Development of a Taxonomy for Visual Literacy in the Molecular Life Sciences

By

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Abstract

The use of external representations (ERs) such as diagrams and animations in science education, particularly in the Molecular Life Sciences (MLS), has rapidly increased over the past decades. Research shows that ERs have a superior advantage over text alone for teaching and learning. Research has also indicated a number of concerns coupled with the use of ERs for education purposes. Such problems emanate from the mode of presentation and/or inability to use ERs. Regarding the later, a number of factors have been identified as major causes of student difficulties and they include visual literacy as one of the major factors. Given that little has been done to understand the nature of VL in the MLS the current study was conducted with the general aim of investigating this area and devising a way to measure the visual literacy levels of our students. More specifically, this study addressed the following research questions: *i)* What is the nature of visual literacy in MLS?; *ii)* Can specific levels of visual literacy be defined in the MLS?; and *iii)* Is a taxonomy a useful way of representing the levels of visual literacy for MLS? To respond to these questions, the current literature was used to define the nature of visual literacy and the visualization skills (VSs). These were then used to develop a Visual Literacy Test made up on probes in the context of Biochemistry. In these probes, the VSs were incorporated. The test was administered to 3rd year Biochemistry students who were also interviewed. Results were analysed qualitatively and quantitatively. The later analysis utilized the Rasch model to generate an item difficulty map. The results of the current study show that visual literacy is multifaceted in nature and is context based in that it requires specific propositional knowledge. In line with this, it was found that visual literacy is expressed through a cognitive process of visualization which requires VSs. Based on the performance of these skills, learners' optimal visual literacy in the context of the MLS can be defined. Such performance can be assessed through the development of probes in the Biochemistry context. Furthermore, the current research has shown that using probes, the difficulty degree of each VS can be determined. In this instance, the Rasch model is a preferred method of ranking VSs in the context of Biochemistry in order of difficulty. From this, it was shown that given the uniqueness of each skill's degree of difficulty, each skill can thus be regarded as a level of visual literacy. Such levels were defined in terms of the norm difficulty obtained in the current study. Given the multifaceted nature of visual literacy, the current study adopted the view that there are infinite number of VSs and hence the number of levels of visual literacy. From the variation in the degree of difficulty, the study showed that there are non-visualization and visualization type difficulties which contribute to the differences in visual literacy levels between Biochemistry students. In addition to this, the current study showed that visual literacy in the MLS can be presented through a taxonomy. Such a taxonomy can be used to determine the level of each VS, its name and definition, typical difficulties found in the MLS as well as the visualization stage at which each skill is performed. Furthermore, this taxonomy can be used to design models, assess students' visual literacy, identify and inform the remediation of students' visualization difficulties. While the study has successfully defined the nature of visual literacy for the MLS and presented visual literacy in a taxonomy, more work is required to further understand visual literacy for the MLS, a field where visual literacy is very prevalent.

Declaration

The experimental work described in this dissertation was carried out in the School of Biochemistry, Genetics, Microbiology and Plant Pathology, University of KwaZulu–Natal, Pietermaritzburg campus, from January 2006 to November 2007, under the supervision of:

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These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University.

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Dedication

In memory of my late grandmother – Khwibi!!!

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- My non-ceasing praises to God the Father, Jesus Christ the Son and the Holy Spirit, for not by might nor by power but by the Spirit of God has this work been successfully completed, indeed, He has come so that we may have life and have it more abundantly.
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- Sne – always…
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  My friends, SCF and theWord – the Word has indeed become flesh, God bless you all.

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List of Abbreviations

4YS	Fourth Year Student
BIOC 304	Biochemistry 304
BIOC 306	Biochemistry 306
Bioc A and B	Biochemistry courses A and B
BP	Biochemist Professionals
C	Conceptual
CI	Confidence Interval
CVI	Content Validity Index
DF	Degrees of Freedom
ER	External Representation
HSRC	Human Sciences Research Council
LTM	Long Term Memory
M	Mode of presentation
MLS	Molecular Life Sciences
MNSQ	Item Fit Mean Square
NBP	Non-Biochemist Professionals
NO	Nitric Oxides
NoER	Nature of external representations
Non-ER	Non-External Representation
NoVL	Nature of Visual Literacy
PMB 1/2	Pietermaritzburg students sample 1 or 2
PMB	Pietermaritzburg
PVT	Psychometric Visual Test
R	Reasoning ability
ROI	Reactive Oxygen Intermediates
SAT-L	Senior Aptitude Test Form – L
SD	Standard Deviation
SoD	Sequence of Difficulty

SPSS	Statistical Programme for Social Sciences version 13
STM	Short Term Memory
TRAT	Trade Aptitude Test Battery
UKZN	University of KwaZulu-Natal
VLT	Visual Literacy Test
VS	Visualization Skills
VWM	Visual Working Memory
WM	Working Memory

1. Chapter 1: Introduction

1.1 Motivation for the Study

Visual literacy and visualization are key components of learning in the Molecular Life Sciences (MLS)[1]. Many biomolecular phenomena are impossible to visualize with the naked eye due to their submicroscopic sizes and associated levels of complexity. Furthermore, these phenomena occur across different levels of organization, from microscopic to macroscopic as well as in different relative sizes (Schönborn & Anderson, 2006). To visualize such phenomena, a range of External Representations (ERs) are used to express the phenomena graphically, which assists learners with constructing knowledge of how these phenomena occur in reality.

ERs such as animations, diagrams and pictures play a critical role in science education. Scientists, engineers, researchers and science educators use models to communicate, represent and clarify abstract scientific concepts (Dori & Barak, 2001; Russell *et al.,* 1997) which would be difficult to accomplish with textual or numerical representations alone. Pictorial models allow learners the opportunity to explore the nature of scientific knowledge, how it is constructed and, how it is related and how it comes to be. As useful and effective as these models may be, sometimes models can generate problems for learners, especially if they are not properly designed or used (Michael, 2002). For instance, students' learning difficulties may be related to the cognitive mechanisms (such as information processing) that students use to perceive and interpret the model. Such difficulties may also be related to the nature of students' conceptual understanding with respect to the propositional knowledge represented by the model (Schönborn & Anderson, 2006; Michael, 2002; Schönborn & Anderson, In Press).

With regard to processing the information presented through ERs in modern science education, the lack of visual literacy is one of the major difficulties faced by learners (e.g.

[1] Molecular Life Sciences in this thesis refers to sciences such as Biochemistry, Genetics and Microbiology

Schönborn & Anderson, 2006; Velez *et al.* 2005). Students often fail to interpret the ER at hand in a manner that will provide them with sound understanding of the concept, and hence both their ability to process ERs as well as their conceptual understanding is compromised. These visualization limitations may be due to a number of *internal* or *external* factors. Internal factors are those related to the cognitive ability of the student whereas external factors are those related to the design and artistic nature of the ER (NoER) itself (Kahneman, 1973).

Concerning internal factors, according to Kahneman's (1973) capacity model, visualization skills (VS) and motivation can both improve learners' ability to interpret information from a given source (Greene & Hicks, 1984). With regard to visual literacy, this premise translates into the notion that, if a student has *enough* VSs, and if they are motivated, then they are in a good position to interpret ERs successfully. In addition, the choice of model type (i.e. the model itself) can also influence learners' ability to visualize the phenomena presented. For instance, for some students colourful models may be easy to comprehend compared to black-and-white models (e.g. Longo, 2002). These influences also impact the mental models that learners construct during interpretation of ERs. For instance, researchers have found that learners who use ERs such as diagrams and pictures, rather than text alone, show more meaningful mental model development (Butcher, 2004; Mayer, 2001). Related to this finding, computerized visual modelling has been taken advantage of by many modern scientists and educators (e.g. Mayer, 2001). There is an opinion that these models allow for improved visualization and hence, conceptual understanding in science (Dori & Barak, 2001). However, what is not always considered with computerized models is the fact that the skills required to interpret and visualize symbols and other spatial elements, generated by the software, are essential for effective learning from these types of models (Dori & Barak, 2001). Unfortunately, this observation has not always been taken into account and has resulted in a range of symbols and graphical markings which are often unfamiliar to students.

