was undertaken next. These results were compared with proportional reasoning ability (as determined by the pencil and paper test) in these two groups of students to establish whether the previously reported results could be substantiated.

The first two sections of this summative test consisted of procedural questions. It was therefore decided to analyse the results of question 1, question 2, the combined result for question 1 and question 2, and to compare these with the overall test result in individual students. Question 1 consisted of 9 sub-questions involving operations which were based on proportion. Question 2 consisted of 10 sub-questions which required manipulation of the Henderson-Hasselbalch equation. As has been explained, this equation describes the relationship between pH and pK_a of a buffer solution and the ratio of unprotonated to protonated species in a weak acid solution. While the first part of these types of questions may be solved mechanically, using this equation to calculate volumes of each in a buffer at a particular pH requires proportional reasoning. Results obtained in these two sections in individual students in each category are reported in Tables 4.6 and 4.7 and were illustrated in scatter plots shown in Figures 4.7 and 4.8. Students were given coded numbers in the tables to ensure anonymity.

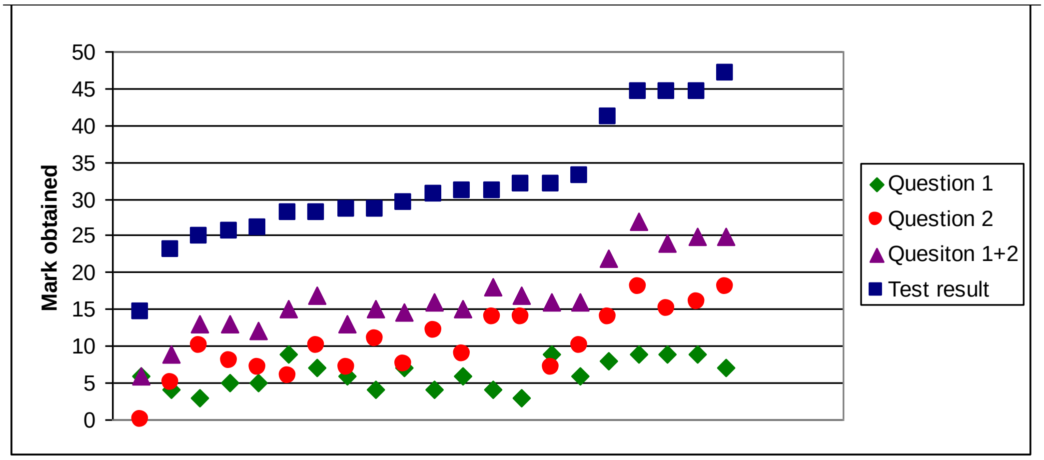

Figure 4.7: Scatter plot of results from group one (low proportional reasoning ability) in the March 2008 summative assessment. This plot shows marks awarded to questions 1, 2, the combination of questions 1 and 2, and the overall result

Table 4.6: Summative test results for group one

Student number	Question 1 /10	Question 2 /20	Total (question 1 + 2) /30	Overall result /55
5	9	6	15	28
6	5	8	13	25.5
7	9	18	27	44.5
8	6	7	13	28.5
18	7	10	17	28
24	9	15	24	44.5
25	3	14	17	32
28	9	16	25	44.5
32	8	14	22	41
40	4	12	16	30.5
46	6	9	15	31
48	4	14	18	31
56	4	11	15	28.5
58	7	7.5	14.5	29.5
61	6	10	16	33
62	5	7	12	26
75	7	18	25	47
79	6	0	6	14.5
87	9	7	16	32
90	4	5	9	23
97	3	10	13	25
Average:	**6.2**	**10.4**	**16.6**	**31.8**

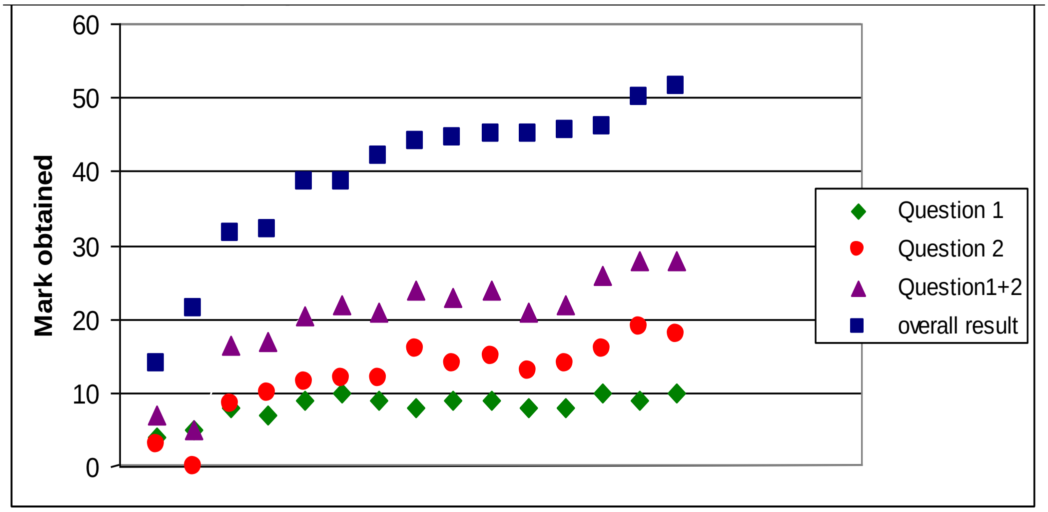

Figure 4.8: Scatter plot of results from group two (high proportional reasoning ability) in the March 2008 summative assessment. This plot shows marks awarded to questions 1, 2, the combination of questions 1 and 2, and the overall result

Table 4.7: Summative test results for group two

Student number	Question 1 /10	Question 2 /20	Total (question 1 + 2) /30	Overall result /55
1	5	0	5	21.5
9	8	16	24	44
13	10	16	26	46
23	4	3	7	14
27	9	15	24	45
35	9	14	23	44.5
51	8	8.5	16.5	31.5
54	7	10	17	32
71	9	12	21	42
77	9	11.5	20.5	38.5
80	8	13	21	45
84	10	18	28	51.5
86	10	12	22	38.5
92	8	14	22	45.5
100	9	19	28	50
Average	**8.2**	**16**	**20.3**	**39.3**

If one compares the performance between individuals in the two groups, it appears that generally group two has performed better than group one, as illustrated on the scatter plot results shown in Figures 4.7 and 4.8 (which although they have different scales on the x axis demonstrate the trend of the results). There are however, a small minority of students in each group who have performed either better than expected in group one, or far worse than predicted from proportional reasoning ability scores in group two which brings into question the statistical significance of the results illustrated in Figure 4.9 (from which it is evident that the modalities of the two groups are different).

These data sets were therefore subjected to statistical analysis using the one-tailed, two-sample t-test, assuming unequal variances using the *Microsoft Excel* package to ascertain whether any observed relationships were statistically significant.

The question asked was: Is the overall result on the first summative test (March 2008) affected by ability to do proportional reasoning? The null hypothesis (H_0) was that the overall March summative test result of students with high proportional reasoning ability (group 2) **≤** the overall March summative test result of students with low ability (group 1). The alternative hypothesis (H_A) was that the overall March summative test result of students with high proportional reasoning ability (group 2) **>** the overall March summative test result of students with low ability (group 1).

The calculated *p* value of 0.014555096 indicated that these results were significant to 5 %.

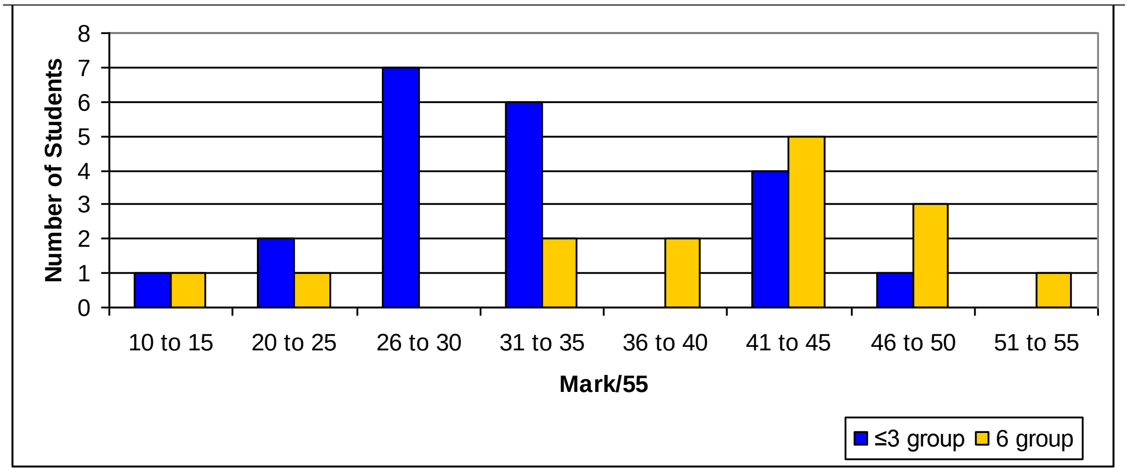

Figure 4.9: Comparison of the performances of group one and group two in the March summative assessment.

However, a comparison of overall performance in the March summative assessment (shown in section 7.3) which is shown in Figure 4.9 above, does not really distinguish whether students have performed better because of their theoretical knowledge or because of the impact of the problems underpinned by the concept of proportion, especially since there were four questions in the test and questions 3 and 4 were worth 25 out of a total of 55 marks (and thus 45 % of the total), meaning that they could have influenced the overall result. As mentioned previously, questions 1 and 2 in this assessment consisted solely of problems which were underpinned by proportion and it was therefore decided to plot the totals obtained from only these two questions for comparison between the two groups. The percentage of students in each group obtaining various discrete totals of questions 1 and 2 was thus plotted onto a line graph from which it is appears that students who had scored 6/6 on the paper and pencil test performed substantially better than those in the group with low scores (≤ 3) on the paper and pencil test.

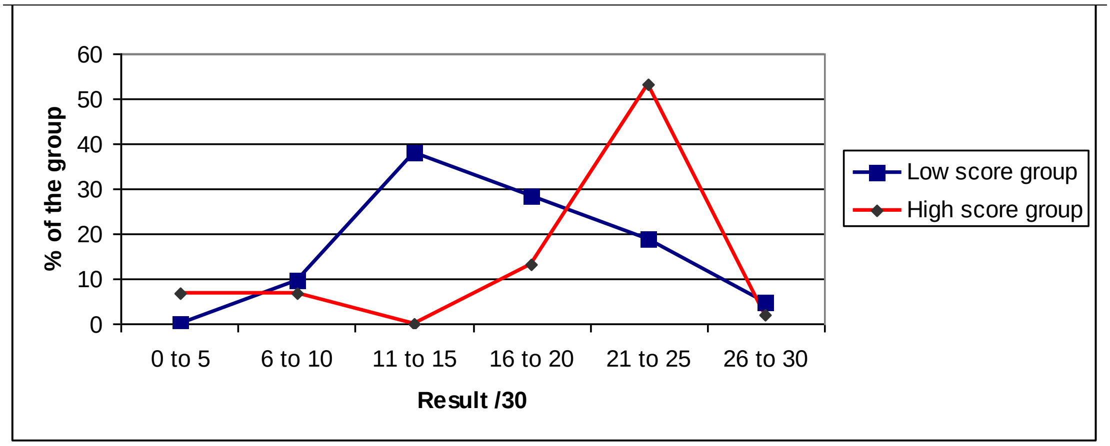

Figure 4.10: Comparison of results of the two groups of the total of questions 1 and 2 of the summative test held in March 2008.

In order to determine whether there was a statistically significant difference between the performances of the two groups in the individual questions underpinned by proportion in this summative assessment, a one-tailed statistical t-test, assuming unequal variances, was performed using the *Microsoft Excel* package on the test results in question 1, question 2 and questions 1+2.

The first question asked was: Is the combined result from questions 1 and 2 on the first test (March 2008) affected by ability to do proportional reasoning? The null hypothesis (H_0) was that the combined result from questions 1 and 2 in the March test in students with high proportional reasoning ability (group 2) **≤** than the combined result from questions 1 and 2 in the March test in students with low ability (group 1). The alternative hypothesis (H_A) was that the combined result from questions 1 and 2 in the March test in students with high proportional reasoning ability (group 2) **>** that the combined result from questions 1 and 2 in the March test in students with low ability (group 1). The calculated *p* value of 0.042748479 indicated that the observed difference in the combined results from questions 1 and 2 were significant to 5 %.

However, one still needed to establish to what extent each of the types of individual questions included in questions 1 and 2 of the March test had contributed most to the statistically significant differences in results observed in the performance on these questions in the two groups. Question 2 revolved around the Henderson-Hasselbalch equation. Analysis of an earlier question involving the Henderson-Hasselbalch equation which had been in included in the pre-laboratory test held on the 21st February, established that there was no statistically significant difference in the number of students in the two groups who were able to answer this type of question at that stage. The results of the differences in performance of the Henderson-Hasselbalch question between the two groups in the March summative assessment were subjected to statistical analysis using a one-tailed statistical t-test (with 34 degrees of freedom), assuming unequal variances, which was performed using the *Microsoft Excel* package.

The question asked was: Is the ability to answer question 2 on the first test (March 2008) affected by ability to do proportional reasoning? The null hypothesis (H_0) was that the ability to answer question 2 on the first test (March 2008) in students with high proportional reasoning ability (group 2) **≤** than the ability to answer question 2 on the first test (March 2008) in students with low ability (group 1). The alternative hypothesis (H_A) was that the ability to answer question 2 on the first test (March 2008) in students with high proportional reasoning ability (group 2) **>** ability to answer question 2 on the first test (March 2008) in students with low ability (group 1). The calculated *p* value of 0.154661748 indicated that any observed difference in the performance in question 2 in the March summative assessment between the two groups was not statistically significant. This confirmed the previous result which leads one to conclude that students may learn to apply the Henderson-Hasselbalch equation to some extent, probably because problems of this type can be solved using an algorithmic approach.

On account of the statistical evidence, one could therefore also conclude that the questions included in question 1 in the March test (which can be seen in the attachments section, 7.3) had contributed most to the statistically different performances on the combined results from questions 1 and 2. To establish the extent of this contribution, the difference in performances of the two groups on question 1 was subjected to a one-tailed t-test, assuming unequal variances using the *Microsoft Excel* package.

The question asked was: Is the ability to answer question 1 on the first test (March 2008) affected by the internalisation of the threshold concept of proportionality, as reflected by the ability to do proportional reasoning? The null hypothesis (H_0) was that the ability to answer question 1 on the first test (March 2008) in students with high proportional reasoning ability (group 2) **≤** than the ability to answer question 1 on the first test (March 2008) in students with low ability (group 1). The alternative hypothesis (H_A) was that the ability to answer question 1 on the first test (March 2008) in students with high proportional reasoning ability (group 2) **>** ability to answer question 1 on the first test (March 2008) in students with low ability (group 1). The calculated *p* value of 0.001773106 indicated that the observed difference in the performance in question 1 in the March summative assessment between the two groups was statistically significant at 1 %. This could have been expected, because the sub-questions included in question 1 in the March summative assessment do not lend themselves to learning by rote and require students to have a conceptual understanding of proportion. On the other hand, as explained previously, initial application of the Henderson Hasselbalch can be learnt through practice without actually understanding conceptually what it entails, which means that it was possible to score at least half of the points on question 2 without being able to think proportionally.

Moving on, another of the research sub-questions asked whether an inability to conceptualize proportion influences general performance and overall results obtained in the Basic Molecular Biosciences II course in summative assessments. In order to answer this, the overall performances in the June examination (i.e. the examination at the end of the first semester) were compared between the students in the two groups. The June examination result was chosen rather than the end-of-year November examination result, because the second half of the year was taught by different lecturers and it was felt that this would introduce additional variables into the experimental data. However, as the first half of the year had been taught by the same lecturer who had taught the proportion based problems it would be advantageous to use this summative assessment instead. Results are shown in Figure 4.11 below.

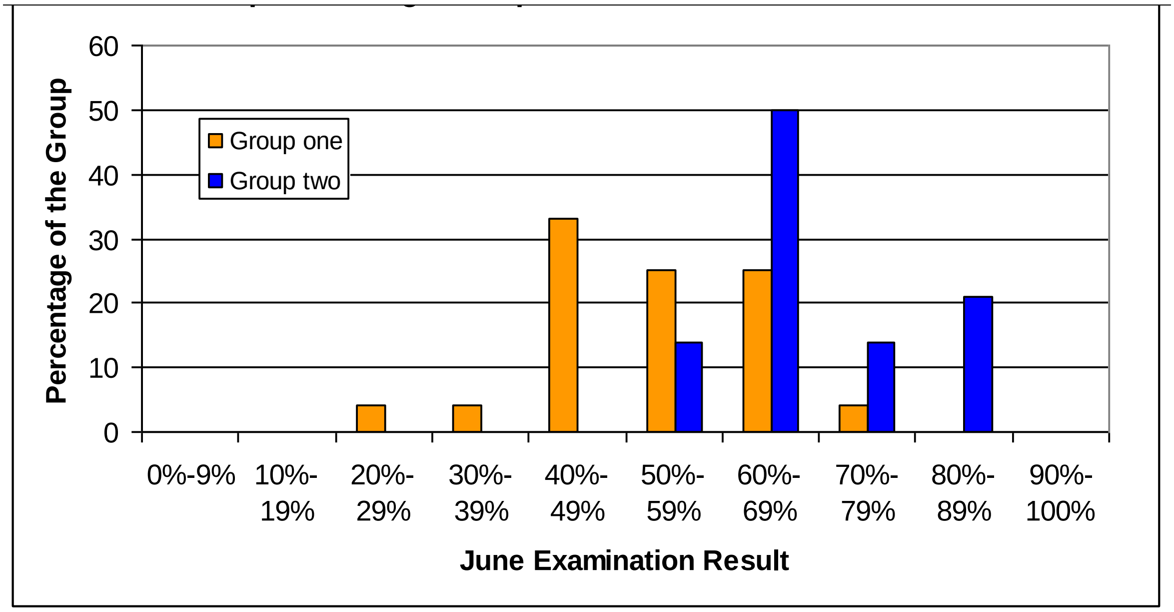

Figure 4.11: Comparison of the June examination results with ability to do proportional reasoning. The results of groups one and two were compared.

Comparing the modalities of the two groups of students in Figure 4.11, it is evident that the highest number of the students with a low score on the paper and pencil test have obtained a grade of between 40 and 50% in the June examination, whereas most of those in the group who demonstrated that they are able to do proportional reasoning have obtained between 60 and 70 %, no-one has obtained a grade of less than 50 %, and 20% of the group has obtained over 80 %. The average result in group 1 was 51 % and in group two was 67 %. This strongly suggests that embedded knowledge of the threshold concept of proportion as reflected by proportional reasoning ability impacts on general performance in the molecular biosciences.

In order to ascertain whether the observed differences were statistically significant, these data sets were subjected to statistical analysis using a one-tailed statistical t-test, assuming unequal variances, using the *Microsoft Excel* package as follows:
The question asked was: Is the overall performance in the June examination affected by ability to do proportional reasoning? The null hypothesis (H_0) was that the overall performance in the June examination in students with high proportional reasoning ability (group 2) **≤** than the overall performance in the June examination in students with low ability (group 1). The alternative hypothesis (H_A) was that the overall performance in the June examination in students with high proportional reasoning ability (group 2) **>** overall performance in the June examination in students with low ability (group 1). The calculated *p* value of 0.000045214256 indicated that the observed differences in performance between the two groups, <u>was significant to 1 %.</u>

It was also decided to compare the performance of the two groups of students in <u>Section B</u> of the June examination. This section which constituted 35 % of the paper contained all the procedural questions which required the ability to perform the operations in the molecular biosciences which are underpinned by proportion. These data sets were subjected to statistical analysis using a one-tailed statistical t-test, assuming unequal variances, using the *Microsoft Excel* package as follows:

The question asked was: Is the performance in Section B in the June examination affected by ability to do proportional reasoning? The null hypothesis (H_0) was that the performance in Section B in the June examination in students with high proportional reasoning ability (group 2) **≤** than the performance in Section B in the June examination_in students with low ability (group 1). The alternative hypothesis (H_A) was that the performance in Section B in the June examination in students with high proportional reasoning ability (group 2) **>** performance in Section B in the June examination in students with low ability (group 1). The calculated *p* value of 0.000600297 indicated that the observed differences in performance between the two groups, was significant to 1 %. The results are shown in Figure 4.12 below.