In relation to the argument above, some scholars have raised a number of issues concerning visual literacy. For example, Schönborn and Anderson (2006) have argued that in Biochemistry, the lack of standard ER symbols or conventions has a major influence on students' difficulties with the visualization of models. This is because it is difficult for students to master the sheer variety of symbols used to represent biomolecular phenomena. In addition, it has been suggested (e.g. Schönborn, 2005) that learners' failure to interpret models may be a result of the lack of VSs required to process ERs. This problem is compounded by the fact that experts often have a naïve assumption that what they refer to as good teaching and learning tools will actually be effective for novices (Schönborn & Anderson, 2006). Also, experts assume that learners do not need to be explicitly taught the necessary VSs to interpret ERs such as animations, but will simply develop them informally through "osmosis" (e.g. Schönborn & Anderson, 2006). However, a large volume of recent research has suggested that this is not always true (e.g. Seufert, 2003; Sims *et al.*, 2002).

In line with the above observations, it has been widely suggested that serious action be taken to assist learners with acquiring VSs (e.g. Schönborn & Anderson, 2006). One way of achieving this may be through the introduction of "formal visual literacy programmes" in all scientific academic curricula. However the problem is that in terms of the MLS, an operational definition for visual literacy remains unclear. Therefore, there are no criteria that may be used to measure an individual's level of visual literacy. In this regard, the overall aim of this research is to define the levels of visual literacy through the use of a taxonomy specific to the MLS.

To guide such a study, it is important to highlight a few suggestions regarding learning and teaching that shape the current author's view of the current status of visual literacy and how it can be improved. According to Grow (1996), concept communication can be argued to be the primary objective of teaching and learning science. During learning, the learner is subjected to new information, which is presented in various forms, such as text, diagrams and animations (Pearsall, 1999; Russell, 1999; Allen, 1990). Information acquisition requires that the source of information must allow the learner to engage in an active manipulation of information. It has also been highlighted that the manner in which information is presented through ERs, should be of a nature that aims to improve learner involvement and hence information comprehension (Russell *et al.,* 1997). In this regard, various researchers (e.g. Dori & Barak, 2001) have suggested that some sources of information (e.g. some textbooks) are not effective teaching and learning tools. As a result more ERs are being developed with which to present information.

In addition to the above, Russell *et al*. (1997) have also indicated that visual literacy is a critical determinant of learners' ability to mentally comprehend, process and reproduce ERs. In this instance, to the current author's knowledge there is no standard – universal – definition for what is meant by "visual literacy". With regards to the MLS, it has been observed that, like other intelligences (Gardner, 1983), visual literacy is multifaceted in that it is context-based and depends largely on the degree of knowledge and experience the viewer possess in relation to the ERs (Healey, 2005).

The literature also highlight that there is a "cognitive effort" that is applied to processing ERs (Healey, 2005). This means that some ERs require more cognitive effort than others, but this varies with people's concept knowledge and experience. In addition, different cognitive mechanisms are involved in visual literacy (Mayer, 2001). In some cases, short term memory (STM) plays a dominant role, while in others visualization is dependant on long term memory (LTM). The type of mechanism often depends on other factors that also influence the process such as, social domain and age (e.g. Burton, 2004; Bloom, 1956).

In the MLS, not much has been done to measure individuals' level of visual literacy, presumably because of the lack of understanding of how such a task can be performed. In this regard, a clear framework of what happens during the visualization process is required. Such a framework would outline what components of visual literacy can be measured and how are they related to other cognitive processes. At the same time, the facets of visual literacy could assist in determining how to measure the "degree of visual literacy" for an individual.

A survey of the current literature reveals that visual literacy is indeed “a literacy” in its own right, that can be learned and improved (e.g. Bamford, 2003; 21st Century Literacies, 2002). Nonetheless, it is not always clear as to how this can be achieved, particularly in fields such as the Biochemistry where little research has been done to understand visual literacy.

1.2 Specific aims and objectives of the research

The current research will aims to untie this deadlock by first formulating a clear framework of what the potential components of visual literacy could be, followed by proposing a process-based definition of the nature of visual literacy. This in turn, will allow the formulation of a taxonomy of visual literacy for the MLS that can be used to measure learners’ degree of visual literacy as a foundation for planning ways to improve visual literacy.

Given such a taxonomy of visual literacy for the MLS, it is suggested that it may aid educators in identifying the level of visual literacy a learner may possess, in relation to the learner’s level of conceptual understanding. In this way, educators and scientists will be able to develop and use models that fit a particular learner’s level of visual literacy and cognitive abilities. Overall, defining visual literacy would contribute significantly to the field as it may decrease learning difficulties associated with visual literacy in the MLS.

In an attempt to fulfil the aims of the research, the following specific research questions will be addressed:

- What is the nature of visual literacy in MLS?
- Can specific levels of visual literacy be defined in the MLS?
- Is a taxonomy a useful way of representing the levels of visual literacy for MLS?

1.3 Addressing the research questions

To address the research questions the present researcher followed the research process outlined in Figure 1.1.

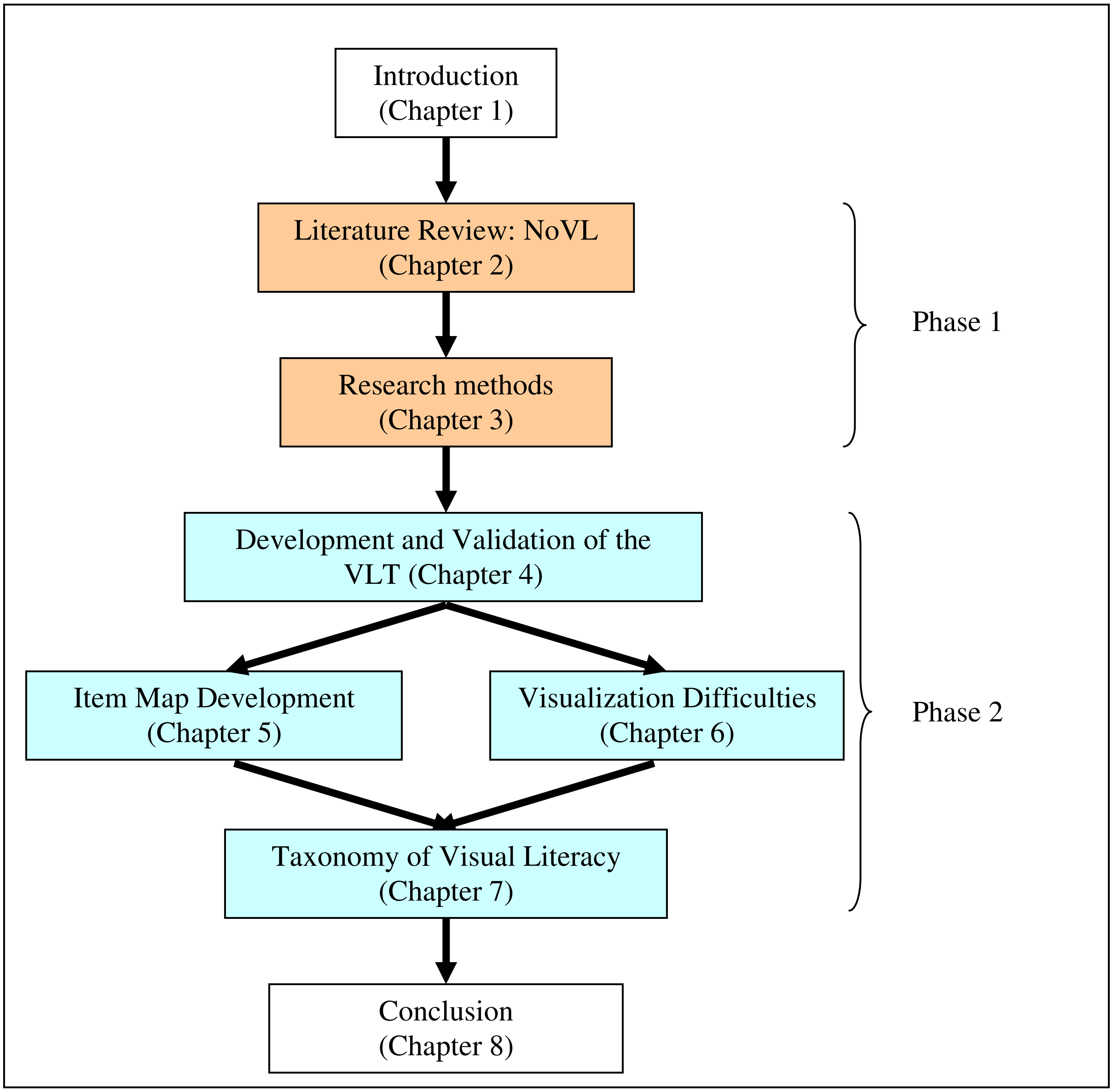

Figure 1.1: An outline of the thesis

As shown in Figure 1.1, the work presented in this thesis is divided into two phases. The first phase constitutes a literature review where relevant papers are analysed and relevant information synthesized in order to define the NoVL (Chapter 2; see Figure 1.1). Information obtained in this phase is verified in the second phase where instruments are designed to probe the critical questions given above (Figure 1.1).

Given that not much is known about the NoVL in the MLS, using the literature review, research methods relevant to the current study are developed and given in Chapter 3

(Figure 1.1). Thereafter, the literature (Chapter 2) is used to identify VSs and to formulate probes for the visual literacy test (VLT) (Chapter 4; Figure 1.1). In the same Chapter, the test is validated and the results presented. Following this, the author provides results obtained using the VLT to develop an Item Difficulty Map (Chapter 5) as well as identifying the nature of visualization difficulties (Chapter 6; Figure 1.1). Using results from these Chapters, in Chapter 7, the author develops a taxonomy of visual literacy for the MLS and then provides a general discussion in Chapter 8 (Figure 1.1).

2. Chapter 2: Literature Review: Characterizing the Nature of Visual Literacy

2.1 Introduction

The literature does not contain one single, well-accepted description or definition on what constitutes and characterizes the NoVL. For example, researchers define visual literacy in different contexts and in relation to different stages of visualization. Some definitions focus on the extraction of information from ERs (Velez *et al.*, 2005), others focus on mental processing (Bamford, 2003) yet anothers focus on the production of ERs (Burton, 2004). ERs can be defined as any form of external visual models that are used to represent scientific concepts (Schönborn & Anderson, 2006). ERs can include, amongst others, diagrams, animations and pictures (e.g. Dunsworth & Atkinson, 2007). For the purpose of this review, the term "external representation" (ER) will be used to define all these sorts of representations. In contrast, non-ERs will be referred to as "mental" models due to the current lack of a full account of how exactly knowledge is coded in the memory system (Thompson, 1995). For instance, computers store information in the form of binary code (Cazzola *et al.*, 2004), textbooks store information in the form of written words, and diagrams store information in the form of graphics and visual icons. Evidence suggests that the human memory stores information either coded as auditory, visual or semantic codes. However, how this information is exactly coded, continues to be an important area of research (e.g. Butcher, 2004; Mrchev *et al.*, 1999).

In order to address the research questions stated in Chapter 1, particularly research question 1, i.e. "what is the nature of visual literacy in MLS?", this literature review will give an indication of:

i) The importance of visual literacy,
ii) The nature of ERs,
iii) The nature of visual literacy (NoVL), and,

iv) How to design an instrument for measuring visual literacy.

The following sections provide a detailed account with respect to the above areas.

2.2 Importance of Visual Literacy

Information communication is the key in science research and development. The learning process is a crucial part of this as it ensures the transfer of knowledge from one individual to the next. A number of researchers have explored the learning process and the development of knowledge (e.g. Dunsworth & Atkinson, 2007; Mayer, 2003; Moreno & Mayer, 1999; Clark & Paivio, 1991). These processes have strong links to literacy education such as the teaching of reading and writing of linguistic words (verbal literacy) and of diagrammatic representations (visual literacy) (Moreno & Mayer, 1999). In science, literacy skills are often seen as a prerequisite for understanding the scientific world.

The literature has raised a number of issues concerning visual literacy. One issue surrounds defining, as well as measuring visual literacy (e.g. Sims *et al.,* 2002). Regarding current definitions for visual literacy, most are yet to be confirmed and agreed on by way of international consensus (e.g. Sims *et al.,* 2002). Concerning research in visual literacy, little has been done to understand it in the context of MLS. However, ERs are a critical component of visual literacy, regardless of the context. Thus, while looking at the importance of visual literacy, one cannot ignore the importance of ERs.

ERs play a critical role in science education as a means of communicating, representing and clarifying abstract scientific concepts (Dunsworth & Atkinson, 2007; Dori & Barak, 2001; Russell *et al*., 1997). Nonetheless, there are some learning difficulties associated with the use of such models. For instance, in abstract sciences such as in the MLS, there is no strict adherence to model conventions since many of the concepts are investigated at the sub-microscopic level (e.g. Schönborn & Anderson, 2006). This inconsistency among external models has been highlighted by a number of researchers (e.g. Schönborn & Anderson, 2006). For example, these authors have shown that a disulphide bond in a protein is represented in textbooks in multiple ways including, amongst others, "–S-S-", a straight black line or a yellow "bar" (Schönborn & Anderson, 2005; 2003). Due to this lack of consistency, and the added complexity of the visualization tool itself, learners may fail to interpret models in the way instructors or textbooks authors expect. In this regard, Schönborn and Anderson (2005) have suggested that a world-wide discussion is needed so that a "visual nomenclature" for the molecular sciences can be implemented and standardized. A possible consequence of such an intervention will be the elimination of idiosyncratic conventions, which will lead to less confusion amongst students. Alternatively, sometimes (but not always) less complex models (e.g. Figure 2.1) provide more emphasis on the critical points of the concept being depicted rather than complicating a relatively simple concept with extraneous detail. In this regard, figure 2.1 shows how different sections of the cell's DNA can be represented. These can be represented as individual ERs or holistically as shown in the figure.

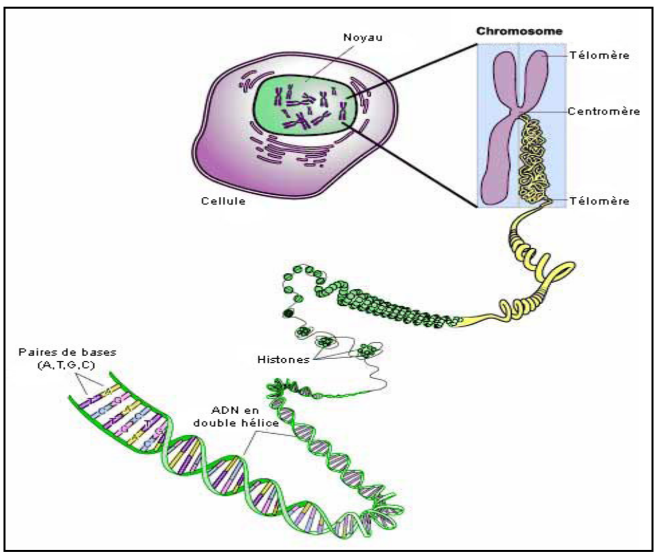

Figure 2.1: An ER showing a model of the organization of DNA in a cell[2]. The Model indicates subsections of a cell and how these combine to form a single cell unit.

In the MLS, concepts are often presented using models that depict a section of an overall model while others depict the entire concept holistically (e.g. Figure 2.1)**.** If not designed or presented appropriately, learners may fail to integrate such models effectively (Schönborn & Anderson, 2005; Russell *et al.,* 1997). In such cases greater conceptual

[2] http://www.chemsoc.org/exemplarchem/entries/2003/imperial_Burgoine/cell-DNA.jpg

knowledge and/or VSs are required to interpret the model. As a result of such demands, visual literacy becomes a critical component of the interpretation of ERs.

As informative as “models” or ERs may be for assisting students’ learn of abstract concepts, if they fail to effectively transfer the information which they are designed to, then they are probably not very useful teaching tools. In addition, research (e.g. Dunsworth & Atkinson, 2007; Mayer, 2001) shows that the lack of visual literacy amongst learners can lead to learning difficulties such as conceptual, visualization and reasoning difficulties, which could have a serious negative impact on the construction of new knowledge. To alleviate this problem, teaching learners the necessary VS could be one way towards improving the acquisition of knowledge (Aanstoos, 2003). Hence, it is crucial that the understanding of visual literacy be contextualized for disciplines such as the MLS. To do this however, it is important to first define the nature of ERs (NoER) and how this affects visual literacy.