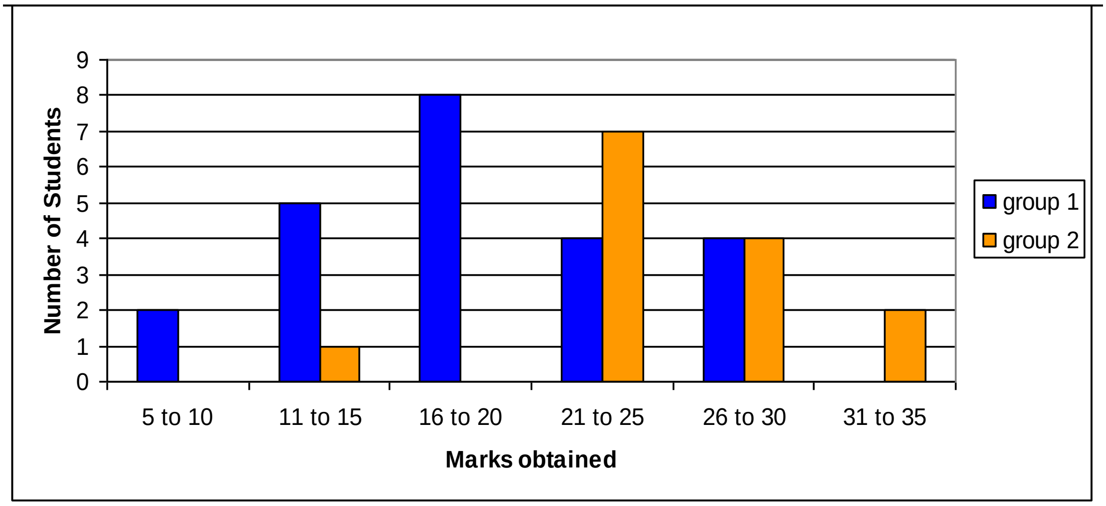

Figure 4.12: Comparison of results in section B between the two groups of students that had demonstrated differing proportional reasoning ability: group 1 obtained ≤3/6 and group two obtained 6/6 on the paper and pencil test.

One might thus conclude that on the basis of the paper and pencil test which was used to judge proportional reasoning ability, it has been clearly shown that conceptual understanding of the threshold concept of proportion, which is indicated by the ability to do proportional reasoning, has created the conditions which enable learning of operations underpinned by the concept in the molecular biosciences field. Moreover, general performance in the Basic Molecular Biosciences II course has been found to be better in students who have scored full marks on the paper and pencil test. Because of the results reported in this section, one might therefore also conclude that <u>actual development impacts on potential development in a particular domain.</u>

Vosniadou (1993) has however, pointed out that it is better to judge conceptual understanding from explanations of understanding rather than from performance alone. In light of this, and also as a form of mediation to encourage development of conceptual understanding and internalisation of the concept, students were asked to discuss with each other and their practical group teaching assistants, via electronic communication forums such as WebCT, email or internet blog sites, what they understood about the concept as it was felt that this would force them to engage with the subject. These discussions formed part of their term assessment mark and so were available for analysis. Also available were informal discussion threads on WebCT.

Formal discussions which were going to be assessed were disappointing in terms of providing clear-cut evidence of a student's individual understanding of the concept because many had accessed information on proportion from the internet and had paraphrased (or not even) the contents. This meant that there were not many instances of actual discussion which provided examples which could be analysed and confidently graded according to the conceptual development of proportional reasoning. However, the informal WebCT discussions proved to be very informative as it was in this forum that students related to each other their difficulty in understanding the concept; those who had understood it attempted to enhance the understanding of those who had not. These discussion threads therefore provided an additional source for rating students' conceptual understanding and it was thus felt that if these ratings could be compared with the ability to answer the paper and pencil test, the questions asked during the lecture at the beginning of the year and could also be correlated with ability to answer questions in the Basic Molecular Biosciences II course which had been included in various formative and summative tests, one would have more support for the conclusions drawn from results in this section.

4.3 A comparison of classification of proportional reasoning ability resulting from analysis of the written discussions on the concept of proportion, with performance in contextual questions, in the Basic Molecular Biosciences II course, underpinned by the concept

In order to create an awareness of proportion, its application and importance in the molecular biosciences, and to assist students in their development of a sound mental model and internalisation of the concept, they were asked to 'blog' on what they understood by the concept and to comment on its application in the Basic Molecular Biosciences II course. In this regard, they were asked to discuss the concept via email, blogs or WebCT with their peers and teaching assistant within their allocated practical group. Informal discussion on WebCT also took place, and it was this that provided the greatest insight into the students' actual thinking and difficulty in understanding what the lecturer might have assumed was a concept that had been grasped previously and internalized.

In light of the above, one specific WebCT informal discussion thread between four students was selected for analysis. This thread was chosen because it was one which illustrates varying levels of actual development in this area in the Basic Molecular Biosciences II class specifically with respect to the individual mental models of proportion. Other discussion threads were disregarded for the purpose of this research, because one could not be sure whether students had copied information on proportional reasoning from other sources. In contrast, the thread selected clearly evidenced the students' own conceptual understanding.

One might postulate that a description of the mental model held by each student would give an indication of their level of actual development in this knowledge area which would, in turn, determine whether they would be able to learn the more contextual material successfully, especially because for those who had not achieved the required actual level of development, the learning level might not fall within the "zone of proximal development" in this domain. In terms of the research question then, one might hypothesize that those students who had indicated by way of their written explanation of the concept, that they had grasped the threshold concept of proportion, would perform better when attempting contextualized problems than those in which it is clearly evident that they have little or no understanding of the concept. All students in the Basic Molecular Biosciences class were therefore allocated number codes to maintain confidentiality, with a view to comparing the performance of those who had clearly indicated an understanding of proportion with those who had clearly displayed a distinct lack of understanding of the concept. Specifically, a comparison was made between their written account of the concept and their ability to solve contextualized problems underpinned by a concept of proportionality, and their general performance in the June summative assessment which included a number of these types of questions. After the students had been selected on the basis of their written accounts, the classification awarded was correlated with their ability to answer the generative question asked in class, the contextualized question which was put to the class during the same lecture, and their performance on the paper and pencil test based on Fleener's (1993) hierarchical classification of proportional reasoning ability. The WebCT discussion thread may be viewed below (My views and classification of the students involved in the discussion are highlighted below each message):

Message no. 27
Author: Student 100
Date: Monday, February 25, 2008 10:28

```
I understand proportion as being a ratio of two quantities (e.g. two volumes or
two masses).The ratio tells us how they are quantitatively related to each other
by using a common multiple to relate them (and not just adding numbers to each
other).

Using the example of the two cylinders given in class, we were given the ratio in
the first part as 4:6 (wide: narrow). We now find the common multiple which
relates them i.e. "how many times taller is the narrow cylinder?" To get this we
divide 4 by 6 to get 1.5 - this means we need to multiply whatever reading we
have in the wide cylinder by 1.5 to obtain the expected reading in the narrow
cylinder. So if we have 6 in the wide cylinder, we multiply by 1.5 to get 9 in
the narrow one. Similarly, if we were given the reading in the narrow cylinder we
would divide 6 by 4 to get the common multiple of how many times SHORTER the wide
cylinder is -

Hope this is understandable :)
```

Clear understanding of the concept and has introduced a conversion factor – therefore able to apply proportional reasoning and to think proportionally – calculated the invariant factor

Classification: Formal reasoning – PR and P.