2.3 The nature of External Representations

Another determinant of visual literacy is the NoER. Here the manner with which models are designed has an influence on visual literacy. To understand the NoERs, it is imperative to first look at the different types of models and what makes a good model.

2.3.1 Types of External Representations

Cartier *et al.* (2001) suggests that there are five common ERs, namely, conceptual models, mathematical models, statistical models, physical models as well as visual models. Conceptual models are textual qualitative models that highlight important connections in real world systems and processes and are used as a first step in the development of more complex models (Cartier *et al.*, 2001). Mathematical (Hameka, 2004) and statistical models (Dacarli, 1989; Gilchrist, 1984) are related in that they use formulae and numerically based approaches to represent information externally. Mathematical models are developed and expressed mathematically by solving relevant equations of logical systems over time or space (Hameka, 2004). Statistical models are used to characterize systems based on their statistical parameters such as the mode, median or mean and are used to define patterns and relationships between numerical data sets (Gilchrist, 1984). Physical models are observable and can be physically manipulated and have characteristics similar to the real system that is being represented (Pederson, 2004; King, 1996). Physical models are especially useful for defining and representing the real world. Visualization models are used to represent and visualize structures, systems and processes and are often externalised on the page or screen (Cartier *et al*., 2001). Examples of such models include diagrams, pictures, animations, and 1-D and 2-D graphics (Schönborn & Anderson, 2006). These models differ in their external representation and use of conventions and colour and are often used by instructors, textbooks and electronic resources to explain and represent complex scientific concepts.

All the ERs presented above are used to represent scientific ideas that describe structures, processes and/or events. In addition, such models can be used both as explanative and/or predictive tools (Schönborn & Anderson, 2006). For instance, a model of the structure of a bacterium can be used to study different structural components such as membranes and chromosomal organisation. With respect to this example, it is important to note that such a model can be simplified or made more complex. For instance, if teaching about the membrane structure of a bacterium, the model used may not include or show the cytoplasmic proteins that the bacterium may contain. So, the elimination or insertion of desired aspects of the represented concept is done to simplify models, or to make them more complex, depending on the context and instructional goals (Schönborn & Anderson, 2006). Ultimately, any model is only a representation of one aspect of the scientific phenomenon that is represented (Wastelinck *et al*., 2005).

Due to the dynamic nature of science, models are consistently developed on the basis of current empirical knowledge and therefore interpreted on the basis of an individual's conceptual knowledge. As science progresses, models that do not satisfy the interpretation of the current scientific understanding in the world are discarded or revised until they fit current world views (Dori & Hameiri, 2003). Therefore, models also play a major role in shaping the direction of future research and play a large part in defining the philosophy of science. Because of these continuous changes, visual literacy then becomes a changing field, where learners have to be able to work with and generate models that will satisfy the understanding of scientific knowledge as it progresses.

One of the changes in the scientific world has been the increase in the use of dynamic models to represent phenomena (Dunsworth & Atkinson, 2007; Kelly *et al.*, 2004). One reason for the popular use of animations is that they can depict situational dynamics explicitly (Kelly *et al.*, 2004). For instance, some research has shown that for learning biomolecular process, animations are better teaching tools when compared with static diagrams or text alone (e.g. Dunsworth & Atkinson, 2007; Mayer & Moreno, 2002; Mayer 2001). Furthermore, if properly utilized, animated visuals allow learners to build coherent and high quality mental models of complex processes of change (Kelly *et al*, 2004). As a consequence, animations which are interactive, allow learners to select and control the presentation of information, based on the required task at hand or on the information that is communicated by these ERs (Dunsworth & Atkinson, 2007; Lowe, 2004; Mayer & Moreno, 2002).

With respect to representing dynamic situations such as molecular processes, static depictions do not have the power to show transitory change (e.g. Lowe, 2003). Therefore, learners are required to infer the situational dynamics themselves, a process which is often cognitively demanding. The resulting processing burdens may be relieved though when the information is presented dynamically through the use of animations. However, much research (e.g. Lewalter, 2003; Lowe, 2003), has shown that the apparent superiority of dynamic ERs over static ERs cannot solely be due to differences in the cognitive or computational properties of the two forms or presentation. In fact, researchers (e.g. Dori & Hameiri, 2003) have shown that animations can actually cause learning difficulties because of factors such as a lack of visual literacy. Therefore, contrary to common assumptions, animations are not *always* superior to static graphics for conveying scientific content (Dunsworth & Atkinson, 2007; Lowe, 2003; 1993).

As effective and infallible as animations seem to be, they can also pose potential problems for learners. For instance, Reinmann (2003) has shown that difficulties can sometimes be caused by the animation itself (i.e. poorly designed animations) and difficulties can sometimes be caused by learners or instructors when they fail to visualize and/or extract the relevant information from the animation efficiently. With respect to the MLS, research shows that such failures could be caused by a lack of VS amongst learners (Schönborn & Anderson, 2006).

The external graphical changes that are involved with animations can also be a source of difficulties for many learners (Lowe, 2004). For example, animations can undergo transformational changes which involve alterations in graphical entities with respect to factors such as size, shape, colour and texture as well as translational changes. Such transformational changes may also involve the movement of whole entities, from one location to another (Lowe, 2003). At the same time, animations can also display transitional changes, with entities, or parts of them, entering and departing from the display over time (Lowe, 2003). Such external changes put a cognitive burden on students which can result in the animation being "overwhelming" (Lowe, 2003), which can actually decrease students' engagement with the animation. The alternative is also true, where a lack of transitional changes in an animation may be "underwhelming" Lowe, 2003). Therefore, such changes may have implications for visualization that are not often a characteristic of processing static diagrams (Lowe, 2004), which makes animations that much more complicated to understand (Dunsworth & Atkinson, 2007).

Given the associated processing complications of learning with dynamic ERs, it is clear that for such models to be effective in conveying scientific messages, the nature of the model should allow learners to use available skills to visualize the model. As a result, in the next section the author looks at the characteristics of a good model.

2.3.2 Characteristics of good ERs

Scientific knowledge in the MLS is often dominated by the use of ERs (Schönborn & Anderson, 2006). Such models are used to teach with; as a result educators tend to solicit learners to produce similar ERs as a means of assessing the learners' conceptual understanding (Schönborn & Anderson, 2006; Seufert, 2003). Often, learners' understanding of concepts will be based on their ability to represent concepts as ERs because most educators only rely on their understanding of the concept or the textbooks depiction of the concept (in a visual format) as a guide to evaluate the learner-produced ERs. A number of researchers (e.g. Webb, 2001) have nonetheless provided guidelines for modelling, particularly for use in Biology and other related fields. Hence, the current author reviews these guidelines as they may be used to determine whether an individual can produce good ERs acceptable to science educators in the field or not, and not only rely on the individual's ability to "mimic" accepted ERs that occur in textbooks.

An initial feeling about models is that there should be a relationship between the real target which is being modelled and the representation of the target (Webb, 2001). Many authors suggest that, where possible, the model should be an acceptable representation of reality (e.g. Hughes, 1997; Lamb, 1987). This makes learning in MLS difficult because "abstract concepts" are often represented through "abstract ERs" (e.g. Figure 2.1). Nonetheless, a good ER would be descriptive so that it clearly and objectively describes the nature of the concept it represents. At the same time, such a model when perceived by a second person, should clearly display the nature of the concept it represents. Therefore the readability of ERs is a critical feature of any model. Furthermore, models can not communicate knowledge unless the viewer draws his/her attention to the model and poses questions which will add a new understanding of the concept to the next level (Dori & Barak, 2001).

Looking at the MLS where microscopic concepts are represented, the power of ERs to convey scientific knowledge relies on the models resemblance of the true situation it represents. This is in line with Rosenblueth and Wiener's (1945) suggestion that "the best model of a cat is another, or preferably the same, cat" p.316). As a result, a good model would be simple enough to capture the entire relevant dimension without compromising the opportunity of serendipitous or creative insight[3].