Reply Reply privately Quote Download

Message no. 32
Author: Student 83
Date: Tuesday, February 26, 2008 13:23

```
I also understand proportion as a ratio between 2 given things, for e.g. if you
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are given are given a volume of 20ml with an x concentration and told that if you take out 2ml from the solution and add it to another beaker containing 18ml what proportion will you get? I think the answer is you need to say 2:20 will be the same as 2:18 you divide each by 2 to get the ratio of 10:9.

If am wrong about my understanding please correct me.

No clear understanding of the concept. However, is aware of needing to set up a ratio but clearly has no idea of what quantities need to be included in it. The advice to "divide each by 2" seems arbitrary in this context as there is no concept of proportionality and an invariant factor.

Classification: Transitional

Reply Reply privately Quote Download

Message no. 33

Author: Student 68

Date: Tuesday, February 26, 2008 13:35

According to what I understand, proportions deal with relationships between quantities.
Those relationships can be linear or inverse. These relationships are given as ratio, e.g. let's say ratio of blind people to deaf people is 1: 4. This means that in every 4 deaf people, one is blind. Well guys correct me if I'm wrong here 'coz this is so tricky.

What I don't understand is, can we also use proportions for more than 2 quantities? And if we do, do we get the right answers? Please help!!

Grappling with the concept; understands that a ratio is involved but has set up the ratio incorrectly and does not understand the aspect of invariance.

Classification: Transitional

Reply Reply privately Quote Download

Message no. 34

Author: Student 39

Date: Tuesday, February 26, 2008 16:30

I'm not sure but I think if u have a ratio of 1:4("one is to four"),it means that the whole(which is five)is made up of 1 part of something and 4 parts of the other and the only way u can have 1 blind person is if u have 5 people, not 4 because this would mean that 1 person is blind and deaf at the same time(Lord Jesus!).This will also change the overall ratio to 1:1:3.Some of Mendel's phenotypic ratio's had the form 1:2:1(e.g. 1 green pea,2 green-blue peas, and 1 blue pea).I think that ratio compares part to part and proportion compares part to whole and proportion can be used to calculate ratio or the other way round and yes we can use proportions for more than 2 quantities(e.g. percentages/fractions of elements in NaOH if given a 100 gram sample)

Understands proportional reasoning but not necessarily able to think proportionally – no mention of an invariant factor – although appears to be able to do proportional reasoning, the concept is not as developed as in student 100 – clue: "I'm not sure but I think".

Classification: Formal reasoning - PR

Reply Reply privately Quote Download

Message no. 38

Author: Student 68

Date: Thursday, February 28, 2008 09:20

Sorry, I'm lost here! Is ratio the same as proportion?

More evidence for the transitional classification.

While students 68 and 83 are evidently grappling with the concept and, if one applied Piagetian labels according to the Thorton and Fuller (1981) scheme, might be considered to be in a transitional stage with respect to obtaining an understanding of proportion and its internalisation, student 100 displays clear evidence of ability to do proportional reasoning and to think proportionally. This is obvious from her rationalization of how to calculate proportion and in the explanation of how to introduce a conversion factor to solve the generative question which had been asked in class. This student therefore clearly understands proportional reasoning because of the introduction of an invariant factor which according to Thorton and Fuller (1981) is explicit evidence of this ability, while Lamon (2007) goes further as she considers that the introduction of a conversion factor signifies an understanding of proportionality, which she places higher on a hierarchical scale of conceptual understanding. Student 100 has thus been awarded the classification of formal – PR (proportional reasoning ability) and P (understands proportionality). On the other hand, although student 83 for example, articulates a realisation that one needs to set up one kind of a ratio she clearly has no idea of how to attempt to do this. Student 68 also conceives that a ratio is important, but is not entirely sure exactly what a ratio is. On this basis this student, although having been classified as transitional, might be considered to be at a lower level of development than all the other students. Student 38 however, appears to understand how to set up the ratio which student 68 was having problems with, and on this basis appeared to be able to apply proportional reasoning and this student points out where student 68 has employed defective reasoning. However, there has been no description of proportional ratios, and no explanation of the importance of invariant factors. However, this might have been because this student was only responding to student 83, although the explanation given could have pointed to the importance of invariance, if the student had realised how important this was. The words “I'm not sure” also indicate that there might be a shade of uncertainty in this student's thinking. Nevertheless, I have classified student 39 as a formal thinker – PR which would place student 39 lower on a hierarchical scale than student 100, but above students 83 and 68.

It was decided that it would be informative to review retrospectively how each of the students who had been awarded the classifications discussed above had performed in the two questions posed to the class, in the paper and pencil test based on Fleener's hierarchical categorisation of proportional reasoning ability, to ascertain whether written accounts could potentially form a reliable basis for classification, and then if deemed so, to evaluate their subsequent performance in contextualized questions which are underpinned by proportion in the first summative test, and their overall performance in the June examination. Results are shown in Table 4.8 which follows:

Table 4.8: Comparison of performance between four students classified to be at different developmental stages from their written explanations of the concept of proportion.

Student number	Piagetian classification based on that used by Thorton and Fuller (1981)	Generative question (correct answer = 9)	Following class question (correct answer = 40)	Paper and pencil test (/6)	Sect B June exam (/35)	June exam mark %
100	Formal (PR and P)	9	40	6	24.5	68
39	Formal (PR)	8	none	5	23	59
68	Transitional	9	44.4	4	16	51
83	Transitional	4	44.4	4	18	50

While the findings reported in Table 4.8 might have been anticipated from predictions based on the classification of conceptual development based on written explanations of their understanding of the concept of proportion, it was noteworthy that student 100 (formal – PR and P) was able to supply the correct answer to both the generative question, and the contextualized question posed in class, and had obtained a score of 6 in the paper and pencil test. In this case certainly, one might conclude that the written account had given a clear indication of ability.

Student 39 (formal – PR), who had been considered to be slightly behind student 100 in terms of development of the concept, had used an additive strategy in attempting to answer the generative question, had not supplied an answer to the next question, but had scored 5/6 on the paper and pencil test. On this basis, these results had supported the classification based on the discussions to some extent. One might however, have anticipated, based on the written account that this student would have obtained the correct answer to the generative question. However, the words “I am not sure” in her account did indicate that at the stage at which the generative question was asked, she was still internalising the concept.

Students 68 and 83, both of whom had been given the Piagetian label as being at a “*transitional”* developmental stage, had both scored 4 on the paper and pencil test which supported the classification given from the written discussions. However, student 83 had surprisingly been able to answer the generative question correctly, but not the subsequent one, while as might have been predicted, student 68 had obtained the incorrect answer to both the questions posed in class. The correlation between the classification in terms of proportional reasoning ability made from the written discussions and the paper and pencil score is illustrated in Figure 4.13.

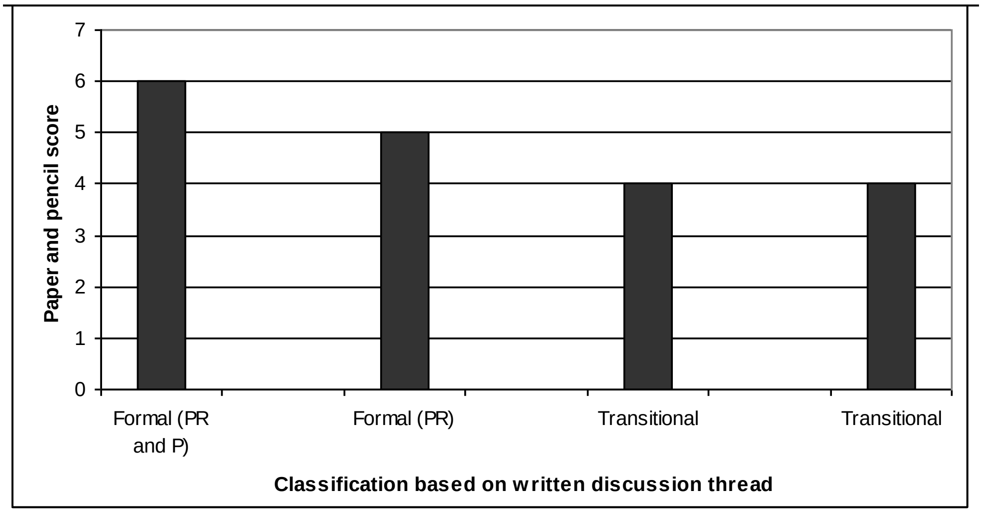

Figure 4.13: Correlation of the performance of four students in the paper and pencil test with the classification of different developmental levels awarded on the basis of their written discussions about proportion.

It appears that there is extremely good correlation between the classification which had been conferred on the basis of the discussion thread and the paper and pencil test result. For example, as illustrated in Figure 4.13, student 100 has answered all 6 questions on the test correctly, student 39 has answered 5 questions correctly, and students 68 and 83 have answered only 4 out of the 6 questions correctly. These results mirror exactly the ranking conferred on each of these students from their written discussions with one another. However, no well-defined correlation was observed with the generative question asked in class. This finding therefore highlights the importance of using more than one example to test proportional reasoning ability.

A more detailed examination of answers to the individual questions in the paper and pencil test provides more evidence for the conclusion that written accounts give a good indication of conceptual development. For example, an interesting finding was that student 83, who displays transitional thinking, was unable to answer the first question (which Fleener, 1993, categorizes as the lowest order of proportional reasoning ability). This question required placement of figures (including fractions and decimals) on a number line. The discussion thread, which for this student suggested an inability to set up a ratio, mirrored this result. Rational numbers (which include fractions) (Lamon, 2007) are examples of ratios. Student 68, however, while answering questions 1 and 2 correctly, was unable to use a ratio to calculate the dimensions of the bioreactor (question 3), which was evident from the discussion thread which indicates that this particular student does not realise that by making a ratio of 1 blind to 4 deaf people implies that there are actually 5 people involved. As would have been expected, neither of these students (68 and 83) was able to do the balance scale question (question 6) which was ranked by Fleener as indicating the highest order of hierarchical proportional reasoning ability. Student 39, who showed in the discussion that she at least understood how to set up a ratio, scored 5 on the test and had answered correctly all the questions except for the final balance scale question. The results presented above thus support Fleener's (1993) hierarchical ranking of questions to assess developmental levels of proportional reasoning. Moreover, they also support reports (Vosniadou, 1994) that verbal accounts of concepts provide valuable evidence for evaluating conceptual understanding and for gaining insight into the mental models used when answering questions.

The next part of this analysis looked at the correlation between the ranking awarded to these four students on the basis of their written discussions about proportion, which as shown previously, agreed with the classification based on the paper and pencil test score, and their general performance in the June summative examination. Results are shown in Figure 4.14 below.

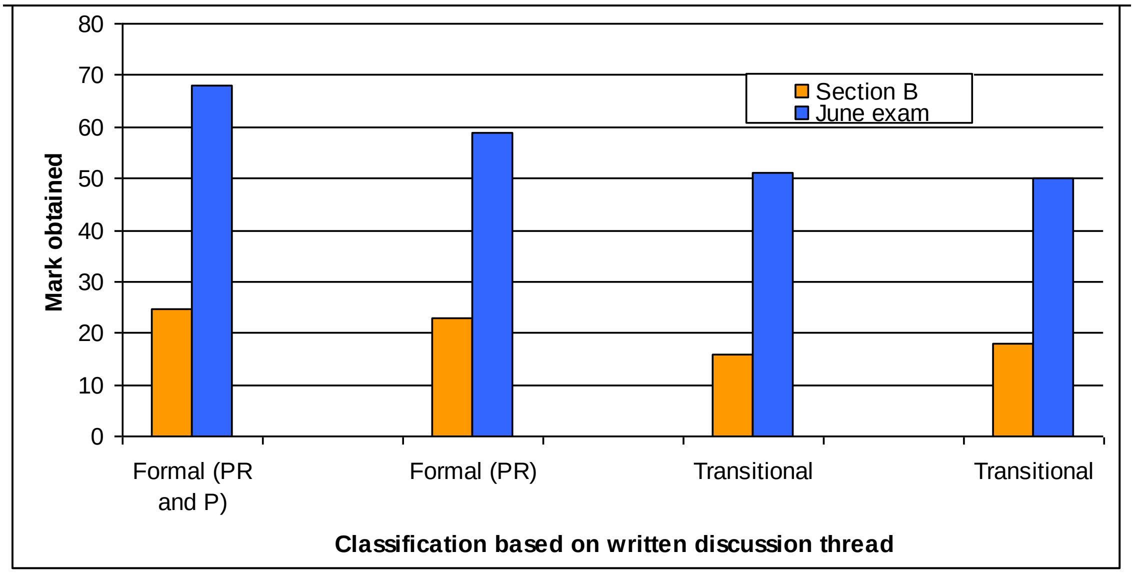

Figure 4.14: Comparison of the performance in section B in the mid-year examination, and the overall midyear examination result of four students with the classification of their developmental levels from their written discussions about proportion

As is evident, performance in the mid-year summative examination also showed a predictable difference between these students: the student ranked with the highest conceptual development (formal, PR and P) obtained 68 % which was higher than that obtained by the student (formal, PR) ranked next in ability, who obtained 59 %. Both of these students obtained higher marks than the two students classified "transitional" who obtained 51 % and 50 % overall.

The mark obtained (out of a possible 35) for Section B of the June examination is specified in Table 4.8 and illustrated in Figure 4.14. As mentioned in section 4.2, this was the section that included the calculations underpinned by the concept of proportion. The marks obtained for this section by the four students, which were 24.5 and 23 for the students scoring 6 and 5 on the paper and pencil test, and ranked formal PR and P and formal PR from their written discussions, and 16 and 18 for the students classified transitional, support the claim that their difference in the overall result was a reflection of their ability to solve problems underpinned by proportion and was not due to differing ability to answer essay questions or to do multiple choice questions on other theoretical aspects of the course.

This observation thus strongly supports previous evidence that the ability to do proportional reasoning, which in this analysis was based on written discussions (which correlated well with scores on the paper and pencil test), <u>does</u> create the conditions for learning of operations underpinned by the concept of proportion in the molecular biosciences. In this regard it answers the research question and substantiates the conclusions drawn in the previous section.

The sub-question, which was whether <u>general performance</u> in the Basic Molecular Biosciences course is affected by ability to do proportional reasoning, also formed part of this analysis. In this instance, general performance, which in this case has been reflected by the overall accomplishment in the June examination (i.e. at the end of the first semester) was better in the two students who had demonstrated ability to apply proportional reasoning, (and best in the one who had shown that she was able to do proportionality), than the two who were at a less advanced stage of conceptual development. One might therefore conclude in terms of <u>this</u> sub-question that the comparison of factors indicated that performance in the June examination increased with increasing ability to apply proportional reasoning, which, in a broader sense, suggests that <u>actual development as measured in this case by the ability to do proportional reasoning has influenced potential development in a general sense and not only in a particular domain.</u>

However, in order to <u>validate</u> the claim that actual development influences potential development from yet another perspective, it was felt that it would be desirable to analyse individual performance of some of <u>these</u> students on <u>specific</u> questions underpinned by proportion. The students chosen were student 100, who had displayed evidence from the written account of the highest level of conceptual development (and had scored 6 in the paper and pencil test), and the two students, 68 and 83, who had been awarded the Piagetian labels of being in a transitional stage with respect to development of the concept of proportion. Student 39 was excluded from this study as she did not demonstrate as distinctive an ability to apply proportional reasoning on the paper and pencil test as student 100 who had scored 6/6.

The questions chosen for analysis were among those included in the <u>first summative test held in March</u> and included the following questions. The complete test is included in Chapter 7 (section 7.3). However, for clarity, numbers to the questions chosen have been reallocated. (Notice that the reasoning required in order to obtain the correct answer to each problem, or the correct solution, is given below each question):

Question 1.1 How many ml of stock solution would you take to prepare 60 ml of an 800X dilution?

This question can be answered by setting up an equation as follows:

Dilution factor = $\frac{\textbf{final volume}}{\textbf{Initial volume}}$

$800 = \frac{60}{x}$

Solve for x

Question 1.2 Give an account of how you arrived at your answer in 1.1.

Question 2 What would the final concentration be if you added 8 ml of water to 2 ml of a 0.8 M solution?

Set up the equation C1V1 = C2V2, where final volume (V2) is 10 ml, initial volume (V1) is 2 ml, and initial concentration (C1) is 0.8 M solution. Solve for C2. This would be an algorithmic approach. Alternatively, one may use proportional reasoning to rationalize that if 8 ml are added to 2 ml then the solution has been diluted 5 times. So if 0.8 M were to be diluted 5 X it would be 5 X less concentrated. So 0.8 M / 5 = 0.16 M

Question 3 Calculate the molarity of a solution of amphotericin B (M_r = 924.1) if 462.05 mg are dissolved in 2 ml of water.

One could use proportional reasoning to solve the problem as follows:

924.1 g / L = 1 M = 924.1 mg / ml

924.1 mg / 2 ml = 462.05 mg / ml = 0.5 M solution

But there are 462.05 mg in 2 ml i.e. half the concentration of above, so concentration is 0.25 M. Alternatively one could set up equations firstly to calculate the number of moles in 2 ml and then work out the concentration from the number of moles per volume.

Question 4 A 30 % solution contains ________ g per 250 ml.

30 % = 30 g / 100 ml = .3 g / ml = .3 x 250 g / 250 ml = 75 g

Question 5 What is 7 % ethanol, expressed in terms of molarity? (M_r of ethanol = 46.06, and density of ethanol at 25°C = 0.789 g ml^{-1})

Ethanol is a liquid so one needs to use the volume and density to calculate the weight in g and then use the formula wt / m wt = no of moles. Molarity = number of moles per liter. Answer = 1.2 M

Question 6.1 Calculate the pH of solution A if 0.05 mol of lactic acid and 0.05 mol of sodium lactate are dissolved in 1 L of pure water. The pK_a for lactic acid is 3.86.

This question was included to see if the student understands the Henderson-Hasselbalch equation and the concept of pK_a which is defined as the pH at which 50 % of the molecules are dissociated. It therefore can be answered by inspection or by plugging numbers into the Henderson- Hasselbalch equation:

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

Question 6.2 If the pH of solution A is adjusted to 4.86 by the addition of concentrated sodium hydroxide, what will the ratio of lactate to lactic acid be?

Use the Henderson- Hasselbalch equation to find the ratio of lactate (A^-) to lactic acid (HA). Ratio is 10:1

Question 6.3 What will the concentrations of lactate and lactic acid in solution A be when the pH is 4.86?

If there are 10 lactate molecules to 1 lactic acid molecule as calculated above, then there will be a total of 11 parts. The total concentration was 1 M (from question 6.1), so one needs to use proportion to calculate the concentrations of each as follows:

[Lactate] = 10/11 x 1 M = 0.91 M; [lactic acid] = 1/11 X 1 M = 0.09 M

Question 6.4 What percentage of the lactic acid molecules in solution A will be deprotonated at pH 4.86?

1/11 X 100 = 9 %

Question 6.5 What volumes of lactic acid and sodium lactate must be mixed to prepare 1 L of 0.1 M lactic acid buffer at pH 4.86?

Lactic acid = 1/11 X 100 ml = 91 ml

Lactate = 10/11 X 1000 ml = 909 ml

Question 7 If you were titrating 250 ml of a 0.1 M solution of lactic acid with a 2 M solution of NaOH, how many ml of NaOH would you have to add to adjust the pH to 3.86?

One needs to calculate the volume containing half the number of moles found in 250 ml of a 0.1 M solution.

Solution is as follows:

0.1 M solution contains 0.1 mole / L

Therefore 250 ml will contain 0.1 / 4 mole = 0.025 mole

A 2 M solution of NaOH contains 2 mol / L, so one needs to calculate how many ml will contain 0.0125 mol

1 ml contains 0.002 mol

So 6.5 ml contains 0.0125 mol (0.125/.002)

Answers furnished to questions by the three students (100, 68 and 83) chosen for this aspect of the research is shown in Table 4.9 below. Answers have been colour coded so that yellow highlighting indicates a correct answer, and red highlighting indicates that the answer is incorrect.

Table 4.9: Comparison of answers to specific questions relevant to the molecular biosciences which were included in the first summative test in March 2008

Question number	**Answers given by student 100 (Formal)**	**Answers given by student 68 (Transitional)**	**Answers given by student 83 (Transitional)**
1.1	0.075 ml	0.075 ml	740 ml
1.2	Assumed a concentration of 1 M and set up C1V1 = C2V2 equation	Found a dilution factor and set up an equation	Subtract the amount given by the volume to get the volume of the stock solution, and divide the amount given to get the volume of H2O added
2	0.16 M	0.64 M	0.2 M
3	0.25 M	250 M	0.25 M
4	75 g	75 g	0.075 g
5	1.2 M	7 g / l	0.120 M
6.1	pH = 3.86	pH = 3.86	pH = 3.86
6.2	10:1	2 : 1	10:1
6.3	Lactate:0.91 M Lactic acid: 0.09M	Lactate: 2.7×10^{-5} M Lactic acid: 1.38×10^{-5} M	[B] = 7.24×10^{-10} M [A] = 1.38×10^{-5} M
6.4	9 %	0 %	1.38×10^{-3} %
6.5	Lactic acid: 91 ml Lactate: 909 ml	Lactic acid = 0.33 L Lactate = 0.67 L	Lactic acid: .09 L Lactate: 0.91 L
7	6.25 ml	12 .5 ml	12 .5 ml

On inspection, it is immediately apparent that student 100, who had shown clearly in both written accounts and by her scores on a paper and pencil test that she understood proportionality, has answered all the questions correctly. This means that she has not only been able to do the calculations obviously involving proportion but has been able to apply the concept to questions requiring calculation of concentration in a solution after dilution, has been able to calculate dilution factors and has been able to apply and manipulate the Henderson-Hasselbalch equation. Surprisingly her strategy for solving question 1 was to use an algorithmic approach. One would have expected her to have calculated a dilution factor. It is not surprising that she was able to do the calculation involving equivalence (which is one that eludes most second year students) because she was able to do a similar question which was included in the pre-laboratory test on the 21st February. However, in that test, she was unable to use the Henderson-Hasselbalch equation. Her result in the summative test analysed therefore demonstrates that she has since learnt to do this independently, presumably because the necessary structures were in place.

The “transitional” student (68) has answered questions 1 and 4 correctly, and while evidently understanding the Henderson-Hasselbalch equation as reflected by the correct answer to question 6.1, has been unable to apply it to answer any of the subsequent questions based on this concept, particularly those requiring calculation of the respective volumes. The second “transitional” student (83), however, has answered question 1 incorrectly. This question was designed to test whether a student could apply proportional reasoning, so in light of this student’s inability to articulate the concept, especially with regard to setting up a ratio, it is not surprising that an incorrect answer was given. The explanation of the strategy used in attempting an answer to the question, in fact shows no attempt to set up a ratio, as the student has used a subtractive strategy which indicates the misconception held regarding proportion. The student is however, able to apply the Henderson-Hasselbalch equation to obtain the correct ratio of lactate to lactic acid which indicates that the mathematical skills are not lacking. However, when it comes to taking the problem further and to apply proportional reasoning to calculate the concentration of lactic acid in the solution, the student is unable to do so. However, she has been able to apply the $C_1V_1 = C_2V_2$ formula correctly to obtain the correct answer to question 3 which might be as a result of learning “by rote” how to solve this type of problem. As expected, she has not been able to calculate concentrations of solutions where actual proportional reasoning was required. So it appears that this student has learnt to do simple mathematical operations in questions which are underpinned by proportion but can only answer those questions that can be solved by ‘following a given series of steps’. These results confirm that her ostensible inability to verbalize the concept of proportion has been substantiated by her apparent inability to solve problems of proportion and settings that require understanding.

Analysis of the answers to these specific questions which are underpinned by the concept of proportion by the three students with differing levels of development with respect to their understanding of the concept of proportion thus provide additional evidence that ability to apply proportional reasoning enhances ability to perform calculations of concentrations or volumes or equivalents, or which use the Henderson Hasselbalch equation and dilution factors. In this regard, the results have substantiated the answer, ascertained from previous research findings, to the research sub-question which probed to what extent an inability to understand proportion impacts on subsequent learning of chemical transformations or more specifically, on the ability to perform calculations of concentrations or volumes or equivalents, or which use the Henderson Hasselbalch equation and dilution factors. In this respect, findings from the analyses reported in this section have thus provided even more evidence that actual development affects potential development. This is because the student who clearly understood the concept has demonstrated that he/she has been able to learn to answer all the specific questions included in the test which were based on the concept of proportion, while the students grappling with the concept have both performed poorly when attempting to answer these questions. This implies that mediation has not resulted in substantial learning, which in turn implies that the area of instruction lay outside their zones of proximal development and that the structures necessary for learning were not yet sufficiently developed.