[3] http://www.idiagram.com/ideas/models.html

Given the above, there are three factors that contribute to one's ability to produce ERs i.e. accuracy, realism and clarity. In this regard, the accuracy of an ER refers to the model's resemblance of the original (either external or mental) system. Realism refers to a model that reflects the original system in its true nature. Clarity of an ER defines its ability to be comprehended and reproduced. Moreover, processing visual information requires the collection of a number of components of intellect. For instance, visual literacy is often context-based; i.e. the ability to ascertain information from a diagram representing DNA replication will require knowledge about components of such a process, its spatial arrangement and so on.

Given the importance of visual literacy and the NoER, the next section will focus on the NoVL. This will include the process of visualization i.e. how are ERs processed in the human cognitive system. Such understanding will be used to determine the NoVL for the MLS.

2.4 Nature of Visual Literacy

To understand the NoVL, it is important that one looks at the theories of learning and visualization in relation of knowledge comprehension and production. This will direct our thinking in terms of what makes a person visually literate or otherwise. After that, the author will look at the different stages of visualization. Understanding theories and the process of learning as well as the stages of visualization will provide understanding of the NoVL.

2.4.1 Theories of learning and acquisition of visual literacy

A number of theories have been put forward to define learning processes. Some of these theories have been shown to be applicable to various forms of learning including visual literacy (e.g. Mayer, 2001). One of these theories suggests that visualization is a cognitive process that involves a number of mental processes (Mayer, 2002). As explained by Mayer's (2003) cognitive theory of multimedia learning, during the visualization process, external pictures first enter the cognitive system through the eyes

(Figure 2.2). The viewer then attends to some aspects of the picture which leads to the construction of a mental pictorial image within WM. Following subsequent construction of mental images, the viewer arranges the set of images into a coherent mental representation called a pictorial model (Figure 2.2). The process involves the selection, organisation and integration of images and is commonly referred to as visuo-spatial thinking (Figure 2.2; Mayer, 2003).

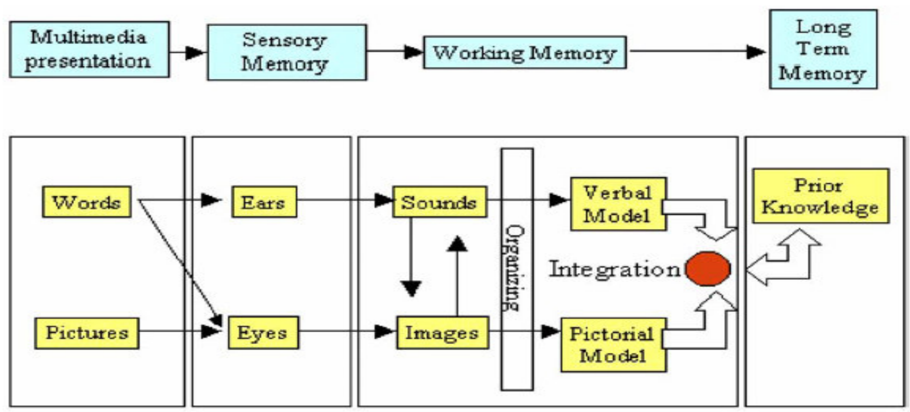

Figure 2.2: An illustration of the cognitive theory of multimedia learning (adapted from Mayer, 2003).

Mayer's (2003) cognitive theory of multimedia learning is related to a constructivist epistemology of learning (e.g. Mayer & Moreno, 2002). According to constructivism (Figure 2.3), viewers actively develop their own understanding of the way the world works, rather than having such understanding delivered to them passively (Thompson, 1995; von Glasersfeld, 1995). Such an outlook requires viewers to be active participators in the visualization process, rather than merely "absorbing" the information presented to them in its "entirety". As part of this process, interaction with the environment is a critical component during the learning process. When presented with visual information that is new to them, viewers select and transform the information, construct hypotheses, and make decisions, based on an already existing cognitive structure (Thompson, 1995, also see component 2 on Figure 2.3). The selection process (Figure 2.2) is a critical one, because viewers will select information which they believe is correct and is the easiest to comprehend and manage mentally (Thompson, 1995). In general, most viewers will tend not to explore complex information immediately but instead will first opt for readily available knowledge (Thompson, 1995).

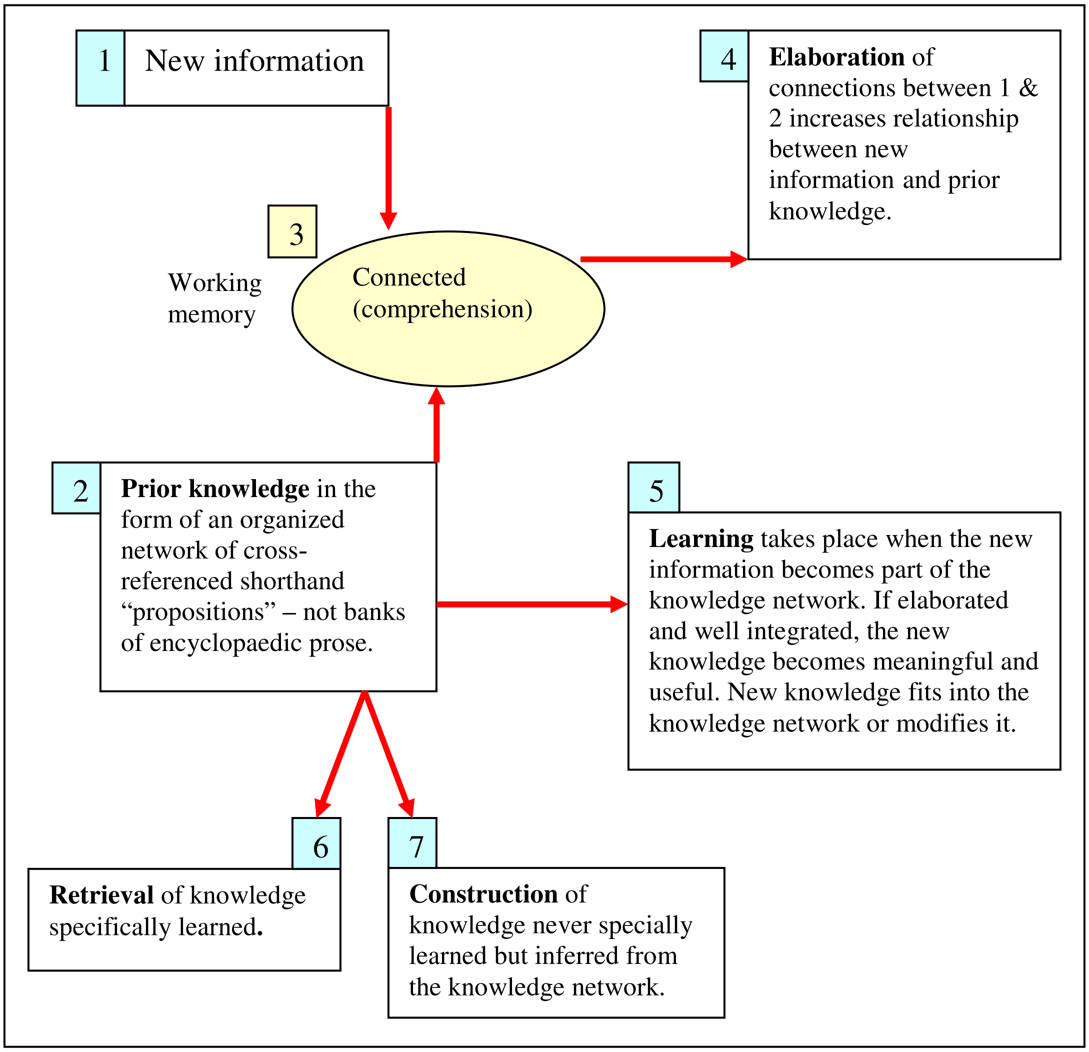

Figure 2.3: An outline of the learning process according to the theory of constructivism[4].