4.4 Analysis of Focus Group Discussions held to try and acquire information which would point to the factors which could have contributed to the development of Proportional Reasoning Ability

Having confirmed that ability to understand and conceptualize the concept of proportion and to be able to apply it, impacts on the learning of operations in the biomolecular sciences which are underpinned by proportion, it was decided to attempt an elucidation of the factors which might have contributed to development of this ability. The importance of this aspect of the research can be rationalized if one postulates that the ability to do proportional reasoning results from the development of internal biological structures in the brain, which makes it significant to question what activities could have led to the development of these specific structures. This part of the research utilized students from the two groups, used in previous research, that had been constituted from the Basic Molecular Biosciences II class on the basis of their performances in the paper and pencil test.

Focus group one was comprised of 10 students randomly selected from the group of 23 who had answered 3 or fewer questions on the paper and pencil test correctly. Focus group two consisted of 10 students randomly selected from the 15 students in the group, who had answered all the questions on the paper and pencil test correctly. Although the intention had been to match the participants in each focus group in terms of gender, demographics and economic status, this was not possible from the students who fell into the different categories of ability forming the two groups, as it transpired that each group displayed distinct demographical and gender differences. Nevertheless, it was decided to set aside the demographical and gender issues and to proceed with the focus groups and to select the students for participation randomly.

Group one included 2 males and 8 females, while group two in contrast, consisted of 2 females and 8 males. Each group met over lunch in the first week of block 4 (23rd and 25th August). The focus group discussions were very loosely structured in that the lecturer facilitated the discussion to include topics like which school/s had been attended, whether students had enjoyed school (and which subjects in particular), whether they had enjoyed maths as a subject, did they feel they were good at it, did they like to solve unknown problems and how they went about solving them, what they felt about their maths teachers, whether anyone was left handed. Their early childhood experiences were also discussed, covering issues like whether they went to a pre-school, how much and what type of input they had received from their parents, siblings or extended family, at what age they had first learnt to count, what type of games they had played, whether they had played with "educational" toys like *Lego* or blocks. Leisure activities were pursued; for example whether they liked to bake, sew, knit or crochet, whether they did or had participated in sports and the types of sports; who had practised any art form, what type and for how long; what type of music they liked and what television programs they watched. Also under discussion was the issue of parental input into their school work. Finally, the discussion finished with how they liked to learn new concepts particularly as to whether they liked to get an overview first or whether they liked to learn one fact at a time so that it could be linked into some form of structure later. The group then finished with a discussion of how they liked to study. Focus group discussions were recorded and transcribed so that they were available for later review.

Group one reported that they were all right handed. The discussion started with a comparison of the schools attended by the students in the group. Generally the schools attended by students in this focus group were regarded by them as '*not that great'*. Some students had attended several schools in the course of their schooling. A number of students commented that they had attended township schools where they had been taught by unqualified teachers and that past matriculants had been brought back to teach in order to help out. However, one student remarked that despite their lack of training and the lack of facilities in the school, the teachers had enforced discipline to the extent of being physically violent in an attempt to encourage the pupils to '*keep going and to do well*'. It was a <u>teacher</u> from this particular school who had actually filled in the application forms for admission to Wits University for this student. Another student commented that although the teachers were not good, their school had had a good principal who had personally applied for a scholarship for her. Another student commented that in school it was "*virtually self teaching – up to us the learners*'. Only one student in the group had matriculated from a very prestigious private school in Johannesburg which he had attended for two years. However, he had spent his earlier schooling moving from country to country in Europe and so had been forced to move from one schooling system to another. Only one other student regarded his school as having been "*good – academically and with regard to the extra mural activities offered and sports facilities available".*

In contrast, group two had one left hander, and almost everyone rated their high school as '*excellent*' and while many rated their primary schools as having been very good or excellent, some had described their primary schools as being '*not very good'*. However, most had attended schools in the "Northern suburbs" of Johannesburg. Nevertheless, one of these students commented that the standard at his high school appeared to have dropped to '*mediocre*' while he was there, but had started off as having been '*very good'*. However, as this high school is situated in an upmarket suburb, I feel that this assessment must be seen in context, especially if one compares it with the situation in the township schools which had been attended by most of group one students. Two of the group two students had done the majority of their schooling in Zimbabwe, one of these having completed A levels which would have given him an advantage over the other students when starting University. Comment was made by another student that his school had employed a "*good compliment of really dedicated teachers*" and that there had been "*good discipline*". Therefore, in summary of this aspect of the discussion, it appears that the students in group two had had a distinct advantage over the majority of the students in group 1 with respect to their secondary schooling and this could therefore have contributed to the development of structures which afforded them greater ability to do proportional reasoning.

Discussions in both groups turned to whether they had enjoyed maths as a subject at school and whether they felt they had been good at it, and whether they had been taught proportion as a concept at school. Students in both groups felt that development of maths ability and enjoyment of maths was "*teacher dependent*".

> *"It depends on the teacher - at high school the grade 10 teacher went on maternity leave, then there was another teacher, then we swapped back to this one and it was a bit of a mess and my maths marks just plummeted." (*Group two student)

Despite this comment having been made by a student in group two, it was evident after reviewing the focus group discussions, that none of the students in group one had been exposed to the same level of teaching as the students in group two. Only one student in group one had managed to obtain an "A" grade (above 80%) in matric and this could be attributed to the fact that he had joined a group of peers whom he had noticed had excellent mathematical ability, and had then become competitive with them, so that he had essentially been peer taught. The others had not been as fortunate and some of the students in group one described their situation as follows:

> "*Even the strategy that the teacher uses [affects one's ability] … but sometimes teachers are clueless. I went to the Star school and a Wits graduate student would help us after class – so I had 3 teachers for maths in matric. As to my actual high school teachers they were clueless – I remember this one time he [the teacher] tried to prove some theorem on the board, and he couldn't do it, so he left the classroom – I think to ask someone - and when he came back we were just laughing at him."*

> *"Maths was great in grade 10 – and then in grade 11 we had a teacher who only taught technology and I thought my life was over"*

> *"Our principal called in a graduate from Wits – and he was just lecturing us and gave us an 'assignment'….. and we didn't know what to do"*

Generally the students in group one commented that they had not had good maths teachers and more significantly, reported that they were required to learn how to solve problems in a specific way i.e. by using certain formulae and following the steps prescribed by their teachers. This implies that they were not encouraged to think and to attempt solutions by using first principles, but were required to learn maths "by rote". As one student put it:

> *"I don't like long methods…. but in school we had to follow a certain method otherwise we wouldn't get marks"*

When asked how they liked to solve problems now, most said that they liked to see an example to "*see how it's done*" and then they liked applying the method to other problems. One student however differed from the consensus in that she said she liked to do things differently although she often reverted to using a formula, (probably because that was how she had been taught to solve problems). Another student remarked on the difference experienced in the first year at University.

> *"That's what changes from school to Varsity because in Varsity (that's what I like about it) they don't teach you one specific method and say you have to follow it…. they show you different ways"*

Interestingly, some group two students found that Maths assessment had been more challenging at school than in first year University, which suggests that their teachers had challenged them to think and to attempt more difficult problems.

"……. I found the level of testing here was not the standard of testing I was used to at our school. It was easer in terms of the extension that they brought across – I felt restricted by the testing in Maths I. It wasn't broad concepts of trying to teach you to make your mind work….. it's more kind of do this, do that….."

Another student who had done the Maths I major course, countered this by explaining that at University there was a difference in approach in the teaching in Maths I major and the pre-requisite Maths I ancillary course which had been done by the rest of the group.

"…it [Maths I major] was hard as compared to the ancillary one but I thought that the way they were teaching us was more of a foresighted way of teaching it. In maths ancillary I think they're just trying to concentrate on certain areas….not like get a broad spectrum and do calculus… it's very confined….. confined to this is what you do and this is how you do it."

Interestingly, one student in group two had only done <u>standard</u> grade maths at school. Nevertheless, she had demonstrated her obvious ability by obtaining 96% for this subject in matric which was probably why she had been accepted into the Science Faculty. Not surprisingly she had found Maths I (even the ancillary course) at University difficult:

"….. I found it easy at school but more difficult when I got here …."

The rest of the group had had much the same experience as those in group one with respect to the maths teaching at their schools, and they generally agreed that they had not been allowed to figure things out on their own:

"…..I feel that at school we were given a few certain methods as he said…. but I feel that here they would throw us into the deep end and say: 'swim' - so they gave us one or two methods and hints on how to do everything else….. but that said, I had a very dismal first year because I had not done add maths at school……."

"…Well [at school] I passed but stayed on like 50s ….

The discussion in group two turned to what they felt encompassed good maths teaching and the students showed great insight when they explained that:

"………It's also that you are driven to <u>want</u> to understand by certain teachers…. Ja ….. their enthusiasm, their approach to teaching – it's just like

putting it on the board and saying 'that's that' or actually explaining what goes on behind it…. that makes it easier…"

"…I think you have to be taught not only the concepts in maths…. but taught how to think in mathematical terms…. and some educators have that capability, some don't…"

If one examines the two previous comments, one might consider that these group two students like to relate new learning to something that is already there, which suggests that they learn by tapping into existing knowledge which has already been internalised; this implies the development of underlying brain structures. Moreover, their comments indicate that they're aware of this process which suggests a meta-cognitive perspective on learning new or difficult concepts which is far more developed than anything that came across in the discussions in group one. One might therefore conclude that some of the students in group two displayed greater developmental maturity with respect to learning. The group generally agreed that teachers who went into the background so that the pupils understood things facilitated learning. With respect to maths learning at school there did not appear to be substantial differences between the two groups, although some of the students in group two had been exposed to better maths teaching at school.

Not many of the group two students remembered when or whether they had actually learnt proportion as a concept at school. One student was aware that although they hadn't learnt it "*as a specific concept……in Science many of the calculations required it".* Once again, this type of comment is indicative of metacognitive awareness of what was required for successful learning in a particular area. Several of the group one students mentioned that they had not learnt proportion at school and had first encountered it as a concept in the Basic Molecular Biosciences II course. One student had seen some of the types of questions in "IQ" tests and said that although he had not been able to do these questions the first time, he felt they would be easier when attempted subsequently because one could reflect on them and learn from the reflective process. Many students agreed with this observation. Another student suggested that even if one could not do or understand something at first, it was:

"….gettable…. not like if you don't have it you'll never get it….. people will get it in time…"

This opinion also displays awareness of the implications of allowing for individual development of the appropriate underlying structures to facilitate learning in a particular area, and an awareness that these structures develop when the brain reaches the appropriate level of maturity. Others suggested that repetition helps the development of ability in certain areas as it leads to those *"a ha"* moments. An "*a ha*" moment might thus be interpreted as the point at which a particular area of knowledge or ability to understand a concept is internalised. Moreover, after unpacking the discussion and comments, it becomes clear that the attainment of knowledge or abilities has to result from self-deliberation, notwithstanding that certain activities or teachers can facilitate the process. However, it has to be as a result of self-discovery or what one would explain in Piagetian terms as "*constructivism resulting from self-regulation".*

Group one then tried to ascertain what would lead to an '*a ha'* moment. While most felt that it occurred when they were relaxed, others felt that a bit of pressure led to them learning concepts that had previously eluded them, possibly because they felt that a little pressure increased motivation and focus. Nevertheless, all conceded the importance of confidence when trying to learn new concepts. One student also described how it appeared that one needed to draw on and organise existing knowledge:

> *"I think you suddenly draw on different bits of information…. like a puzzle. Often when you're trying to learn something, e.g. a and c relate but you need b to understand c – sometimes you can jump the gap…....You take the pieces of the puzzle and mix them but….. it's like it's the wrong way around…… and then suddenly it's the right way round"*

This description again points to the importance of drawing on existing brain structures and knowledge, and the importance of relating different concepts in the appropriate way, or the importance of the impact of organisational principles when learning new knowledge. Interestingly someone else pointed out the importance of curiosity in learning new concepts and commented that this could be triggered by enthusiastic teachers. By its very nature, curiosity implies reference to and extension of existing knowledge, so this observation confirms the importance of underlying structures in subsequent learning. Group two also felt that a bit of pressure helped them to work out and learn concepts which they had not quite understood and my impression was that they were generally more confident than the students in group one about whether they would actually learn something difficult. Pressure seemed less threatening to the students in this group, and was seen rather as a motivating factor, which forced them to apply themselves to a particular problem or area of difficulty as is conveyed by the following extract from the discussion. (Also evident from this discussion thread was that students in this group tended to keep up with the work so that they knew that they understood the concepts as they were covered).

Student a: "*….you were speaking about working under pressure: and I think for me it happened earlier this year for one of the chemistry papers. I spent 2 days trying to understand one concept in chemistry which I didn't get, and this was 2 weeks before the test or exam and I remember it was on the morning of the exam, and I still didn't get the concept but on that morning I had that 'ah ha' moment that you get. I think it depends on the amount of pressure and the stakes"*

Lecturer: *"So too much is not good but a little bit is beneficial?"*

Student a: *"Yes"*

Student b: *"Too much is good for me."*

Student c*:* *"I have to have some pressure"*

Student b: *"Like if you have 2 weeks to do an assignment you won't do it…. but then when it gets closer to the time you suddenly have to do it then 'ah ha' happens.*
Lecturer: "*It's necessary to get one motivated or does the pressure help conceptual understanding?"*

Student d: *"I feel like… uh…. I do put myself under pressure…..I usually try to keep up to date with the class just knowing what we're doing"*

Student b: "I think that helps because when exam time comes you just have to go over the work… but you know what it's about – not like starting from the beginning and starting all over"

Student e: *"I think it definitely isn't a stress if you know you've heard it before and you just have to go over it – not like skipping lectures and trying to self study"*

Student b: *"Ja and it's like going to pracs if you've actually gone over the work and not like going there without knowing what you're going to do – and then you never really get the concept"*

Lecturer: *"Are you all like that? Do you all try and keep up?"*

Several students: *"No"*

Student f: *"I do but sometimes if you do too much work – you just feel like you've had too much – maybe your brain is like……….."*

Lecturer: "It's full?"

Student f: "Ja it's full".

Student g: *"I also think it depends on the character of the person….the psychological characters. If you're a driver who is goal oriented – most of those people are foresighted – while some people are analytical – they just want to keep pace – and see the whole picture not necessarily the small picture – but the whole picture…"*

This led to whether they liked to link concepts, to see the whole picture first or to build up a concept bit by bit gradually. While most of group two liked to see the big picture first, some pointed out that it was important for them that they understood the basics as they went along so that they could build the picture. One student however countered that she found it very irritating if she didn't know what things were needed for and what one was working towards. No-one liked learning facts in isolation which leads one to suspect that they were learning in a way that allowed them to link concepts on the way to becoming experts rather than like novices as illustrated by the following discussion thread:

Lecturer: How do you like to learn new concepts?

Student q: Well I think [I like to see] the entire picture and then fill in the details

Lecturer: I see, so tell me are you all like that?

More students together: Ja

Student r: Um I'm not quite sure – I think with certain concepts – it's necessary to work from the basic concept and then get into the bigger picture and <u>then</u> have that 'ah ha' moment – because it seems that you synthesize the smaller details better because after doing those you get the bigger picture:

Student s: I think…..um…. as Student r said, you do get the picture <u>after</u> you've learnt the basics…. <u>but</u> I find it irritating while we're learning not to know what the final goal is… Why we're building up this picture.

Student t: I can't study without things being linked…. like I can't just study randomly. I have to know where it fits in

Student u: <u>I</u> start from the beginning – that's why I take long – I want to know why we're doing the first step, and step by step – then after the fourth step I link it back to the first step.

The discussion indicated that although most of the participants expressed a need to know where the concept was leading, many insisted that they had to make sure that they understood the basics before moving on. This might imply that they are in fact linking and rationalizing each basic underpinning concept with what knowledge they already have, or in Piagetian terms inducing a state of equilibrium if the new information had invoked a state of disequilibrium as they were learning it.

Both groups discussed how much input and help with their schoolwork they had obtained from their parents or caregivers. Of the students in group one, only one student felt that his parents, particularly his mother, had pushed him with his school work. Another student recognised that his mother (who is a teacher) had supported him and had bought him reference resources and had referred him to someone who could help him if she was unable to. However, this student also said that his father had a drinking problem and had been an extremely disruptive influence to his studying, and had continually tried to get his mother to move him to an inferior but cheaper school, and to stop spending money on "*educational stuff*" which he felt was wasting money. Another student commented that:

> *"My parents never saw my school book ever. When it came to my report, I had to show them – they wouldn't ask…."*

The other students in group one felt that although their parents had shown interest, they had been unable to help them. For example, some had single parents who were too busy working or too uneducated themselves to help, but had pushed them to do their work, enquired about how they were doing and had formed relationships with their teachers to keep track of their performance. One student however, felt that although she appreciated the interest shown by her parents it had been difficult without actual help. She recognised that this was because:

> *"……my father grew up looking after cows. But it was hard because you expect someone to help you with homework. But I couldn't get support because my parents were clueless. However, I was close to teachers at school and one of my teachers helped me to come to open day and get the forms. So my parents were supportive but they didn't know where or how to help out…."*

So generally, group one had parents who, although they might have shown interest, had not possessed the social or cultural capital which would have resulted in actual assistance. This might have impacted on the developmental levels of the students in this group.

In contrast, students in group two had received substantial help from their parents. Only one student, who had been brought up by her grandmother, commented that her grandmother had not really interacted with her. However, she had compensated for this by spending all her spare time playing with and learning from other children. Another commented that he hadn't been helped by his parents but that this was because he had never asked and had never required their help because he had completed his homework at school before he arrived home. One student's parents were both teachers and they had insisted that she study hard and do the homework set for the day. Another, related how her mother had encouraged her and helped her to look up anything she wanted to know, while one student divulged that:

> *"I battled in primary school – with reading….. and right through especially in the lower grades I battled and I think I was going to be held back and I know my mom put a lot of effort into trying to get me up to the same level as the other kids…"*

So it appears that generally students in group two had obtained more tangible and more interactive support and help with their schoolwork than students in group one. This could have been another factor which assisted in their attainment of higher levels of actual development in certain areas (like proportional reasoning) than those in group one.