Once certain segments of the external information have been selected, viewers transform it to storable mental forms (see component 5 on Figure 2.3). They do so by constructing hypotheses, from which cognitive judgements and decisions are made concerning the soundness of the forms of information which they have selected (Thompson, 1995). Following this, newly constructed information is memorized and stored in the LTM for

[4] http://www.longleaf.net/ggrow

future use (Figure 2.2). Therefore, after mentally processing new information, viewers construct new forms of information based on already existing knowledge. This knowledge is represented in the form of schema and mental models of information (see component 7 on Figure 2.3) (Thompson, 1995).

Mayer (2003) suggests that visual information can only be processed once such information has been properly *perceived.* Another claim stated by Wileman (1993) suggests that visual literacy involves "the ability to 'read' information presented in pictorial or graphic images" (p. 114). Hence it can be concluded that visual literacy involves seeing and comprehending information from ERs as the first step of visualization.

Once information has been comprehended from such ERs, the information enters the mind where *organising* occurs (Mayer, 2003). According to Bamford (2003), visual literacy involves discriminating and making sense of visual objects and images. Other authors (e.g. Wu & Krajcik, 2006) suggest that visual literacy involves the ability to analyse and interpret images. In this instance, the analysis process would require prior knowledge of the same or different subject matter. Hence, the constructivist theory's argument of reliance on an already existing cognitive structure to construct hypotheses and mental schema is plausible (Thompson, 1995).

Once visually represented information has been perceived, selected and then integrated into prior knowledge, new mental schemata are then constructed (Thompson, 1995). This can only be achieved if the ER can be mentally processed and recognised by the viewer (Burton, 2004). Again, understanding new visual images depends on existing knowledge. However, there are cases where individuals do not perceive new information but immediately respond by producing new ERs. For instance, other people will depend largely on prior knowledge, and not on new information for them to create new models. In this case, the new models created are entirely a cognitive product and *begin* as human imaginations (Gnoinska, 1998).

ERs can be produced after being formulated through mental processes. A number of researchers agree that visual literacy involves the production of new visual images (e.g. Burton, 2004; Brill *et al.,* 2000). According to Burton (2004), a visually literate person is able to make ERs. Furthermore Brill *et al.*, (2000) add another component to visual literacy by suggesting that the assumption underlying a concept of visual literacy is that "images communicate meaning" (p. 9). These researchers look at the production of ERs with the aim of communicating concepts. In this manner, it is not enough for an individual to be able to comprehend and make sense of images to be referred to as visually literate, but also, they should be able to communicate their thoughts using ERs (Brill *et al.*, 2000). Communicating one's thoughts through ERs can include drawing on paper, generating ERs on a computer, manipulating ERs with software tool and manipulating an ER externally.

Components of visual literacy can be seen through elaborating on Mayer's (2003) theory of multimedia learning (Figure 2.2) which indicates that there is a distance (the measure of which is another mystery) between the point of visual perception and the point of mental processing the perceive information as well as the point of expressing one's knowledge in the form of visual images. In other words, processing visual information is a process that takes place in different organs (e.g. eyes and hands) through transmission of information or stimuli. These points are separated by several activities that take place in between, i.e. selection, organizing etc., which are facilitated mainly in the WM.

While an explicit definition of visual literacy is unavailable, based on literature, the current study adopts that visual literacy involves the ability to:

- accurately perceive visual information (Greater Washington Educational Telecommunications Association, 2004)
- extract meaningful information from an ER (e.g. Velez *et al.*, 2005)
- understand and produce visual messages (Aanstoos, 2003; 21st Century Literacies, 2002; Mayer & Moreno, 2002)
- construct meaning from visual images using cognitive skills (Swenson *et al.*, 2005; Bamford, 2003)

Given the above, in the next section the author looks at the stages of visualization and how they can be used to define the NoVL.

2.4.2 The stages of visualization

In order to describe the NoVL, it is important to explore all the possible stages that affect the development of visual literacy. According to current and popular theories of learning and visualization such as constructivism and the theory of multimedia learning (Mayer, 2003; 2001; Figures 2.2.and 2.3), the manner in which viewers perceive ERs may differ from one individual to the next (Healey, 2005). As suggested by constructivist theory, constructed mental models are unique to each individual (Thompson, 1995). Nonetheless, all the cognitive processes involved in the creation of such mental models are similar across all individuals (Mayer, 2003). Because of this similarity, it is possible to generalize the theoretical process of visualization (Figure 2.4). Such a process will be framed on the two theories of learning i.e. the constructivist theory and the theory of multimedia learning.

According to Mayer's (2003) cognitive theory of multimedia learning and the constructivist theory (Thompson, 1995; von Glasersfeld, 1995), learning from ERs involves "perception" as a first step of processing visual images (Figure 2.4). Furthermore, Burton (2004) suggests that the process of visualization also involves, as major steps, "visual imagery", "integration" and "production" of ERs as a means of expression (see Figure 2.4). In this instance, "*Visual perception* is the way the eye and brain work together to "take in" information about the outside world and make our visual experiences meaningful, whereas *Visual imagery* are the actual 'pictures in the head', which is concerned with the way individuals process information and recreate images in their mind's eye (Figure 2.4; Burton, 2004). *Integration* involves mainly the revision of new mental models until the desired model or understanding is obtained and ready to be communicated (Burton, 2004; Figure 2.4). *Visual communication or production* is transmitting (generating ERs) and receiving ideas purely by visual means" (Burton, 2004, p. 3; Figure 2.4). In the following sections we explore each one of these stages (See Figure 2.4) in more detail.

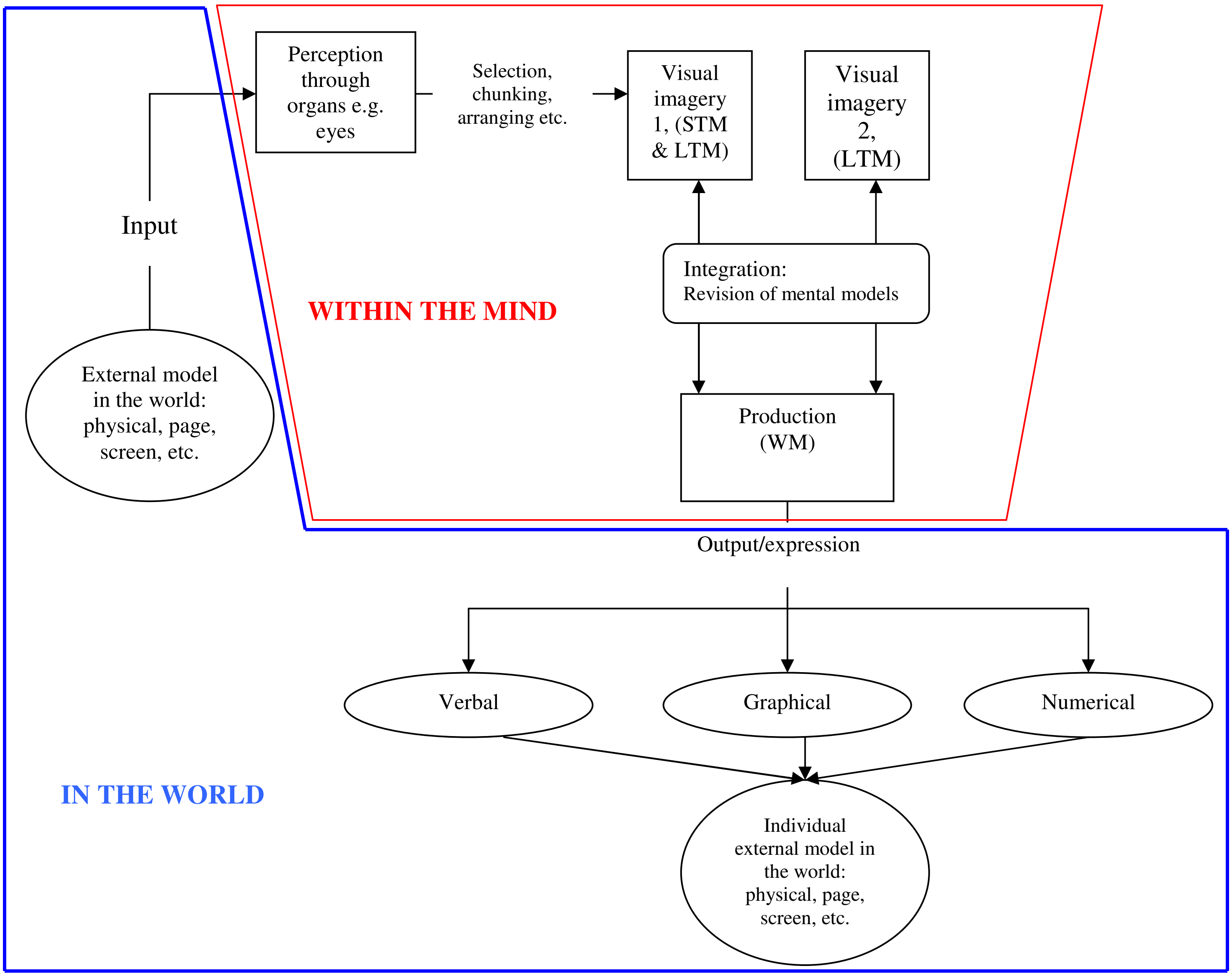

Figure 2.4: A theoretical framework of the process of visualization.