Students in group two also had a highly enriched early childhood with lots of educational toys and learning opportunities. For example, one student explained that they had not had a television in their house because her parents had rather done artwork and activities with her. This was in contrast to virtually all the students in group one who recognised that they had only been exposed to certain things "*later in life*". They felt that this meant that they had been less observant generally and less cognizant of learning opportunities than children who had been exposed to more experiences in early childhood:

> "*A kid that's quite innocent until a late age hasn't been exposed to much - Whereas a kid who's been exposed to much more, is far more observant and notices certain facts…"*

Also discussed in the two groups were sports and leisure activities. A number of students in group two had done a lot of artwork; one student's mother was a professional artist and had encouraged him, with the result that he had adopted drawing as a hobby. Another admitted that she still drew and that it was still something she did "if she wanted to de-stress". Yet another explained that:

"My family especially dad and grandfather are big in carpentry and I did that in high school and I find that especially with B Sc it's not very creative and I find I need something outside to stimulate and get a bit of balance."

This was something that he had in common with another student in group two who enjoyed woodwork at high school and

"…..now if something is broken I can take it apart and fix it".

One student had a great interest in music and had started playing the piano at a young age and now played the guitar as did another student in group two who had also started learning the violin. Another used to sing and write poems. One might hypothesize that art and music would involve proportion, art because of the relative sizes one would have to put onto paper, and music because notes in music can always be described in terms of the temporal proportion they occupy in a bar or musical phrase. One might then also postulate that sport, especially a ball sport, would involve some kind of proportional thinking and students were quizzed as to whether they had taken part in or still did take part in any sports. Responses from group two students to the question were the following:

"I love playing tennis but it's the Varsity thing, I don't have time anymore…"

"Well I played tennis and I tried netball it didn't work out – but stuff like table tennis I like, and I play soccer with my brothers at home – whatever"

"Well now... um …I love table tennis and I play whenever I go back home and volleyball as well – so... um …"

"Yes – cricket and chess"

"Ladies soccer, volleyball and athletics"

"Squash and rowing"

"I played tennis and did outdoor things like hiking. I was in the school tennis team"

"I did a little bit of hockey but would have been interested in girls' cricket if they'd offered it, and I did athletics. Now I do long distance running but I'm not very good at it."

"In primary school I did cricket, soccer, athletics and then in high school I did cricket and hockey in standards 6 and 7"

"I did tennis and I also did indigenous games"

"I also used to do indigenous games"

This was very interesting because every sporting activity had involved (albeit subconscious) calculation of distance, and required the participant to relate the distance to the force used. In other words, it involved a subconscious calculation involving proportionality. It was felt that these types of sporting activities could have constituted another factor which would have laid the ground structures for subsequent development of ability to do proportional reasoning.

Group one students, once again, had not had the same opportunity with respect to many of these activities. Only one had played the piano and recorder at an early age. No-one in the group currently played any sport, but one used to play netball and do athletics, one had played volleyball, one basket ball, one girls' soccer, one girls' cricket, and one had tried dancing at University. As a group they had played substantially less sport than the students in group two, particularly with regard to sports which required precision and estimation when hitting or throwing a ball, and most had only done so in high school and generally not at primary school. On this basis, it was decided that this was a factor which needed further investigating as to whether it was indeed a factor which had contributed to the development of the brain structures which enabled proportional reasoning.

When asked if they remembered when they learnt to count, not many of group one could remember actual details, but a couple of students thought that they had learnt before they went to school, and one student said that she had learnt at the pre-school which she had attended from the age of two. Similarly, group two students could not really remember details, but a couple thought that they had learnt at crèche; all the members of this group knew that they had been able to count and add before they first attended school.

Most of group one admitted to being visual learners, preferring to draw patterns and pictures as an aid to learning. Only one student liked to learn from a page of notes and another commented that he didn't like colours for headings or on pages because "*they distracted him*". Generally though, students in this group liked making tables and using diagrams but <u>many disliked flow charts</u>. In group two most were also visual learners, apart from one auditory learner who explained:

"*I prefer being told – consultation – coming and asking and getting it from you – and then if I go home I can easily recall – I can hear what you said….."*

The others had various ways of visualizing when they learnt:

"I usually synthesize everything into 4 pages if I can and then I remember that in my head, able to recall every point – can see them in my mind – even every diagram"

"I'm just very visual….write things, and diagrams and flow charts – I can't just read something"

"I synthesize images and visualizations in my head and then I try and remember those"

Some of the accounts given by group two members seem to be more sophisticated than the accounts given by group one members about their visualization strategies which were more conventional and tangible because they relied on actual drawings, tables and pictures. The remarkable group two accounts pointed to visualization strategies "in their minds". It might be significant that group one learners pointed out that they didn't like flow charts, as these are indicative of links and organisation of information. In this regard, these learners were more typical of novices than experts and might therefore be hinting at less developed cognitive levels in the area. As if to confirm this assessment of the students in the two groups, one might use the following explanation from one group two student of why he liked teaching, as further evidence of higher order thinking ability of the students in group two:

"…..teaching increases my understanding so much – because you have to synthesize it to make it easier for the person. That increases my own understanding so much……"

After reviewing the focus group discussions, it was decided to design a questionnaire which would interrogate some of the areas which had emerged, especially with respect to the observations that group two students had experienced more enriched childhoods, had received more parental input, had all played a ball sport, taken art in traditional sports or danced from an early age, and had generally attended better schools. The intention was that the questionnaire would be given to a random group of students so that subjective impressions of the importance of certain factors in the development of proportional reasoning ability could be more objectively confirmed or discarded.

4.5 Analysis of the questionnaire designed in response to information which emerged from focus group discussions

A questionnaire (attachment 7.6) was designed to interrogate which factors might enhance development of proportional reasoning ability based on suggestions which had emerged from the focus group discussions. The questionnaire was then administered to 33 of the Basic Molecular Bioscience students who were majoring in Biochemistry and Cell Biology, after having been piloted by three students doing Biochemistry and Cell Biology II who were not part of the Basic Molecular Biosciences II class. While it would have been ideal to administer the questionnaire to the whole class, owing to logistical constraints on the day it was only possible to administer the questionnaire to a subset of students in the Basic Molecular Biosciences class, viz. those who were majoring in Biochemistry and Cell Biology. This subpopulation was chosen because, of the three majors courses offered concurrently with Basic Molecular Biosciences, this was the only course which contained members from both of the two groups (i.e. low and high proportional reasoning ability) which had been identified previously.

It was established that 9 (27%) members of this group of students, who were majoring in Biochemistry and Cell Biology and doing the Basic Molecular Biosciences II course concurrently, had scored 6 on the paper and pencil test, 6 (18%) students had scored 5, 11 (33.3 %) had scored 4, and 7 (21%) had scored 3 or less. Compared to the scores in the whole Basic molecular Biosciences II class, there was a higher percentage (27 % versus 14.7 %) in this cohort of students who had scored 6, and by the same token fewer (18 % versus 34% in the total Basic Molecular Biosciences class) who had scored 5. Those scoring 4 and 3 or less comprised a similar percentage to those in the whole class. The distribution of scores in the whole Basic Molecular Biosciences class is shown in Table IX below. Since the distribution in terms of percentage of the group in the lower scores was similar in both the Biochemistry and Cell Biology II class and the whole Basic Molecular Biosciences II class, and the trend had been to have a higher percentage scoring 6 rather than 5 in the Biochemistry and Cell Biology cohort, it was considered that characteristics found in the various categories would be representative of those found in the corresponding category in the whole class.

Table 4.10: Distribution of scores on the paper and pencil test in the Basic Molecular Biosciences II class compared to scores in the Biochemistry and Cell Biology II class.

Score on paper and pencil test	% of BMB class	% of the Biochemistry and Cell Biology II class
6	14.7 %	27 %
5	34 %	18 %
4	27.5 %	33.3 %
3 or fewer	23.5 %	21 %

The questionnaire was designed to elicit the following information, starting with whether the person had played or did still play a ball sport or had taken part in traditional sports, which sport, when it was started and for how long it had been played. The same questions were asked about musical instruments, artwork, woodwork, sewing or handcraft. Also interrogated were early childhood opportunities, like whether the student had played with educational toys, had attended crèche or pre-school; they were also asked to evaluate whether they felt that their early childhood had been "enriched". Students were also asked to rate the primary and high schools they had attended, to indicate whether they had liked maths at school and whether they recalled learning 'proportion' at school. They were asked whether they liked to learn the "big picture" before or after learning new concepts, and whether they liked to link new information to what they already knew or rather to learn it independently from what was already known. It was felt that these factors would cover what emerged from focus group discussions and that an analysis of responses would give a more objective indication of factors which might enhance internalisation and conceptual understanding of proportion. Each of the factors was therefore considered separately, was graphed after analysis and is reported below. The information regarding how students in the various groups liked to learn new concepts was not included in this report as it was considered that while this was interesting, it did not add anything towards answering the research question.

Since focus group discussions had suggested that group two students had generally attended better schools than those attended by group one students, it was decided to look at this aspect of the questionnaire first. It must be pointed out that in this and subsequent analyses, students were grouped according to their scores on the paper and pencil test based on that designed by Fleener (1993) to test proportional reasoning ability, so that one group consisted of those who had scored 6/6 on the test, one comprised those who had scored 5/6, one was made up of those who had scored 4/5 and one group consisted of those who had scored 3 or less on the test. This differentiation was more detailed than that used previously where only two groups were used for comparative purposes in the quantitative research. However, it was deemed that in this section it might provide additional information as it would distinguish between groups of students at different stages of conceptual development, rather than just on the two groups, who previously, had been classified as having low or high proportional reasoning ability.

Figure 4.15 indicates that 56 % of students scoring 6 assessed their primary school as being excellent, while just 33 % had rated it good and 11 % as "not good". In comparison, most of the students scoring 5, 4 or ≤ 3 (67 %, 64 %, and 57 % respectively) had assessed their primary school as being "good", a smaller amount (17 %, 36 %, and 14 % respectively) as being excellent and 29 % of those scoring ≤ 3 as "average".

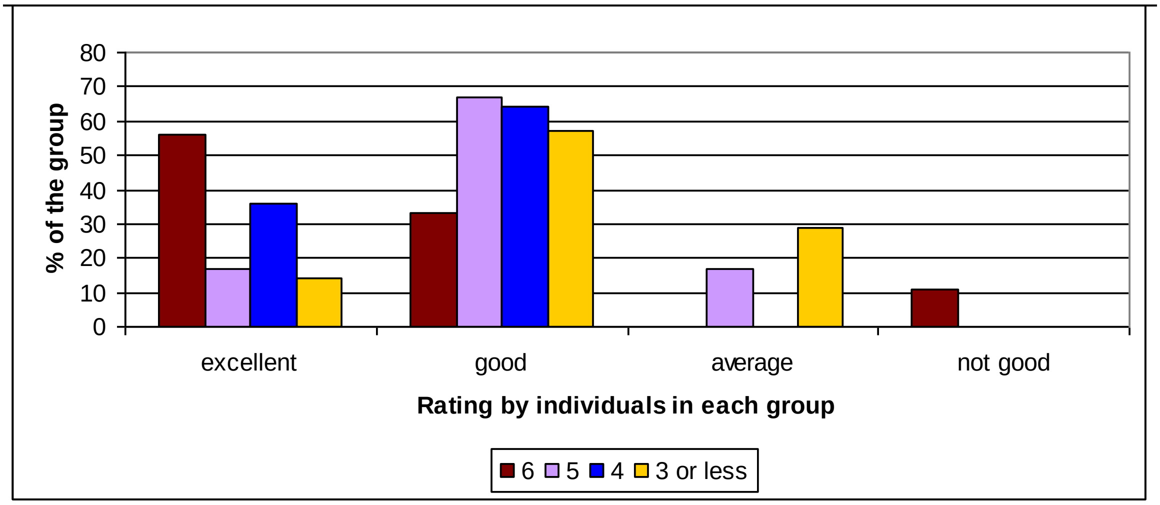

Figure 4.15: Comparison of student rating of primary schools attended within groups with different scores on the paper and pencil test which assesses proportional reasoning ability on a hierarchical scale

There did not therefore seem to be a noticeable <u>trend</u> of disparity between the groups, although there was a noticeably higher assessment of "excellent" from the group who scored 6. However, because so many of the group scoring 3 or less had attended what they considered to be a "good" school, one could not conclude that primary school attendance had been a major contributing factor to the development of proportional reasoning ability.

On the other hand, when one views the ratings of the high schools attended (Figure 4.16), it is evident that more students (56 %) from the group scoring 6 had attended, what was in their opinion, an "excellent" high school than students who had scored ≤ 3 (29 %), many of whom (43 %) had rated their high school as "average", as incidentally, had the group scoring 4 (36 %), compared to only 11 % of the group scoring 6, and 17 % of the group scoring 5. On this basis, the high school attended might have contributed to the development of conceptual understanding as reflected by proportional reasoning ability, especially as the majority of students (67 %) in the group with the next highest score (5) had rated their high school as "good".

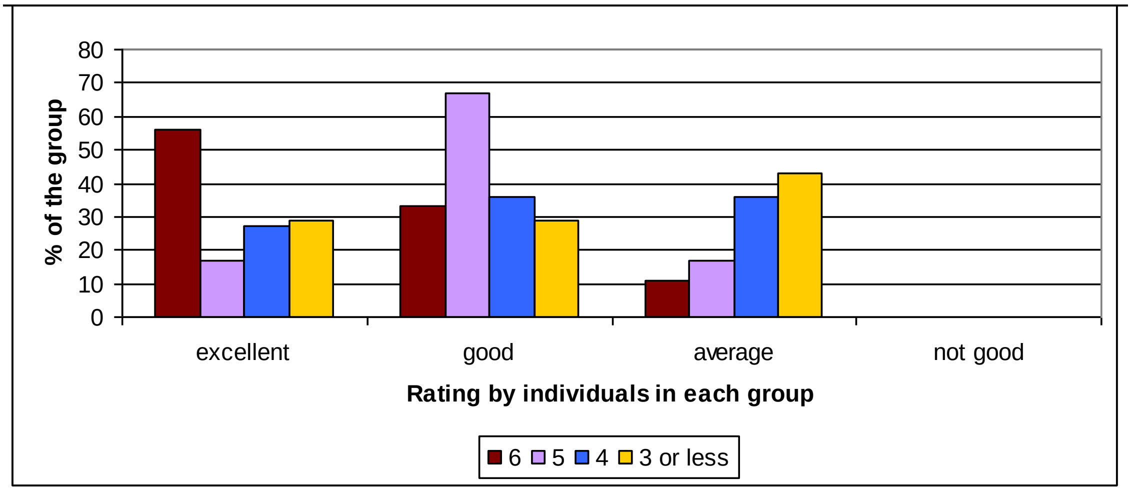

Figure 4.16: Comparison of student ratings of the high school attended within groups with different scores on the paper and pencil test

Another factor which, from focus group discussions, appeared to contribute to the development of proportional reasoning ability, was that participation in a ball sport, some form of dancing, or traditional sports had been undertaken at an early age. Results from the questionnaire indicate a clear trend of differences between the groups as shown in Figure 4.17 below. It is evident from Figure 4.17 that 100 % of students in the group scoring 6, 83 % of those scoring 5 , 72 % of those scoring 4, and 43 % of those scoring ≤ 3 had participated in a ball sport or dancing.

These results were subjected to statistical analysis as shown below:

The question asked was: Is the proportion of individuals who had participated in a ball sport or dancing different across the different groups that consisted of individual students who had demonstrated different proportional reasoning ability on the paper and pencil test? The null hypothesis (H_o) is that the proportion of individuals who participated in a ball sport or dancing is the same across the groups. The alternate hypothesis (H_A) is that at least one of the groups differs in the proportion of individuals that have participated in a ball sport or dancing.

A chi squared test for association was run; specifically the test for association between the groups obtaining scores of 6, 5, 4, and ≤3 in the paper and pencil test and participation in a ball sport or dancing. A *p* (probability) value was calculated to be 0.064393 which was not significant to 5%. Therefore although one could observe a linear line between the number of students in each of the groups who had participated in a ball sport or dancing, based on statistical analysis one could not say <u>conclusively</u> that participation in that type of activity would have resulted in the development of structures which would enhance conceptual understanding of proportion when in was taught in a more formal environment.

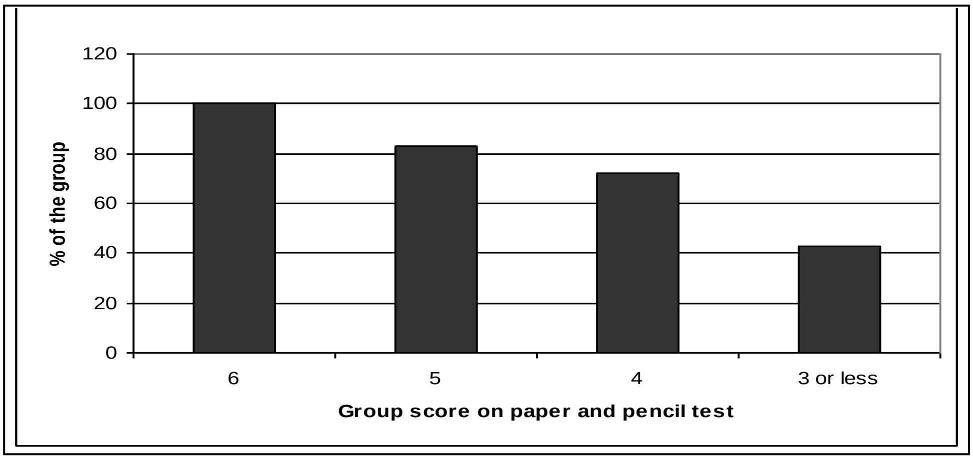

Figure 4.17: Participation in a ball sport or dancing by individuals in groups with different scores on the paper and pencil test

The next factor evaluated from the responses to the questionnaire was whether students had played (or still played) a musical instrument. The rationale for investigating this as a potential factor which might enhance development of proportional reasoning ability was that the value of each note in music forms a portion of a musical bar or a musical phrase, and that therefore playing an instrument and / or learning musical theory might subconsciously develop the ability to understand and apply the concept of proportion in other circumstances, as the brain structures necessary for this capability would have been developed from working on timing in the musical activity. Individual responses from students grouped according to their scores on the paper and pencil test are shown on Figure 4.18. It is evident that not many students in any group had played a musical instrument. However, 33 %, 33 %, and 36 % of students in groups scoring 6, 5 and 4 respectively had played a musical instrument, while only 14 % of the students scoring ≤ 3 had done so. Therefore while there are not distinct differences between this activity between the groups scoring 4 or more, the number of students who had done so in the group of students scoring ≤ 3 was substantially less. Notwithstanding this, it is not possible from an analysis of the questionnaire responses to conclude that playing a musical instrument contributes to the development of proportional reasoning ability, nor however, can one completely rule it out as a factor as not many of the students had had the opportunity to play one. Nevertheless, the results were subjected to statistical analysis as shown below:

The question asked was: Is the proportion of individuals who had played a musical instrument different across the different groups that consisted of individual students who had demonstrated different proportional reasoning ability on the paper and pencil test? The null hypothesis (H_o) is that the proportion of individuals who had played a musical instrument is the same across the groups. The alternate hypothesis (H_A) is that at least one of the groups differs in the proportion of individuals who had played a musical instrument.

A chi squared test for association was run; specifically the test for association between the groups obtaining scores of 6, 5, 4, and ≤3 in the paper and pencil test and playing a musical instrument. A *p* (probability) value was calculated to be 0.775425 which was very definitely not significant to 5%.

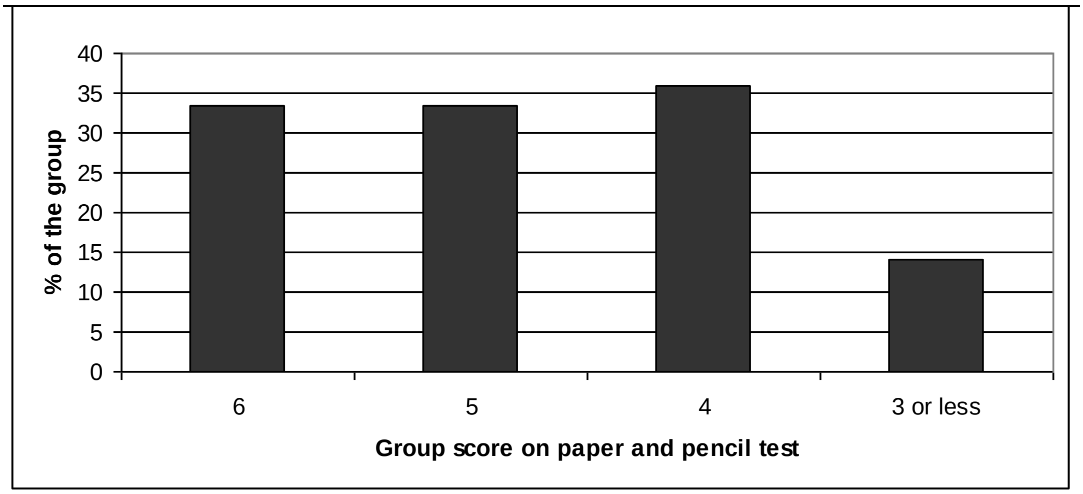

Figure 4.18: The number of individuals in groups with different scores on the paper and pencil test who had played a musical instrument.

The next factor examined from the questionnaire responses, was whether individuals had done artwork or a handcraft. The rationale for including this as a potential factor was because art and handcrafts involve the practical use of proportion. Results are shown in Figure 4.19. Once again, substantially more of the students in the groups scoring 6 or 5 (67 % and 83 % respectively) than those in the groups scoring 4, or ≤3 (46 % and 43 % respectively) had done art and / or a handcraft.

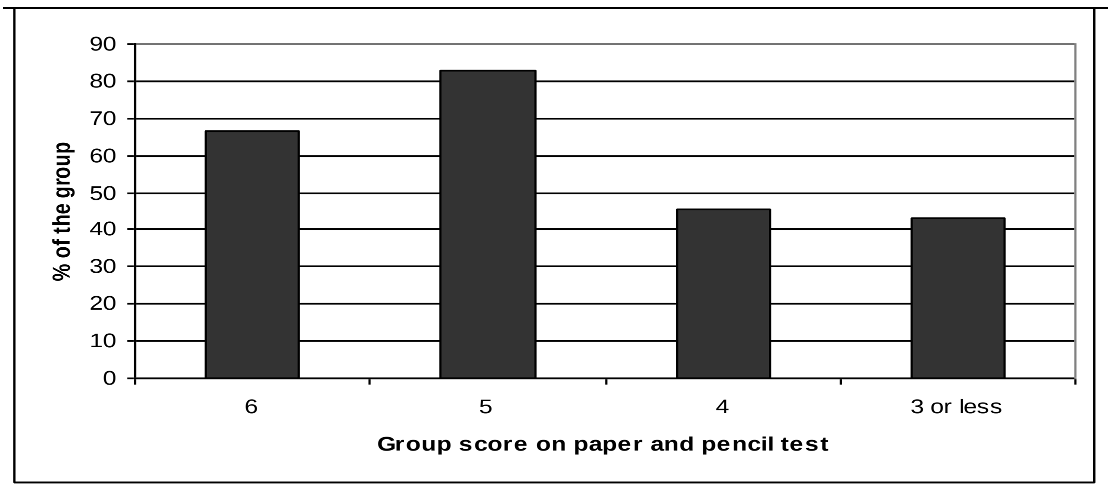

Figure 4.19: The number of individuals in groups with different scores on the paper and pencil test who had done art and /or a handcraft

However, although there were more students in each of the two higher scoring groups than those in the lower scoring groups, it would be difficult to justify this as contributing significantly to development of proportional reasoning ability as there is no clear trend between all the groups, particularly as the statistical analysis of the results which is shown below did not suggest that this was a significant factor contributing to the development of proportional reasoning ability.

The question asked was: Is the proportion of individuals who had done artwork or a handcraft different across the different groups that consisted of individual students who had demonstrated different proportional reasoning ability on the paper and pencil test? The null hypothesis (H_o) is that the proportion of individuals who had had done artwork or a handcraft is the same across the groups. The alternate hypothesis (H_A) is that at least one of the groups differs in the proportion of individuals who had done artwork or a handcraft.

A chi squared test for association was run; specifically the test for association between the groups obtaining scores of 6, 5, 4, and ≤3 in the paper and pencil test and doing artwork and /or a handcraft. A *p* (probability) value was calculated to be 0.359405 which was very definitely not significant to 5%.

The next factors to be examined were the impact of early opportunities. These take on particular significance if one presupposes that the relevant brain structures which produce proportional reasoning ability could have been cultivated early in life. Individual factors considered were whether individuals had played with “educational” toys and games, whether they attended pre-school and whether they regarded their early childhood as having been enriched by parents, siblings or care-givers, as focus group discussions had suggested that the last factor, in particular, was one which had been lacking in the group who had low scores in the paper and pencil test. Results are shown in Figures 4.20, 4.21 and 4.22 below.

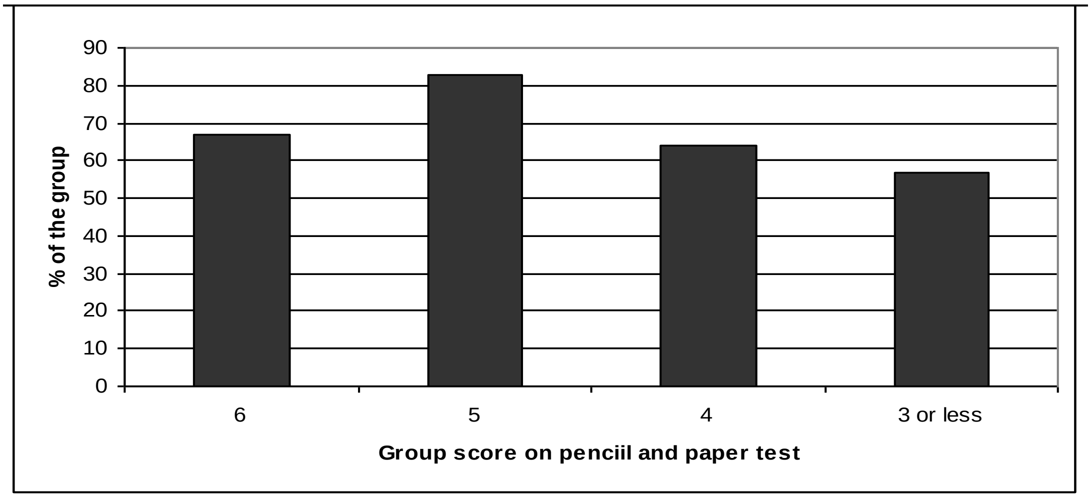

Figure 4.20: The number of individuals in groups with different scores on the paper and pencil test who had played with educational toys

Playing with educational toys, which most students cited as having been "*Lego*", did not appear to have been the major factor either, as the number of individuals in each group who had done so were 67 %, 83 %, 64 % and 57 % of the students scoring 6, 5, 4, and ≤ 3 respectively. These results were therefore subjected to statistical analysis. The question asked was: Is the proportion of individuals who had played with educational toys different across the different groups that consisted of individual students who had demonstrated different proportional reasoning ability on the paper and pencil test?

The null hypothesis (H_o) is that the proportion of individuals who had played with educational toys is the same across the groups.
The alternate hypothesis (H_A) is that at least one of the groups differs in the proportion of individuals who had played with educational toys.

A chi squared test for association was run; specifically the test for association between the groups obtaining scores of 6, 5, 4, and ≤3 in the paper and pencil test and playing with educational toys. A *p* (probability) value was calculated to be 0.781622 which was very definitely not significant to 5%. One could therefore conclude that playing with educational toys did not contribute significantly to the development of structures which enhanced ability to perform proportional reasoning.

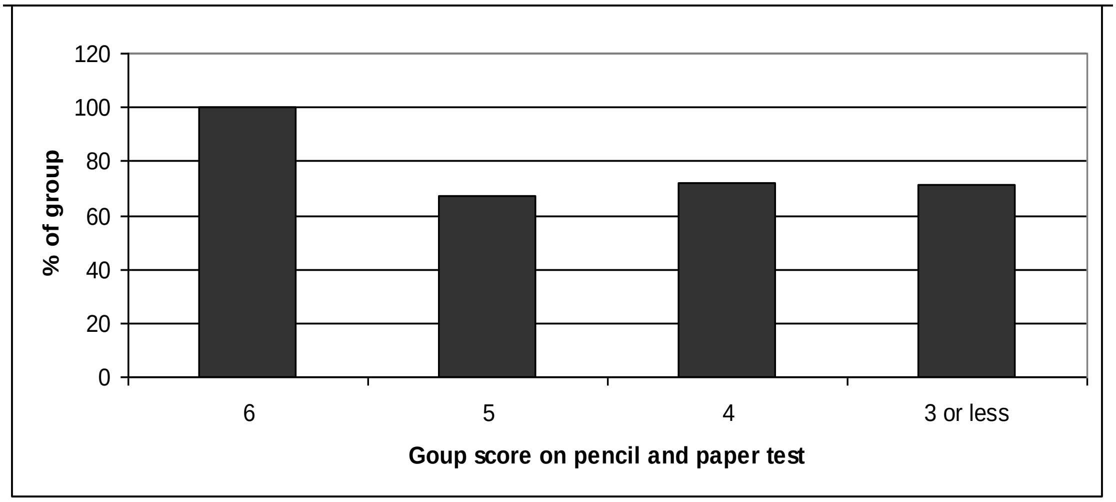

Figure 4.21: The number of individuals in groups with different scores on the paper and pencil test who had attended pre-school.

While 100 % of the students in the group scoring 6 had attended pre-school, so had 67 %, 72 % and 71 % of the students in the groups scoring 5, 4 and ≤ 3 respectively (Figure 4.21). Pre-school attendance therefore did not appear to be a factor which would have enhanced ability to apply proportional reasoning. This was confirmed by statistical analysis.

The question asked was: Is the proportion of individuals who had attended a pre-school different across the different groups that consisted of individual students who had demonstrated different proportional reasoning ability on the paper and pencil test? The null hypothesis (H_o) is that the proportion of individuals who had attended a pre-school is the same across the groups. The alternate hypothesis (H_A) is that at least one of the groups differs in the proportion of individuals who had attended a preschool.

A chi squared test for association was run; specifically the test for association between the groups obtaining scores of 6, 5, 4, and ≤3 in the paper and pencil test and attending a pre-school. A *p* (probability) value was calculated to be 0.3314 which was very definitely not significant to 5%. One could therefore conclude that on the basis of statistical results, pre-school attendance had not enhanced ability to understand the concept of proportion.

However, as had been suggested by the focus group discussions, enrichment in early childhood appeared to be a major factor in the development of proportional reasoning ability. Figure 4.22 points to a clear trend between the numbers of students who had been “enriched” in the various groups. Once again 100 % of the students in the group who scored 6, regarded that their childhood had been “enriched”, followed by 67 % of those who scored 5, 45 % of those who scored 4 and only 29 % of those who scored ≤ 3. An interesting feature of the responses obtained was that a few students had classified their childhood as having been enriched because a parent or grandparent had inculcated in them ‘the correct way for an African child to behave’. This type of response was not included in the number of positive responses to the question in the context of this report, because I was specifically looking for evidence of some form of academic enrichment. Overall though, the results illustrated in Figure 4.22 support the observation which emerged from focus group discussions, that early childhood enrichment plays a distinct role in laying the groundwork for development of the brain structures needed to perform proportional reasoning. The results were also subjected to statistical analysis:

The question asked was: Is the proportion of individuals who had reported an enriched early childhood different across the different groups that consisted of individual students who had demonstrated different proportional reasoning ability on the paper and pencil test? The null hypothesis (H_o) is that the proportion of individuals who had reported an enriched early childhood is the same across the groups. The alternate hypothesis (H_A) is that at least one of the groups differs in the proportion of individuals who had reported an enriched early childhood.

A chi squared test for association was run; specifically the test for association between the groups obtaining scores of 6, 5, 4, and ≤3 in the paper and pencil test and having had an enriched early childhood. A *p* (probability) value was calculated to be 0.018492 which was significant to 5%. This statistical result allowed me to confirm my impression from the focus group discussions that an enriched early childhood, particularly with respect to personal input from parents, siblings or care-givers, had laid down the brain structures necessary for ability to internalize the concept of proportion. Personal attention and interaction therefore seems to lay the foundation for the development of the structures needed to embed this type of conceptual knowledge

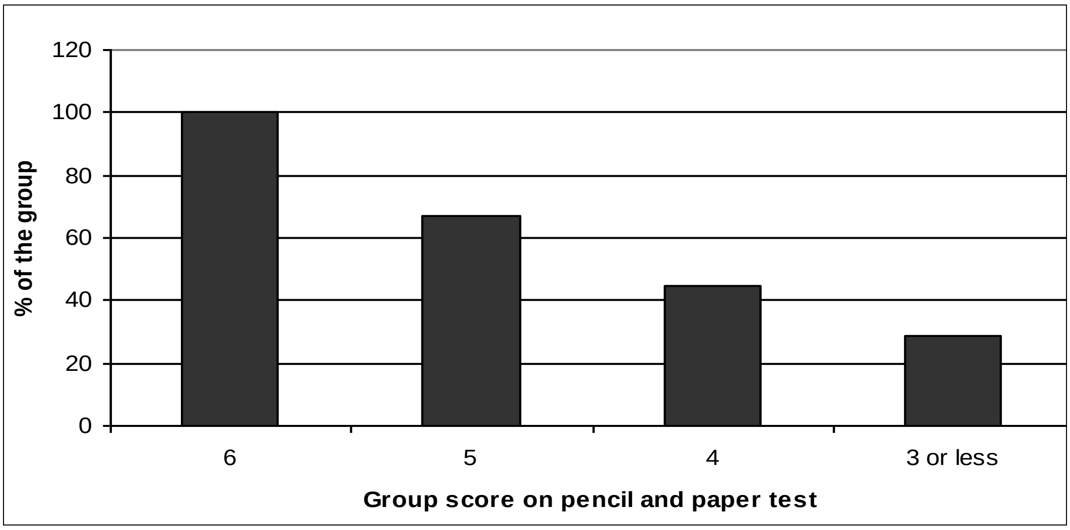

Figure 4.22: The number of individuals in groups with different scores on the paper and pencil test who regarded their early childhood as having been "enriched".

The final factors examined were how many students in each group had enjoyed maths at school and how many recalled learning about proportion at school. It was felt that students who said that they enjoyed maths would have done so because they were good at it. One might rationalize that students who were good at maths would be able to do proportion problems, and one would therefore expect that the individuals in the group scoring 6 would have enjoyed maths the most. However, contrary to expectations, most of the students had enjoyed maths at school, and surprisingly, more students (86 %) in the group scoring ≤ 3 than in any of the other groups indicated that they had enjoyed maths. The percentages of students in the other groups who stated that they had enjoyed maths at school were 78 %, 83 %, and 82 % in the groups scoring 6, 5 and 4 respectively. So maths enjoyment (and maybe on this account performance) did not appear to be a factor in enhancing ability to do proportional reasoning. This substantiated an issue that had emerged in the focus group discussions where it came to light that one of the students who had scored only 1 in the paper and pencil test had received an "A grade" for higher grade maths in matric. The statistical analysis performed on these results is shown below.

The question asked was: Is the proportion of individuals who had enjoyed maths at school different across the different groups that consisted of individual students who had demonstrated different proportional reasoning ability on the paper and pencil test? The null hypothesis (H_o) is that the proportion of individuals who had enjoyed maths at school is the same across the groups. The alternate hypothesis (H_A) is that at least one of the groups differs in the proportion of individuals who had enjoyed maths at school.

A chi squared test for association was run; specifically the test for association between the groups obtaining scores of 6, 5, 4, and ≤3 in the paper and pencil test and having enjoyed maths at school. A *p* (probability) value was calculated to be 0.980836 which was not significant to 5%. This statistical result allowed me to confirm my impression from the focus group discussions that an enjoyment of mathematics did not necessarily result in an enhanced ability to develop conceptual understanding of proportion.

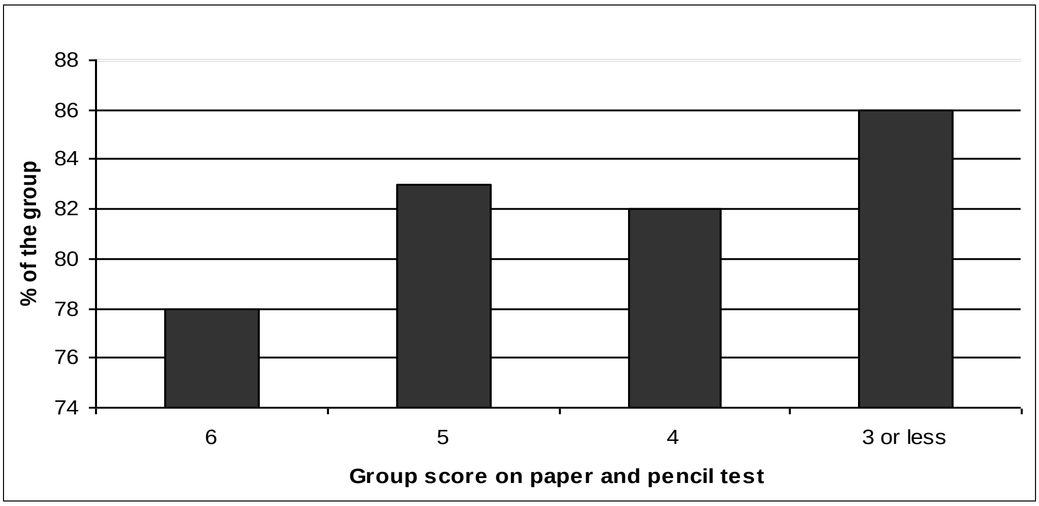

Figure 4.23: The number of individuals in groups with different scores on the paper and pencil test who indicated that they had enjoyed maths at school.

However, what could be regarded as more significant with respect to conceptual development was whether the student could recall having learnt "proportion" at school. 100 % of the students in the groups scoring 6 and 5, 82 % of those who scored 4, and only 43 % of those who scored ≤ 3 could recall having learnt it at school. This could therefore have been a factor which would have resulted in the disparity noticed between groups scoring 6 and those scoring ≤ 3. Results are shown in Figure 4.24. It had emerged from focus group discussions that students in the group scoring ≤ 3 had not received the same standard of tuition as those in the group that had scored 6. Therefore, while they might have done proportion problems at school as this section formed part of the school curriculum, they might have been taught to solve these problems mechanically "by rote", or as a skill requiring them to select the correct algorithm, and might, on this account, not have received sufficient insight to reflect on or to internalise proportional reasoning ability or even to subsequently recall having done this section of the syllabus, as it might have been called 'rational numbers' and referred to as 'comparison of ratios' instead of it having been made explicit that this knowledge construct dealt with ' proportion'. On the other hand, it was possible that their teachers had not been aware of the relationship between rational numbers and the concept of proportion, especially as it had appeared from focus group discussions that the low scoring group had, in general, not rated their high schools as highly as the high scoring group had. What was extremely interesting though was that a statistical analysis of the results yielded the following:

The question asked was: Is the proportion of individuals who had learnt proportion at school different across the different groups that consisted of individual students who had demonstrated different proportional reasoning ability on the paper and pencil test? The null hypothesis (H_o) is that the proportion of individuals who had learnt proportion at school is the same across the groups. The alternate hypothesis (H_A) is that at least one of the groups differs in the proportion of individuals who had learnt proportion at school.

A chi squared test for association was run; specifically the test for association between the groups obtaining scores of 6, 5, 4, and ≤3 in the paper and pencil test and having learnt proportion at school. A *p* (probability) value was calculated to be 0.014923 which was significant to 5%. This statistical result thus provided the confirmation that having learnt proportion at school definitely enhanced ability to internalize the concept of proportion and in this respect it supports Vygotsky's idea that learning takes place as a result of mediated activity, and his assertion that scientific concepts, in particular, develop as a result of systematic instruction (Vygotsky, 1986).

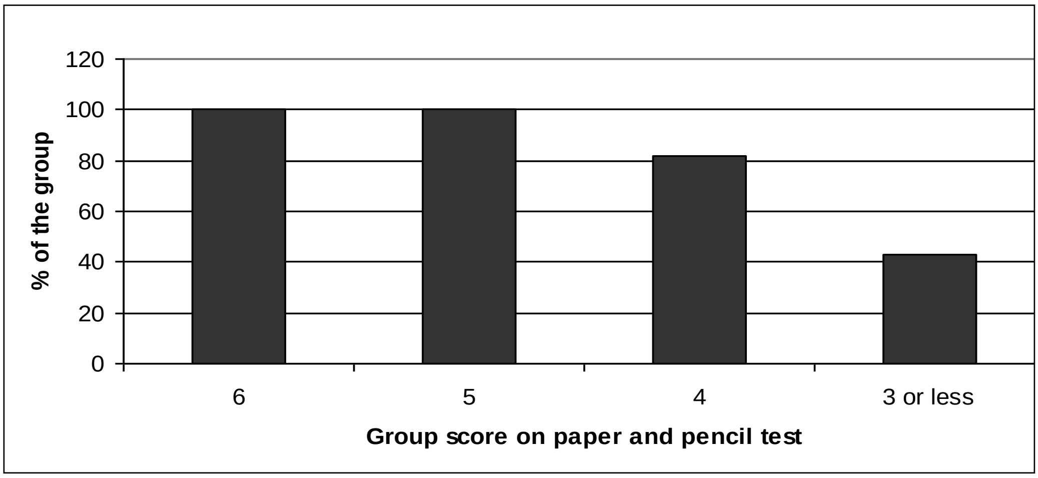

Figure 4.24: The number of individuals in groups with different scores on the paper and pencil test who indicated that they had learnt proportion at school.

A summary of the different factors investigated in the questionnaire is presented in Figure 4.25 below.

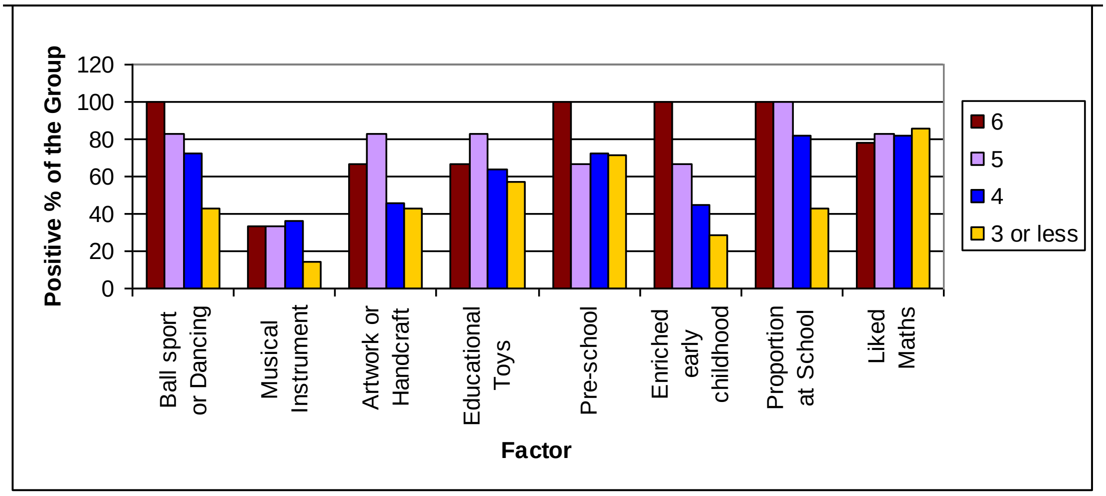

Figure 4.25: Summary of the impact of various factors which might contribute to the development of proportional reasoning ability in individuals in groups with different scores on the paper and pencil test based on Fleener (1993).

Based on the results reported above, one might thus conclude that significant factors in the development of proportional reasoning ability were enrichment in early childhood, and having received specific instruction on the concept of proportion at school. The high school attended seemed to play a role, which suggests that better instruction might have resulted in better learning. Perceptions of whether the individual liked mathematics as a subject did not appear to be significant. However, despite the very obvious significance of a couple of the factors investigated, one should nevertheless be aware that none of the factors, like enrichment in early childhood, and having learnt proportion at school, might be sufficient on its own to have enhanced development of the ability. Since published reports have indicated that the ability to do proportional reasoning cannot be taught, it is probable that some of the factors would have worked together in laying down the internal brain structures necessary for reaching the required level of maturity for development of this concept and for formal cognitive processes. For example, while early participation and / or dancing was not statistically significant to 5 %, it might nevertheless have contributed to the development of the neural structures in the brain, which would have facilitated internalisation of the concept of proportionality. The significance and implications of these observations will be discussed further in the next section.

5 DISCUSSSION

This study aimed to establish to what extent embedded knowledge of a threshold concept, which was reflected as the ability to apply proportional reasoning, created the conditions for the learning of operations underpinned by the concept of proportion in the molecular biosciences. In this regard it was broken down into a number of sub-questions which were investigated empirically and will be discussed in the course of this general discussion. However, the superseding area under investigation was both framed by, and, in the process of this research, enabled me to investigate empirically, Vygotsky's conception of a zone of proximal development, which he suggested was the area where learning occurred. Therefore, from this over-riding perspective, the research question actually endeavoured to establish to what extent actual development, as determined by abilities that could be performed without assistance, affected or created conditions for potential development, which were conceptualised as abilities that had been learnt and could thus be performed without assistance after mediation. Actual development was thus assessed by measurement of proportional reasoning ability, and potential development was assessed by ability to perform operations in the molecular biosciences which formed an essential part of the second year Basic Molecular Biosciences course curriculum. This study has restricted its investigation to the class of second year students registered for Basic Molecular Biosciences II in the School of Molecular and Cell Biology at the University of the Witwatersrand. As mentioned previously, this class was chosen because the operational procedures which are required in order to practice in the molecular biosciences are taught in some depth and are an area of focus in the first semester of this course. Moreover, this course is a co-requisite for all the major courses offered in the school of Molecular and Cell Biology and a pre-requisite course for all the major third year courses offered in the school. The research question therefore has relevance to the pedagogy used when teaching these large classes, and to the throughput numbers in the school.

It should, however, be noted at the outset, that many years of Apartheid in South Africa have resulted in ongoing problems in the education system, as well as social circumstances, which could have contributed to a larger than expected percentage of second year of students being unable to use proportional reasoning. One needs to be careful therefore, about making broad statements about these results being typical of all second year student populations, which means that international comparison of these results is not advisable. On the other hand, this disparate group of second year students has provided a unique opportunity to study knowledge acquisition and learning *per se*, and to investigate empirically the role of Vygotsky's ZPD, and so it was this aspect rather than elucidating the proportional reasoning ability of the class, which would have been similar to the focus in many of the other studies reported by Tourniaire and Pulos (1985), that was the primary focus of my research.

The research approach I used was multi-pronged and initially involved investigations yielding quantitative results which had been obtained under various conditions in a number of situations. This, I felt, enabled me to draw valid conclusions, in the first instance, about the actual levels of development as reflected by proportional reasoning ability, because I had not relied on only one method of assessing proportional reasoning but had used a variety of assessment instruments which were chosen for reasons which will be discussed later in this section. In the second instance, I determined potential development from a number of sources, which included general results in summative assessments like tests and examinations, as well as specific procedural knowledge questions which had been included in them, problems posed during lectures, and questions included in the weekly pre-laboratory tests. As the lecturer of the first semester of the course, I was fortunate to have access to and be privy to all this information. The research also had a qualitative aspect which aimed to elucidate factors which might have contributed to actual developmental levels and which involved focus groups discussions. These led to the design of a questionnaire, the analysis of which enabled me to bring a quantitative side into this aspect of the research as well. Therefore, after generalisations which are included to place the research in context, the individual empirical results will be discussed.

The study was conceptualized after a consistent observation, made during 25 years of University teaching, that many of the second year students that I have taught, are not able to perform certain essential operations in the molecular biosciences field. This inability, in some cases, continues throughout the second year of study, despite various teaching interventions, access to academic development programs which are run by another lecturer, and which are designed to deal with "problem areas" like these, and providing opportunities for 'one on one' tuition with the lecturer or peer post-graduate teaching assistant during practical sessions. In fact, what is quite disconcerting is that it has also been observed that some students who manage to obtain an undergraduate degree, still experience difficulty in performing these operations which form part of the daily practice in a molecular biosciences laboratory, which makes post graduate studies in the field very difficult for them. It then occurred to me that despite the mediation, students could have been experiencing difficulty because they were not at the stage of cognitive development in that domain which would have allowed them to access, or fully appreciate, the conceptual principles required to perform these operations, especially if one subscribes to Vygotsky's assertion that learning occurs in the zone of proximal development (ZPD). In light of this, it was therefore considered that it would be valuable to determine experimentally if this was indeed the case, because if so, it might suggest which pedagogically relevant changes could be implemented in the future. In addition, a study like the one conceptualized would provide empirical evidence for the existence of Vygotsky's proposed ZPD as, by implication, this suggests that actual levels of attainment constrain potential development.

Examination of the operations and procedural knowledge which posed difficulties brought the realisation that all were underpinned by the concept of proportion and depended, to a large extent, on ability to reason proportionally. As this is a content area in the South African high school mathematics curriculum, and a good pass in higher grade mathematics at matriculation is a pre-requisite for entry into the Science Faculty, and all students are required to do a first year university course in mathematics (Maths I ancillary, or Maths I major), it had always been assumed that students would have internalised the concept and that it would not cause difficulty by the time students entered their second year of study at University. Conversations with other lecturers have indicated that I was not alone in this assumption. However, perusal of the literature on studies conducted in the USA suggested otherwise; for example, Thorton and Fuller (1981) who administered 2 problems which required proportional reasoning to 8000 first year college students in the USA concluded from their first study problem that at least 25 % of first year college students were unable to do proportional reasoning, and that at least 20 % had used an additive rather than a multiplicative strategy. More recently, Lamon (2007) has estimated that more than 90 % of adults do not reason proportionally, although she does not support this statement with any empirical data.

An obvious initial task then was to ascertain what percentage of the Basic Molecular Biosciences II class was able to do proportional reasoning. However, the methodology needed careful consideration, especially since several of the published studies had been criticised for basing judgement of proportional reasoning ability on the ability to solve a single problem only, without having determined the strategies used to solve it. Also important was to take into account the debate on whether to base one's judgement on explanations of responses or on performance alone. Moreover, as I was lecturing the class, which was to be used as the experimental sample, for the first semester, I was aware of ethical considerations and the possible effects of interactions between the student and myself if verbal accounts were to form the basis for judgement. Also, from another perspective, the class consisted of 106 students, so if one were to determine the percentage of the class that was either able or unable to do proportional reasoning, it was deemed that a more practical strategy would be to base one's judgement mainly on performance, and in as many instances as possible on written explanations of strategies used by individual students when attempting to solve the problems put to them.

A pilot question was therefore put to the class during one of the lectures given in the third week of the first semester in order to ascertain at this early stage of the year how many of the class appeared to be able to do proportional reasoning. The question posed on this occasion was one used by Lawson (2003) to test strategies used by college students to solve a question requiring proportional reasoning. I have referred to this as a generative question on the grounds that the students in the Basic Molecular Biosciences II class had not been acquainted with this specific problem previously and had not received explicit instruction on its solution even though they might have encountered other proportion based questions during the course of their schooling. It was also felt that the nature of the question was such, that an analysis of the numerical responses to it would provide clues as to the strategies which had been used to solve it, and would thus give indications of the mental models held by individuals.

The method used for data collection, which was via the *Interwrite* PRS system which uses radio waves for transmission of responses, allowed for instant visualization of the results (and thus provided individual feed-back). It was thus possible to immediately implement a teaching intervention which included an explanation of where a large number (51 %) of the participants had used defective reasoning, a demonstration of the correct strategy to use in problems of this type, as well as encouraging peer group discussion to allow time for revision of individual conceptual understanding. Also an advantage with this system was that subsequent analysis of individual responses was possible because the software permits storage of these on the lecturer's laptop. Results are reported in section 4.1. One draw-back was that not all of the students attending the lecture had hired a responder at this early stage of the year as there were only 79 responses to the question (and only 82 students had registered for the session) and the class consisted of 106 students, most of whom were estimated to be present. So although one could ascertain how many of the respondents had not been able to do proportional reasoning, this pilot question did not give a true indication of the percentage of the class who were unable to do so. It was therefore realised at this early stage that an additional test of proportional reasoning ability would have to be implemented.

With respect to this case however, one might have presumed that a teaching intervention immediately after students had been made aware of the concept of proportion and the immediate feed-back provided by the *Interwrite* PRS system would have improved the conceptual understanding of those who did not obtain the correct answer to the problem, especially if one perceives the issue through a Piagetian framework, in that the question would presumably have provoked a situation of '*disequilibrium*' for several students in the class. This might have affected the estimation of the number of students who were unable to do proportional reasoning if a test was to be implemented at a later stage. However, it has been reported (Vygotsky, 1999) that concepts cannot be taught or imposed from the outside, but must be developed individually as conceptual understanding is internalised. Referring specifically to the concept of proportion, Lawson (2003), has suggested that this will only occur after '*considerable time and a repeated experience of the same strategy in a number of novel contexts*' (p23), which implies that while the question might have been the instigator of '*disequilibrium*', internalisation and full understanding of the concept will only occur after '*self-regulation'* which from a biological perspective would involve re-organisation of knowledge. This idea is also supported by Vosniadou's (1994) hypothesis that conceptual change only occurs after enrichment or revision of existing structures. Looking at the issue from a more contextualized perspective, Lamon (2007) considers that the emergence of proportional reasoning ability involves more than a normal developmental process, that it takes a long time to surface, and that instruction plays an important role in its appearance.

Lamon (2007) lists two general categorical types of problems requiring proportional reasoning: comparison problems and missing value problems. The generative problem presented to the class in my study, falls into the missing value category, since students were, in effect, given three of the values and were asked to predict the fourth. In their study, Thorton and Fuller (1981) used two problems, both of which would have been categorised as missing value types. However, despite both problems having the same categorical classification, students did not score as highly on their second problem which required the calculation of the height of a tree from its shadow in relation to the shadow and height of a person as in this instance, only 60 % obtained the correct answer. That problem was very similar in form and presentation to the problem I used initially in my study, so perhaps provides a better basis for comparison of results than those obtained from their first problem which involved scaling up of a recipe which was presented in a format making it obvious that a missing value needed to be calculated. It was felt that the recipe type of problem as it was presented in their study could give inflated estimates of proportional reasoning ability as its presentation ensured that students did not need to set up their own ratios in attempting a solution, which made it possible to just use a mechanistic approach to arrive at the correct answer without any reasoning ability *per se*. In light of this I feel that one is justified in using Thorton and Fuller's second problem results as a basis for comparison. In this situation, they established that 60 % of first year college students in the USA were able to solve the second problem. My results at this stage indicated that only 49 % of the respondents in my class were able to solve a similar problem presented to them. This was therefore fewer than the percentage of 8000 first year biology college students who participated in Thorton and Fuller's study. One might have anticipated from these published results that the proportional reasoning ability of my sample would have been higher, given that they were second year students being compared with first year students. However, I have already drawn attention to one of the limitations of this aspect of my study, which was that one would not be able to state that all second year university students would exhibit the same levels of ability, because of the unique conditions that existed in South Africa for so many years under an Apartheid government. Nevertheless, it is still interesting to note differences from those found in other international studies.