2.4.2.1 Perception

According to researchers (e.g. Healey, 2005) not everything we see is always "fully" processed by the WM, be it extracted from dynamic or static models (Zhou & Feiner, 1998). In other words, there is a time-gap between the time when information is perceived (seen) to the time when it is cognitively processed in the WM during which cognitive processes such as selection, rearranging and so on take place (Figure 2.4). This has led to the suggestion that there are at least three levels of perception, viz. low-level, middle level and high-level perception (Healey, 2005; van Schoren, 2005). Researchers propose that low-level perception involves mainly feature extraction whereas high level perception involves concept formation, a cognitively demanding process highlighted greatly by the involvement of the working memory (Healey, 2005). Middle-level perception on the other hand is, feature integration into mental representations of perceptual organizations and high-level perception is functionality of perceptual organizations and their interaction with memory and knowledge (Healey, 2005; van Schoren, 2005).

2.4.2.1.1 Low-level perception without cognitive effort

Expanding on the idea of low-level perception, Healey (2005) suggests that it involves preattentive visual tasks. Preattentive tasks are those that require little cognitive effort to perform and include target detection, boundary detection, region tracking and counting and estimating (Kawahara & Yokosawa, 2001). Such tasks are for instance, performed when one tracks the presence or absence of a particular item, when one detects the different texture boundaries between different items, when one detects the unique visual element on a background and when one estimates the number of items that contain a unique feature (Healey, 2005). Further explanation of the preattentive tasks is given by the Texton theory (Julész, 1981a), which states that every visual image is made up of small elements called textons which are detected during preattentive perception (Julész & Bergen, 1984; Julész, 1981a; Julész, 1981b). Detection of these textons can be measured by the response time and accuracy (Treisman, 1991). Such a measurement could be obtained through asking the viewers to "complete a task (e.g. target detection) as quickly as possible while still maintaining a high level of accuracy" (Healey, 2005).

Experimental evidence has also shown that performing preattentive tasks precedes focused attention (Healey, 2005). This is informed by a finding that eye movements take about 200 milliseconds (Stevenson & Roorda, 2005) to initiate detection and related to this, preattentive tasks can be performed "in less than 200 to 250 milliseconds" of viewing the image (Healey, 2005). In this regard, preattentive tasks are performed in parallel with eye movements and with little or no effort to analyse them in the working memory. A similar MLS's scenario would be when students are asked to point out different molecular structures based on, for instance, shape, colour or size.

It is thus plausible that a visually literate person is able to perceive information from a given visual source before analysis in greater detail is required. Nonetheless, there is a difference between the rates it takes individuals to perceive information (Stevenson & Roorda, 2005). At the same time, the accuracy of perceiving such information is an interesting question to explore. One can argue that, experience and skill can improve one's ability to perceive information in a short space of time but with a fair amount of accuracy (Healey, 2005). In other words, the current author will include skill and experience to formulate levels under the stage of perceiving of models without cognitive analysis of such. However, such levels would be context based, for instance, experience would be in a specific field of study and ERs used will be of the same field. In this regard, experience with still diagrams may not reflect the ability to perceive information in motion ERs.

Nonetheless, from an educational point of views, the ability to perform preattentive tasks may be a reflection of individuals' ability to visualize concepts. This is because some learners spend little effort reading ERs and hence apply little cognitive effort to understanding such ERs. At the same time, the ability to perform such preattentive task may minimize the cognitive energy required to interpret ERs giving the learner more energy for subsequent tasks (Cooper, 1990).

2.4.2.1.2 High-Level perception of information from dynamic ERs

Related to the above, high-level perception begins when *cognitive effort* is being applied to interpret and make sense of the visual information (van Schoren, 2005). During this stage of visualization, more attention is given to the ER and more time is taken to extract information from a more complex environment and organize it into mental representations (Chalmers *et al.*, 1991). The performance of these tasks is referred to as post-attentive and is involved in the interpretation of all static ERs (Healey, 2005). This leads to the question of whether there is a difference in the way static and dynamic ERs are perceived with regard to pre- and post attentive tasks. This is because, in the MLS, dynamic models are often used to communicate concepts such as biomolecular processes.

Concerning dynamic visualization, researchers suggest that motion stimuli can be classified into first-order stimuli and second-order stimuli (e.g. Baloch *et al.,* 1999). In first-order stimuli, the moving configuration is characterized only by luminance over time whereas in the second-order stimuli the motion stimuli is characterized by a number of factors including contrast and texture (Cavanagh & Mather, 1989; Chubb & Sperling, 1988). Unlike first-order stimuli, second-order stimuli display no difference between the luminance of the objects, so luminance can not be used to discriminate between them (Baloch *et al*, 1999). Hegdé *et al.*, (2004) have suggested that second-order stimuli are critical for transmitting information about the relative depth of overlapping surfaces e.g. depth cues. The ability to detect both the types of stimuli is very important in visual literacy as it determines an individual's ability to perceive items as they appear relative to the background.

With regard to dynamic ERs, the question of presentation speed can not be disregarded. This is because research has shown that viewers may find it difficult to perceive information from a model because they can not cope with the pace at which concepts are presented (Mayer, 2001). In this regard, Mayer's (2001) "Interactivity Principle" of Multimedia Learning suggests that deeper learning occurs when learners are allowed to control the presentation rate. Mayer's (2001) Interactivity Principle argues that such animation presentation improves learning because it allows learners to activate their cognitive processes at their own rates and this reduces chances of cognitive overload (Dunsworth & Atkinson, 2007; Whelan, 2007; Robinson, 2004; Mayer, 2001). The ability to detect speed plays a significant role in visual literacy especially with regard to dynamic visuals as it allows learners to perceive what is shown on the background clearly and be able to comprehend information as required.

As a result of the information provided by dynamic ERs, it is clear that once cognitive functionality has been included in the processing of perceived information (post-attentive), a number of features can be used to characterize the manner in which people visually perceive information. For instance, there is a likelihood that an individual may be able to recognize a first-order stimulus (characterised by luminance) but not a second-order stimuli or vice versa. For instance, some students in MLS may be able to differentiate symbolism based on colour and not texture, e.g. cellular organelles that have different colours but quite similar texture and shape such as the mitochondrion and the chloroplast. Such distinguishing of symbols may be based on the persons experience and skill with the given task. At the same time, the ability to recognise differences between rates at which a dynamic ER "runs" also can not be disregarded. Furthermore, the ability to recognise items in motion ERs that are presented at different speeds is another element of visual literacy. Added to this, is the potential factor of a static and/or dynamic background. Altogether these factors can be used to characterize visual literacy at the perception stage (Figure 2.4) as they define one's ability to visualize models at the perception stage.

Once ER-presented information has been "correctly" perceived, it is then transferred to cognitive structures for further processing in order to provide sound "meaning" to what was perceived. Overall, the accuracy of the mental schema that is constructed from perceived information relies heavily on the precision with which the information is perceived.