If one assumes that proportional reasoning ability gives an indication of the actual level of development and that this would impact on potential development if learning takes place in the zone of proximal development, then one might predict that students who were unable to solve the problem estimating their proportional reasoning ability would be unable to solve a contextual problem based on material which had been covered in the lecture. Therefore, responses to a problem (underpinned by proportion) typical of those used daily in the molecular biosciences, which was posed to the class after they had received instruction on how to do similar problems, were collected using the *Interwrite* PRS system and were used for analysis.

Solving the actual question asked did not really require much more than to realise that a solution had been diluted ten times. However, this seemingly simple observation did require the ability to reason proportionally, as students were given the information that nine millilitres of water had been added to one millilitre of the solution. It was evident from the values given in the responses that several students had attempted to solve this problem mechanistically by using a formula (which required them to slot in a missing value) they had learnt in a previous lecture and which they had previously learnt in the first year Chemistry course, which was a pre-requisite for entry into the Basic Molecular Biosciences II course. I feel that since the second question was asked during the same lecture period, the analysis of the responses and comparison with an individual's response to the generative question would have provided an initial suggestion of the answer to the research question; by this I mean that it would have provided a good indication of the extent to which an ability to apply proportional reasoning created the conditions for the ability to perform a contextual operation after mediation. This point does not only have relevance in the context of this research question, but has bearing on all learning in this discourse which fits into the type that Bernstein (2000) refers to as a '*vertical hierarchical discourse'*, which implies that knowledge is built up in a hierarchical manner.

Surprisingly, 38 % of the respondents to the first question (15 % of those who had answered it correctly and 24 % of those who had answered it incorrectly) did not attempt to answer the second, which suggests that they were unable to do so. Of interest was the finding that 35 % of students who responded to the second question (23 % of the number of responses to the first question), had answered both the generative question and second question correctly. This suggests that their actual level of development, as reflected by their ability to apply proportional reasoning, had allowed them to access the material while it was being taught. In contrast, 46 % of the initial respondents who had obtained the <u>incorrect</u> answer to the generative question, had either answered the second question incorrectly or had not attempted an answer. This result supported the central hypothesis in this research, as it was evident that their actual level of development had <u>constrained</u> potential development, or more specifically, that the inability to do proportional reasoning has impeded access to procedural knowledge that was based on the concept of proportion. However, although the 9 % who had achieved the correct answer in the second question after answering the first question incorrectly was significantly different from the 23 % who had answered <u>both</u> questions correctly, it was felt that, at this point, the evidence was not compelling enough to make a clear case for reaching that conclusion and, on this account, it was realised that more empirical data was needed.

An analysis of the actual <u>values</u> obtained to the first question revealed that many students who were not able to answer the generative question had either used an additive strategy or had misused a multiplicative strategy. Regarding the values obtained to the second question, it was evident that most of those who had answered incorrectly had used an algorithmic approach without being able to reason proportionally, which had resulted in misuse of the formula. I have classified this approach as being consistent with the Piagetian label of a 'concrete' operational level with respect to the development of understanding of the concept of proportionality; it also highlights these students' conceptual misunderstandings. As explained earlier in the text (4.1), the Piagetian classification is because incorrect application of this particular formula indicates that there was no understanding of the <u>relevance</u> of the various values which need to be substituted into it, and probably not even recognition that the formula is consistent with a proportional reasoning construct. I feel that this <u>substantiates</u> the hypothesis that their level of actual development in terms of proportional reasoning ability had impeded their ability to access the more contextualized knowledge which in this instance involved the calculation of a concentration after recognising that a solution had been diluted ten times, and implies that the first question had probably also been answered with a mechanistic approach. However, it would be remiss not to point out that even students who had achieved the <u>correct</u> answer to the generative question might not have been thinking proportionally, as they could also have used a mechanistic approach when solving the problem. So in view of the promising results obtained from the pilot study it was decided to find a suitable instrument for testing proportional reasoning ability which could be applied to the whole class under test conditions to obviate any effects of potential copying of answers.

In this regard, it was decided that a contextual adaptation of Fleener's (1993) QQTPR paper and pencil test would be the most suitable assessment instrument. I was particularly attracted to Fleener's claim that it tests ability in a hierarchical manner because this, I feel, is congruent with the idea that proportionality and proportional reasoning ability are part of a concept which develops over time and not a procedural knowledge construct that one is either able or not able to do. This is supported by published accounts (Tourniaire & Pulos, 1985) that suggest that students are better at some types of problems than others. However, I was a little apprehensive about the balance scale question that was the final problem included in the test. Although literature suggests that this particular problem is a benchmark for measuring ability to solve compensatory problems which are deemed to be indicative of the highest level of proportional reasoning ability, a criticism which might be levelled at the example type is that it relies on knowledge of physical concepts as well as on the mathematical construct of proportional reasoning. However, because the balance scale problem had been explored through connectionism, which had suggested how conceptual knowledge develops ontologically, and because it was one of Piaget's tasks for assessing development of a formal operational level, it was decided to leave the question unchanged, as this would allow speculation using established educational theories which discuss its ability to signify attainment of a specific cognitive level. The notion of a graded assessment instrument also appealed to me because connectionist accounts of the balance scale problem had suggested that, even though outward signs of having achieved this type of thinking might have been lacking from measurement of performance, inner developmental processes could nevertheless have been taking place (Elman *et al.*, 1996). An instrument which therefore measured performance on an increasingly difficult scale had the potential for suggesting at which stage students were in the process of conceptual development, and I felt that it would be both practical and would elicit estimations of conceptual ability that might otherwise only have been established after verbal accounts.

However, another issue to which I wish to draw attention is that the paper and pencil test was administered during a pre-laboratory test period towards the end of the first semester. This was unfortunately at least 2 months after the generative question had been asked. In light of the time delay in administering the paper and pencil test, one might not have expected to find a correlation between results from the two assessment vehicles; it was deemed that the activities of the semester, albeit that these were actually all contextualized issues which were based on proportionality, might nevertheless have supported development of proportional reasoning ability, and that an assessment so late in the semester would not truly reflect the level of ability at the start of the second year, and thus might influence results aimed at resolving the research question. On the other hand, since the research hypothesis is that students who did not have well developed proportional reasoning ability would not be able to access these procedural constructs, it was possible that there might have been minimal or no effect. The results from the two proportional reasoning assessment instruments have been correlated in the form of a table (4.5) showing numbers of students placed into categories based on the score obtained in the paper and pencil test, compared with their ability to answer the generative question. From Table 4.5 one is able to ascertain the number of students who do not appear to have fully developed conceptual understanding. In this regard, I feel that instead of answering the research sub-question which wished to determine how many second year students could not apply proportional reasoning, it was more appropriate to use analysis of the paper and pencil test to determine how many of the class could apply proportional reasoning to the highest level. Based on results from the paper and pencil test, only 14.7 % of the second year Basic Molecular Biosciences II class demonstrated that they were able to do so. This number is substantially fewer than those who supposedly could from the Thorton and Fuller (1993) study, but is more in line with Lamon's (2007) estimate that "90 % of adults cannot think proportionally".

Besides, the comparative analysis between the ability to answer the generative question and the score on the paper and pencil test indicated that of the 15 students who obtained a score of 6 in the paper and pencil test, only 1 student had answered the generative question incorrectly, which suggests that this sub-set of the class had highly developed conceptual understanding, and could thus be used to calculate the percentage of the class could "do proportional reasoning". These students were therefore also selected to be the control group. I then had to select a group of students who would form the experimental population of students who had low proportional reasoning ability.

Of those students who had scored 5 on the paper and pencil test, 14 had answered the generative question incorrectly which suggests that development of proportional reasoning ability in these students was less highly established and that conceptual understanding was still in progress. Since the research design necessitated an analysis between the ability to perform certain procedural operations which had been taught during the first semester of the course and to relate the performance of these with proportional reasoning ability, it was decided to exclude students who had scored 4 and 5 from this area of the research, as it was felt that their ability was developing and that while they had not demonstrated that they had full conceptual understanding, they had also not made it clear that their development of the concept was undisputedly limited. Attention therefore turned to those students who had obtained 50 % or less for the paper and pencil test.

There were 23 students who obtained a score of ≤3/6 and on comparison with their performance on the generative question it was found that all except 4 had answered the generative question incorrectly. On this basis it was decided that it would be suitable for these students to form the experimental population, and thus the two groups that were used for further research were as follows: Group one comprised the 23 students who had scored ≤ 3, and group two consisted of the 15 students who had scored 6. (It was deemed necessary to include students scoring 3 in group one as only 8 students had scored ≤ 2, which could have affected the statistical significance of the results if such a small cohort had constituted the experimental population.) Further research which attempted to answer the sub-questions of whether the ability to apply proportional reasoning had affected either general performance in the course, or the ability to answer procedural questions which related to material that had been taught during the course, was thus centered on the comparative performance of these two groups.

Results from analysis of performance on operations, (all of which are underpinned by proportion), like the Henderson-Hasselbalch equation, equivalence, and dilutions which had been included as questions in various pre-laboratory tests, corroborated the original hypothesis. This was because it was clear that, under these circumstances, performance on the questions chosen for analysis was, for the most part, significantly better in the group that had high proportional reasoning ability. In this regard, it was taken as confirmation of the hypothesis that actual development creates conditions for potential development, as group one students performed badly on these questions, thus suggesting that their low ability to do proportional reasoning had impeded their potential development in this conceptual domain. The finding also supported Vygotsky's contention that knowledge is only acquired in the zone of proximal development, as the students with low scores had demonstrated that they had not been able to answer many of the questions requiring proportional reasoning ability unaided, and thus mediation had not resulted in a positive affect on their ability to answer specific questions based on the construct.

If one views Vygotsky's argument in confluence with I. Moll's (1994) interpretation of his '*natural line of cognitive development',* and interpolates the findings with biological evidence, it is suggested that the brain structures would have to have been sufficiently developed before new knowledge constructs could be accessed, especially in light of Tsien's (2007) contention that knowledge is organised in the brain from the general to the specific. Therefore, students who had not mastered the concept of proportionality would have had little conceptual knowledge to draw on when attempting to understand and apply more specific contextualized problems based on the concept. On the other hand, by only viewing performance on these tasks, one might have mistaken ability to answer the questions with an ability to have fully understood them and to be able to do similar questions under different circumstances, as some students could have learnt the processes mechanistically and would thus not have had to apply any kind of reasoning to obtain the correct answer. Regardless, it was nevertheless clear that there were distinct differences between the performances of these two groups, to the extent that it appeared that an inability to apply proportional reasoning had impeded the ability to answer questions after mediation and on their general performance as demonstrated by the result obtained in the examination at the end of the first semester.

It has also been suggested that ability to do proportional reasoning affects ability to learn and acquire knowledge in a scientific field. Notwithstanding the suggestion of Inhelder and Piaget (1958) that it is a characteristic that signifies the formal operational stage of cognitive development, Lamon (2007) has highlighted that it forms the basis for understanding many concepts inherent in physics, like sound, light, and force to name a few. Thus, another research sub-question was to establish whether internalisation of the threshold concept of proportion, as reflected by the ability to do proportional reasoning, would impact on overall performance in the Basic Molecular Biosciences II course. Therefore, in order to answer this question, another analysis compared results obtained in the summative examination at the end of the first semester between the research population (group one) and the control group (group two). It was clear from this analysis that group two had performed significantly better than group one, and it was thus concluded that overall performance is impeded by an inability to think proportionally.

Up until this point, proportional reasoning ability had been assessed using performance on problems as the main criterion. As a result of Vosniadou's (1993) contention that explanations provide a better indication of conceptual understanding and of the mental models held about concepts, the practicality of obtaining verbal accounts of the concept was deliberated. Vosniadou's methodology involved interviews with a number of students. However, even although these would have taken place after I had finished my lectures to the class, I felt that research results might be compromised by the fact that I had been their lecturer. Moreover, from an ethical perspective, I did not want any student to feel singled out, compelled to participate, or to be under the impression that the marks could in some way be prejudiced even if given the assurance that this would not happen. One of the teaching interventions, I had used to enhance conceptual understanding and internalisation of the concept of proportion, especially as it underpinned so many of the operations we had covered during the year, was a "due performance" requirement that students communicate their understanding of the concept of proportion in writing using email, blogging sites, or WebCT. It must be emphasized that these were assessed on the basis of the writing and development of arguments (as Basic Molecular Biosciences II is a writing intensive course, in which writing is used pedagogically to enhance learning), and not on conceptual understanding. It was decided to examine the student accounts to see whether a retrospective analysis of some of them had the potential for grading proportional reasoning ability. This brought the realization that formal accounts did not provide an adequate resource for this. However, informal discussions on WebCT were very enlightening and it was therefore decided to select one discussion thread for analysis and to ascertain whether it held potential for substantiating previous findings on the research questions.

The students' identities were disguised by the allocation of numbers before I allocated scores or grades on the basis of their written accounts, so that the fact that I might be aware of different capability with respect to performance in the course would not affect my judgement of their proportional reasoning conceptual development based solely on what they had written in this discussion thread. In line with the grading system of Thorton and Fuller (1993), students were graded as using a formal operational, transitional or concrete operational cognitive level. As it was also possible to do so from their accounts, I decided to differentiate between the two that I had decided were at the formal operational level, as I felt that one had indicated that he / she had understood proportionality while the other could probably do proportional reasoning but had not yet reached the pinnacle of conceptual understanding. The other two students were categorised as being at a transitional stage of development. A comparison was then made between the categorisation of these four students which had been made solely on the basis of their written discussion, with their score on the paper and pencil test, their answer to the questions which had been posed during the lecture period, and their performance in the first summative assessment. The correlation between the judgement of their ability made on the basis of the discussion thread and the score on the paper and pencil test was remarkable, which led me to the conclusion that verbal accounts would provide a sound basis for assessment of conceptual development. The ideal would be, however, to use pencil and paper tests and verbal explanations together before one made a final judgement on a student's actual developmental level. Nevertheless, because of the good correlation between the grading based on the written discussion and the paper and pencil test, and because only one of these students (who had scored 6) would have formed part of the control group in the previous analysis, it was decided to compare the performance of these four students with their grading from the discussion thread, their score on the paper and pencil test, and their performance in the summative assessment examination held at the end of semester one. It was most interesting to see that in these four students at least, the overall results in the examination as well as in section B of the examination, which was the one which had included the procedural questions underpinned by proportionality, correlated extremely well with the development of their conceptual understanding of proportion. This was despite one of the students having obtained 5 and two having obtained 4 for the paper and pencil test which means that I had excluded them from previous comparisons on grounds that were discussed previously. After that observation, I compared the performance of three of these students on specific questions which had been included in the first summative test held at the end of March with their categorisation of proportional reasoning ability, as it was felt that this was just one more vehicle for assessment of potential development.

Once again, it was evident that the student, who had scored 6, had outshone those who had scored 4 on the paper and pencil test. Something else that I had rationalized, was that all of these students could be considered as hard working, since the fact that they had embarked on informal discussions on the concepts covered in lectures pointed out that they had engaged with the lecture material. This made me confident that any differences in performance in summative assessments and on specific questions underpinned by proportion had resulted from their actual development of the concept and was not due to disparities in work ethic.

After reviewing results from the three analyses discussed above, I decided that there was sufficient evidence to conclude that an ability to do proportional reasoning created the conditions for the ability to perform contextual operations based on the concept of proportion. The experimental results had therefore provided the evidence which enabled one to answer the research question, and moreover to conclude that learning does take place in a particular zone; this zone lies between the levels of actual and potential development. Empirical evidence has thus supported Vygotsky's assertion that learning occurs within the zone of proximal development.

The final sub-question at hand at this point in the research was to determine *ex post facto*, what factors may have led to the establishment of proportional reasoning capacity in the first place. As stated previously, the ultimate purpose of this section of the study was therefore to produce a set of hypotheses which could be used to generate a deeper range of factors considered to be important for the development of proportional reasoning. This sub-question was investigated using two focus discussion groups: one group was comprised of students who obviously understood proportion and the other group was made up of those who showed weak proportional reasoning ability. Participants were encouraged to talk about their various life, recreational and educational experiences, in guided but informal discussions which were recorded and later transcribed. The strategy employed was to transcribe and review the recordings in order to identify factors or events which were experienced by the participants in one group but not in the other. It was considered that this would allow me to develop the hypotheses which could be tested in a questionnaire to be administered to a different sample of students from the Basic Molecular Biosciences II class.

One of the factors to emerge from the focus group discussions was that enrichment in early childhood probably played a part in development. In this regard, there was obvious disparity between the two groups. The hypothesis formulated therefore was that early childhood enrichment would have encouraged the development of proportional reasoning ability. Results from the questionnaire validated the hypothesis, as when the responses were correlated with scores from the paper and pencil test, it was obvious that results were significantly different between the groups scoring, 6, 5, 4, and ≤3. Although Vygotsky (1986) was referring to the development of general concepts when he proposed that: '*the development of the processes that eventually result in concept formation begins in earliest childhood……",* his statement seems to be supported by the suggestions resulting from this aspect of my research. Students with weak proportional reasoning ability had not had the same degree of enrichment in early childhood, especially with respect to the interaction they had experienced with their parents, older siblings or care-givers. Many reported having played with educational toys and of having attended a pre-school. However, personal involvement from care-givers appeared to be a far more important factor, as it was evident that the number of students who reported that they were party to an enriched early childhood with respect to input from parents or care-givers increased substantially from those in the group who scored ≤3 to those who scored 6. If one thinks about this within a Vygotskian framework, it is possible to explain these findings in the following way. As pointed out by Vygotskian scholars like Daniels (2001) and L. C. Moll (1990) in their writings on the subject, Vygotsky was a social constructivist. However, within a social constructivist framework, the central tenet of his proposed zone of proximal development learning theory is mediation (Vygotsky, 1986). Therefore, it might be surmised that social and cultural circumstances would provide the tools to be appropriated by individuals as signs for use in their development. Considered in the context of my research, however, it can be concluded that the tools themselves would not be sufficient to initiate internalisation of the signs for development, but that mediation would have been necessary to do so, as most of the students, regardless of their score on the paper and pencil test seemed to have been provided with "educational" toys to play with, either at home or at the pre-school most had attended. What was lacking in most of the students with limited conceptual understanding of proportion was input from care-givers which would therefore have provided the mediation which would have prompted the development of internal signs. For those fortunate enough to have internalised the signs necessary for development of proportional reasoning ability, attendance at a good high school and direct mediation in the concept would have enhanced their conceptual development. Statistical evidence did in fact show that having learnt proportion at school was a significant factor which contributed to conceptual understanding, which once again highlights the importance of mediation in learning. These findings also support Vygotsky's (1986) proposal that scientific concepts are formed as a result of systematic instruction. From a biological perspective mediation or "systematic instruction" would have facilitated, (or initiated), the development of the appropriate brain structures which were necessary for further development based on the concept, especially in light of Tsien's (2007) conclusion that learning structures are coded in the brain from the general to the specific.

While this was not shown to be statistically significant, it was also evident that participation in a ball sport, traditional sports or dancing at an early age also seems to have enhanced development of the concept of proportional reasoning. Once again, one might envisage that both of these, for the most part, mediated activities would have provided tools which could have enhanced the development of this concept. To be successful in a ball sport, the mind has to perform continuous sub-conscious mental calculations of how much force to apply to cover a certain distance when either hitting or throwing an object; likewise in dancing where the force needs to be applied by the musculature of the legs to cover the distance required. The relationship between force and distance could therefore have been the internalised sign which enhanced development of the concept of proportion, and necessitated the development of the foundational structures in the brain, which could be drawn on when explicitly exploring the concept at a later stage via formal instruction.

From his own empirical studies on the development of higher order functions, Vygotsky (1999) concluded that the development of all operations whose development depends on signs follow similar patterns of development. In light of this he states firstly that: *"The history of development of each of the higher mental functions is not the direct continuation and further improvement of the corresponding elementary functions, but undergoes a radical change of direction in development and subsequent movement of the process to a completely new plane; each higher* *mental function is, thus, a specific neotransformation". (p42),* and secondly that: *"higher mental functions are not built up as a second story over elementary processes, but are new psychological systems that include a complex merging of elementary functions that will be included in the new system and themselves begin to act according to new laws; each higher mental function is, thus, a unit of a higher order determined basically by a unique combination of a series of more elementary functions in the new whole."* (p43).

Putting this theory into the context of the empirical results described in this research report, it thus appears that if students are not able to do proportional reasoning, they will need to change their mental model to accommodate the process in order to reach the required level of actual development before they will be able to develop further which would allow them to independently perform the operations based on proportion in the molecular biosciences. An example of this was evident in the students who used additive, instead of multiplicative, strategies to solve problems involving proportion. In these situations, potential development will thus be constrained by the actual level attained. This means that, for students who have not reached the required actual level of development, mediation and instruction will fall outside of their zone of proximal development. Therefore, while they might learn to perform operations based on proportional reasoning mechanically, and by using formulae by "aping" seen methods, they will not have understood the basis of these operations and will probably not be able to perform those which differ from the ones learnt "by rote"; in real terms this means that authentic learning will not have taken place. In Vygotskian terms, one might consider that any demonstrated ability had resulted directly from external stimuli rather than from internalised knowledge. Therefore, if a student has not internalised a particular concept, he / she will not be able to learn effectively anything which is underpinned by that concept. From a pedagogical point of view, this means that instructors need to ensure that the underlying concepts are well on the way to being understood, before proceeding to build on them or introducing new concepts.

If we are to consider this last point from the perspective of mediation or instruction in tertiary education, should we not be implementing programs to ensure that the concept of proportion has been understood before students are expected to achieve the ability to perform the specific operational abilities (based on the concept) required of them in the various courses for which they are registered? Academic support programs might thus be geared to achieving this ideal. This immediately suggests that an area for future research which would be to ascertain what types of activities or mediation would lead to conceptual understanding of proportion in young adults who had probably missed out on these opportunities while they were at school or in their early years because of home circumstances. One might also question how long it would take to achieve full conceptual understanding and a highly developed ability to think proportionally. From the University's perspective, one might therefore advise the first year co-ordinators to test proportional reasoning ability when students enter tertiary education, and to set up programs which would lead to the development of conceptual understanding, rather than trying to address attainment of an ability to perform the contextualized operations in the course which are based on proportion. Since it has been postulated that scientific achievement in general, (which was corroborated by my findings regarding overall achievement in the Basic Molecular Biosciences II course), was dependent on ability to apply proportional reasoning, this would be time well spent, especially as pre-requisite courses for many of the second year major courses include maths, physics and chemistry. Many of the knowledge constructs in these courses depend on the conceptual understanding of proportion.

In summary, the multi-pronged mixed method approach used in this study has enabled me to establish that less than 15 % of the class registered for the Basic Molecular Biosciences Ii course, in the School of Molecular and Cell Biology, has demonstrated full conceptual development of proportion. The largest portion of the class is at a transitional stage in terms of conceptual understanding and 23 % have limited development of the concept of proportion. Furthermore, the inability to apply proportional reasoning has been shown to impede ability to access and perform more elaborate contextualized procedures in the molecular biosciences, like calculations of concentration, dilution factors and equivalents, which are underpinned by proportionality. Moreover, this inability to conceptualize proportion has influenced general performance and overall results obtained in the Basic Molecular Biosciences II course summative assessments, as the group of students who had mastered the concept were shown to have performed substantially better in the March summative assessment test and the June examination. Focus group discussions aimed at elucidating the factors which might have supported and resulted in conceptual understanding of proportion suggested that participation in a ball sport or dancing, early childhood enrichment, the high school attended and specific instruction on the concept had contributed to conceptual development. A questionnaire designed to interrogate these factors, and administered to a different sub-section of the Basic Molecular Biosciences II class, confirmed statistically that early childhood enrichment and specific instruction on the concept were significant factors which could have enhanced conceptual understanding. From this perspective this empirical study, has, by resolving the issues raised in the sub-questions, answered the research question which investigated the effect of proportional reasoning ability on mediated learning of operations underpinned by this concept in the molecular biosciences.

Finally to wrap up from a theoretical perspective, the research findings reported here have supported I. Moll's (1994) reading of Vygotsky's conceptualisation of the zone of proximal development which takes into account the natural line of development. The results suggest that actual developmental levels have created the structures necessary for potential development in a particular domain. In this regard, it has been shown, by investigations on the concept of proportion, that it is not possible to satisfactorily advance further in a particular domain, without sufficient development at a foundational level. My research has also suggested factors which may have contributed to laying the foundation for the development of proportional reasoning ability. From a biological perspective, one can speculate that the necessary brain structures have to be established, and conceptual understanding has to be internalised as embedded knowledge, before further knowledge based on the specific concept can be accessed. The internalisation can occur through explicit mediation in a particular field as well as from signs commandeered as a result of development initiated by another activity. In conclusion then, this empirical research has established that within Vygotsky's social constructivism learning theory, actual levels of development create conditions for potential development in his conceptualization of the zone of proximal development.

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7. ATTACHMENTS

7.1 Paper and pencil test developed for the Basic Molecular Biosciences II class for the hierarchical categorisation of proportional reasoning ability (based on QQTPR model of Fleener, 1993)

1. Place each number below on the number line provided. If a number cannot be placed on a number line, circle it and explain why it cannot be put on the number line.

   0.022, 1.67, -1.5, 7/8, 1.26, 13/7, 0.3, 5/4.

-2_______________-1_______________0_______________1_______________2

2. Suppose in a large 100 g box of *Smarties* there are the following number of each colour:

   12 red, 24 light brown, 16 yellow, 18 green.

   If you purchased a 40 g box of *Smarties*, how many *Smarties* would you expect to have in the box?

3. You have decided to construct a bioreactor in the laboratory that is an exact replica of a commercial bioreactor. Suppose the column length of the commercial bioreactor was 1200 cm and the diameter was 100 cm. What would be the height of your laboratory reactor if the diameter was 5 cm?

4. You need to order chemicals for the laboratory out of your research grant. You price chemical X from two sources. The pricing from each is shown in the table below:

Product	Chemical company A weight	Price	Chemical company B weight	Price
Chemical 1	500g	R143.00	400g	R86.00

   Which Chemical company would you buy Chemical X from and why?

5. The density of substance B is twice that of substance A. If 100 ml of substance A has a mass of 1000g, what mass would 100 ml of substance B have? Why?

6. A meter stick is balanced at its natural balance point on a fulcrum. A 100 gram weight is placed 20 cm to the left of the fulcrum. Where would a 200 gram weight be placed if the stick is to be balanced again? Show how you arrive at your answer.

7.2 Letter providing information about the research and requesting consent of participants in the study

This letter serves to inform you that I am currently researching the extent to which the ability to use proportional reasoning impacts on performance in areas underpinned by this concept in the Basic Molecular Biosciences II course and on general performance in semester one in the course. The research also aims to establish factors which might have contributed to the development of the ability to apply proportional reasoning. I therefore request permission to analyse your responses to questions requiring proportional reasoning which were asked during class, your responses to questions included in pre-laboratory tests and summative assessments and to compare these with your performance in the Basic Molecular Biosciences II course. The results of the research will be written into a research report for my M Ed degree and may be presented at a conference or submitted for peer review in a journal in the future. However, I undertake to conceal individual identities in any published form and in any public forum. My research findings will not prejudice your course results in any way, or in subsequent selection procedures for honours or masters programmes and you will not be penalised should you not consent to take part in this research.

Dr EA Brenner

Should you agree to participate in the study I respectfully request that you give your consent by completing the following:

I, _________________________________ (Student number: ____________________) do not object to participating in the research outlined above, and hereby give permission for Dr EA Brenner to analyse and include my responses to questions posed in class, in pre-laboratory tests and in summative assessments, provided that my identity is concealed should the results be presented in any public forum. Should I be selected, I agree to participate in focus group discussions aimed at elucidating factors which might contribute to the development of proportional reasoning ability.

Signed: ______________________________ Date: _________________

7.3 Basic Molecular Biosciences II March Summative Assessment

Name: ______________________________ Student Number: _______________

BMB (MCBG2025) TEST MARCH 2008

Time: 90 minutes **Marks: 55**

Please write your answers in ink in the spaces provided on the question paper. Show all calculations.

Question 1 **(10 marks)**

1.1.1 How many ml of stock solution would you take to prepare 60 ml of an 800X dilution? (1)

1.1.2 How many ml of water would you add? (1)

1.1.3 Give an account of how you arrived at your answers in 1.1.1 and 1.1.2. (1)

____

____

____

1.2 What would the final concentration be if you added 8 ml of water to 2 ml of a 0.8M solution? (1)

1.3.1 Calculate the molarity of a solution of amphotericin B (M_r = 924.1) if 462.05 mg are dissolved in 2 ml of water. (1)

1.3.2 A 30 % solution contains ___________ g per 250 ml. (1)

1.3.3 What mass of erythromycin (M_r = 733.9) would be required to prepare 200 ml of a 2M solution? (1)

1.3.4 What is 7 % ethanol, expressed in terms of molarity? (M_r of ethanol = 46.06 and density of ethanol at 25°C = 0.789 g ml^{-1}). (2)

1.3.5 Calculate the osmolarity of 3 M $MgCl_2$. (1)

Question 2 **(20 marks)**

2.1 Which is the stronger acid?

Lactic acid (pK_a = 3.86) or acetic acid (pK_a = 4.76). Justify your choice. (2)

____

____

____

2.2 Calculate the pH of **solution A** if 0.05 mol of lactic acid and 0.05 mol of sodium lactate are dissolved in 1 L of pure water. The pK_a for lactic acid is 3.86 (2)

2.3 If the pH of **solution A** is adjusted to 4.86 by the addition of concentrated sodium hydroxide (ignore any dilution), what will the ratio of lactate to lactic acid be? (2)

2.4 What will the concentrations of lactate and lactic acid in solution A be when the pH is 4.86? (2)

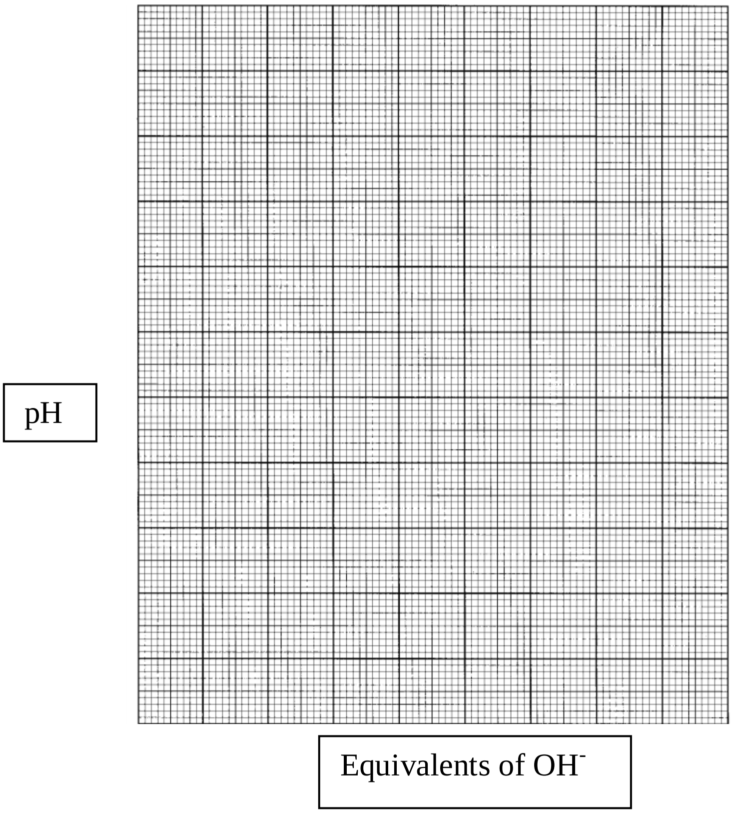
2.5 What percentage of the lactic acid molecules in solution A will be deprotonated at pH 4.86? (1)

2.6 What percentage of the lactic acid molecules in solution A will be protonated at pH 4.86? (1)

2.7 What volumes of lactic acid and sodium lactate must be mixed to prepare 1 L of 0.1M lactic acid buffer at pH 4.86? (2)

2.8 Sketch the titration curve for lactic acid on the axes below. (4)
Label the following:

- The pK of lactic acid
- The buffering range
- The regions where lactic acid is protonated
- The regions where lactic acid is deprotonated.



2.9 If you were titrating 250 ml of a 0.1 M solution of lactic acid with a 2 M solution of NaOH, how many ml of NaOH would you have to add to adjust the pH to 3.86? (2)

2.10 Describe how a titration curve of carbonic acid (H_2CO_3) would differ from that of lactic acid?

____

____

Question 3 **(15 marks)**

3.1 Match the following. Write the letter of the matching group in the space next to its name: (6)

Acetyl ________

Alcohol ________

Aldehyde ________

Amino ________

Aromatic ________

Carboxyl ________

Ester linkage ________

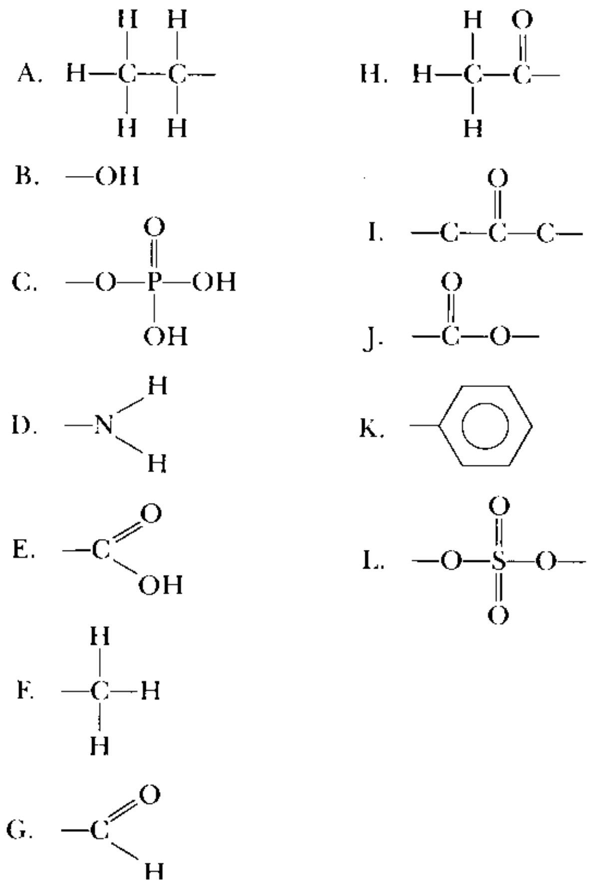
Ethyl ________

Keto ________

Methyl ________

Phosphate ________

Sulfate ________



3.2 Read the following extract from the article entitled 'Cell Defences and the Sunshine Vitamin' written by Luz E. Tavera-Mendoza and John H. White and published in Scientific American in November 2007 on pages 36 – 44.

'Since the 1980s various lines of evidence have pointed to vitamin D's protective effect against cancer. Many epidemiological studies have shown strong inverse relation between exposure to sunlight and the incidence of certain types of cancer. Studies in animals and cell cultures have supported that association and helped to pinpoint the mechanisms that may be involved. Recognition that 1,25 D has a broad range of biological activities far beyond its role in calcium homeostasis has thrown into sharp relief a large body of epidemiological evidence that low vitamin D levels correlate strongly with certain types of disease, among them cancers, autoimmune conditions and even infectious diseases, such as influenza, as well as with seasonal variations in illness rates. In addition, many of the noted physiological responses to vitamin D seen both in the laboratory and in clinical studies are optimized only when circulating concentrations of 25D are higher than is typical in many populations. Members of the vitamin D research community are therefore coming to a wide-spread consensus that substantial numbers of people in temperate regions of the world have levels of vitamin D that are well below optimal concentrations for health, particularly in the winter months.'

3.2.1 Write one sentence whereby you could relate the essential information contained in this extract in an essay. (2)

____

____

____

____

3.2.2 How would you cite the authors in the text of your essay? (1)

____

3.2.3 Write two premises and a conclusion which would indicate deductively valid reasoning used by the researchers. (3)

3.2.4 Comment on the inductive strength of the argument used by the researchers stating the factors that would lend weight to their conclusion. (3)

____

____

Question 4 **(10 marks)**

State with reasons whether the following statements are true / false.

4.1 Thin layer chromatography has water bound to the stationary phase.

T / F because

____

____

4.2 Cation exchangers have bound anions which are exchanged by cations in the mixture you wish to separate.

T / F because

____

____

4.3 In gel chromatography the largest molecules are eluted first.

T / F because

____

____

4.4 Tungsten lamps are used in UV spectroscopy.

T / F because

____

____

4.5 Electrophoresis under non-denaturing conditions can be used to determine the molecular weight of a protein.

T / F because

____

____

4.6 Centrifugation in a bench centrifuge with a swing out rotor with an average radius of rotation of 125 mm operating at 4000 r.p.m generates a g value equal to 2235.

T / F because

____

____

4.7 The absorbance of light by a solution at a particular wavelength is indirectly proportional to the concentration of the absorbing substance and to the length of the light path through the solution.

T / F because

____

____

4.8 A blank solution always has an absorbance value of zero.

T / F because

____

____

4.9 A hypsochromic shift refers to a decrease in the λ at which a chromophore absorbs.

T / F because

____

____

4.10 In fluorescence spectroscopy the λ of the emitted light is longer than that used to excite the molecule.

T / F because

____

____

7.4 Letter of invitation to focus group discussions

Dear ________________,

Thank you for agreeing to be part of a focus group for my M Ed research. In this regard, I'm inviting you to a discussion at lunch time – 13h15 on Monday 25th August in Gate House 002 (on the ground floor).

A light lunch will be served. Please indicate your availability by emailing me at liz@biology.wits.ac.za or SMS me at 082 800 4141.

Thank you again. See you after the study break!

Regards,

Dr Liz Brenner

7.5 Points brought into guided focus group discussions

Thank you for coming. I really appreciate your time. Help yourself to food. Do you mind if I record the session, so that I can go over it afterwards? May I call on you to check if I've transcribed it accurately afterwards?

Are there any left hander's here?

Which schools did you attend? Did you like school? Which subjects?

How about Maths? Did you like Maths at school? What could you say about your maths teachers? Were you good at Maths?

Do you like to solve problems that you haven't seen before? How do you solve them? – Intuitively, logically or try to remember a method or formula you could use?

Do you like 'playing games with numbers'?

Did you go to a pre-school? What was it like? Do you remember the types of activities you did there?

Did your parents do activities with you when you were little before you went to school?
Like what? Read you stories? Teach you to count? Do you remember when you could count?

Did you play with blocks? Lego? Did you bake when you were little? Now? Sew, Knit, Woodwork, build? Hobbies? Art? Design – patterns?

What were your favourite games when you were younger?

How much did your parents help with schoolwork?

What about sporting activities? Dancing?

Does anyone do crosswords? Sudoku?

How do you feel about questions which require you use proportion? Can you do them? When did you learn to do so? Was it something you learnt at school? or could you 'just do it?'

How much TV do you watch? Which programs? What kind of music do you like? Does anyone play a musical instrument? Had any music lessons?

7.6 Questionnaire designed to elucidate factors which contribute to the development of proportional reasoning ability.

Thank you for your time in completing this questionnaire. Whatever you answer will remain confidential. The information will be used for research only. None of what you say will in any way affect your marks. If you do not wish to participate you will not be penalised in any way. Please elaborate your answers if you can.

Student Number: ________________________________

Have you played (or do you still play) a 'ball sport' or have you taken part in traditional sports?

Yes	No	If yes: which sport/s?	When did you start playing each one and for how long did you play?

Have you learnt to play a musical instrument?

Yes	No	If yes: which instrument?	When did you start playing each one and for how long did you play?

Have you ever done artwork outside what you might have done in the school curriculum?

Yes	No	If yes: what type of artwork?	When did you start and for how long did you do it?

Do you do (or have you done) woodwork or sewing or a handcraft?

Yes	No	If yes please elaborate

Did you have any 'educational toys' (like blocks, Lego) before you started grade 1?

Yes	No	If yes: which can you remember playing with?

Did you go to a preschool or crèche?

Yes	No	If yes: at what age did you start and for how long did you attend?

Would you rate your very early childhood (from babyhood until before you went to school) as having been enriched with a lot of input from your parents, other carers, friends or older peers?

Yes	No	If yes: please elaborate

How would you rate the primary school you attended?

Excellent	Good	Average	Not good	Dreadful

How would you rate the high school you attended?

Excellent	Good	Average	Not good	Dreadful

When learning something new do you like to find how it links with something you already know or rather to learn it independently from what you already know?

Link it	Independently	Please elaborate briefly

When learning something new do you like to see the ‘big picture’ first or rather to build up knowledge and understanding from basic simpler facts so that you only discover the big picture later?

Big picture first	Big picture afterwards	Please elaborate briefly

Were you taught ‘proportion’ as a concept at school?

Yes	No	If yes: in what grade?

Did you like maths at school?

Yes	No	Why?