2.4.2.1.3 Post – attentive cognitive processing of ERs

A number of researchers have proposed the manner in which humans process ERs in their cognitive systems. For instance, Koedinger and Anderson (1990) highlight that during "chunking" of information, learners organize pieces of information into coherent patterns called chunks (Koedinger & Anderson, 1990). This chunking may be followed by selecting and rearranging of information (e.g. Mayer, 2001; Figure 2.2). Furthermore, Healey (2005) suggests that this occurs soon after the preattentive task performance and is characterised by increased attention given to the ER. At this stage, a number of activities occur. These include selection, rearranging and chunking (Mayer, 2001; see Figure 2.2). In this regard, it is important to understand what happens once images have passed the visual organs.

A set of principles, known as Gestalt principles, have been developed to account for the manner in which ERs are processed cognitively during the post–attentive stage (Behrens, 1984). With respect to the Gestalt argument, amongst others, there are four main factors that determine how humans "chunk" information (group things according to visual perception), namely, proximity, similarity, closure and simplicity (Figure 2.5). During and after the categorization of information as per Gestalt principles, such information also undergoes processing as defined by other theories of learning such as the constructivist theory of learning. Hence the Gestalt principles can be used to account for the way viewers cognitively perceive and respond to ERs during the post – attentive stage.

The *closure* principle suggests that our minds tend to complete figures even in cases where information is missing (see A in Figure 2.5). The principle of *proximity* (also referred to as the principle of *contiguity*) suggests that when visual features are placed closer to each other, they are perceived as belonging "together" (see B in Figure 2.5; Mullet & Sano, 1995). As a result, when integrated with prior knowledge, such items, depending on how close are they to each other, are grouped as a "group" by the visual system. According to the *similarity* principle (see C in Figure 2.5), items that have commonalities such as shape, size, colour, texture and orientation are often grouped as belonging together (Mullet & Sano, 1995). Finally, according to the *simplicity* principle, items are grouped together according to symmetry, regularity and smoothness (see C in Figure 2.5). All these principles reflect the behaviour of the cognitive system towards new visual information that has been perceived.

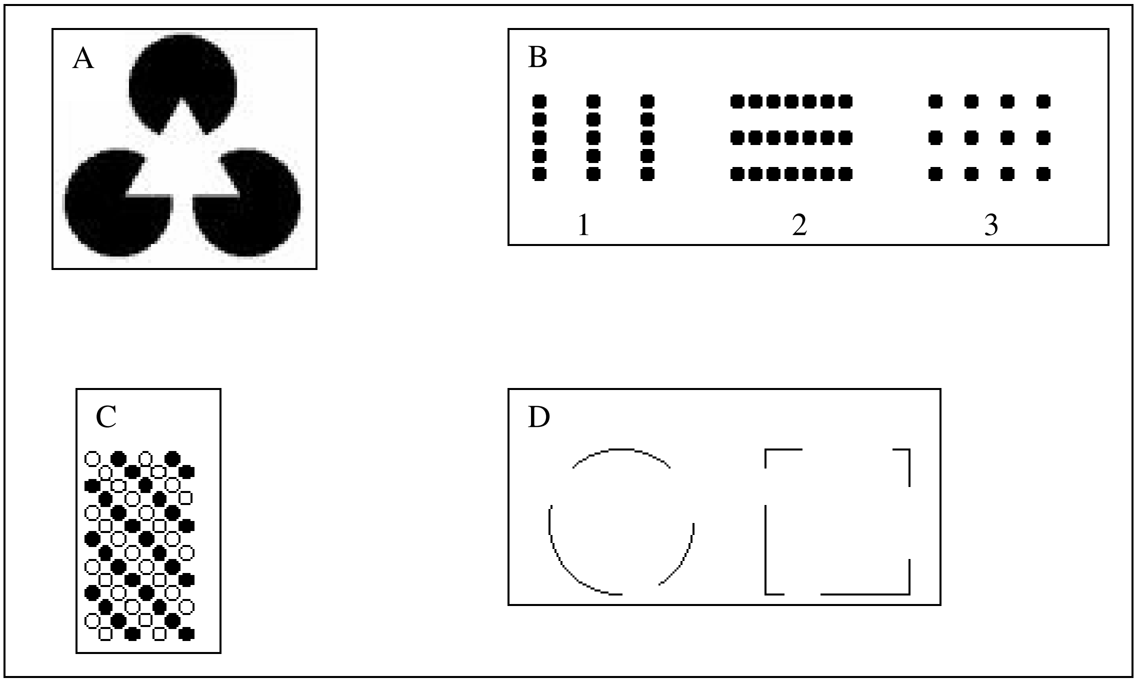

Figure 2.5: The Gestalt principles[5]. In A, the principle of closure signifies our tendency to see complete figures even when part of the information is missing. In such a diagram we perceive three black circles covered by a white triangle, even though it could just as easily be three incomplete circles. In B, as stipulated by the principle of proximity, those parts that are closest together, we perceive the group (1) as three vertical lines of dots and the group (2) as three horizontal lines of dots. The dots in (3) are equally spaced and do not suggest an orientation. In C, the similarity principle suggests that we group together those parts that appear 'similar'. Hence in C, we see separate white diagonal lines and black diagonal lines rather than vertical or horizontal lines of black and white dots. And in D, according to the principle of closure, we group together parts that give the appearance of closed shapes.

From the above arguments, the current author adopts a view in relation to perception, a number of abilities are required. These include amongst other the ability to perform preattentive tasks, extract information from complex environment(s), cope with the pace at which concepts are presented, detect speed, differentiate symbolism based on colour and not texture, detect first and second order stimuli, recognise items in motion ERs that are presented at different speeds as well as to chunk information with respect to the Gestalt principles. In the next section the author looks at visual imagery

[5] gseweb.harvard.edu/ ~t656_web/Spring_2002_stud... and, www.agocg.ac.uk/reports/ virtual/vrmldes/usesa.htm

2.4.2.2 Cognitive processing of ERs

Given the above stated account on perception, this section will take our thinking further to focus on how the mind processes ERs. According to researchers (e.g. Mast *et al.*, 2003) there are at least four types of visual imagery or ER-processing abilities. These (can be tested individually) are: "*(1)* the ability to generate vivid, high-resolution mental images; *(2)* the ability to compose mental images from separate parts; *(3)* the ability to inspect patterns in mental images; and, *(4)* the ability to mentally rotate patterns in images" (Mast *et al*., 2003, p. 238). For the purpose of the current research, the current author reviews only two of the visual imagery types which deal with the manner in which images are processed. These are hereafter referred to as "visual imagery 1" and "visual imagery 2" respectively (Figure 2.4).

2.4.2.2.1 Cognitive processing of ERs – visual imagery 1

Visual imagery 1 is where individuals rely on STM and LTM to interpret visual information (Figure 2.4). This is such that, responses are stimulated by what has been seen and stored in the STM. This information is then evaluated with respect to the information stored in the LTM such as existing mental schemata and mental models and is driven by the need to respond as explained by constructivist theory (Mayer, 2003; Thompson, 1995).

Regarding interpreting ERs, a number of studies have been conducted to try and understand what exactly occurs when people view ERs. One such study was conducted by De Santis and Housen (2007; 2000) who investigated how people processed information when viewing artistic work. In this instance, based on what goes on in the minds of such people, the researchers derived five stages of cognitive processing during viewing of the ER (Table 2.1; Housen, 1992). According to De Santis and Housen (2007; 2000), people behave differently when faced with an ER. This behaviour is defined by a number of factors such as knowledge, skill and experience.

As presented in Table 2.1, the five stages of visual literacy in aesthetic development can be described by Accountive, Constructive, Classifying, Interpretive and Re-creative actions respectively (Housen, 1992). De Santis and Housen (2007) suggest that based on their reactions towards an ER, viewers can be categorised into one of these stages, but as viewers gain more knowledge related to the field, such as MLS, viewers can progress from one stage to the next. In the accountive stage, viewers make their judgements about ERs based on prior knowledge, i.e. what is known and also what is liked (De Santis & Housen, 2007; 2000; Housen, 1992). In the constructive stage, viewers rather employ logical and accessible tools of knowledge to make judgements about the ER (De Santis & Housen, 2007; 2000; Housen, 1992). In this instance, should the image not fit what it *should* be like according to the viewer, then such an image makes no sense to the viewer.

Table 2.1: The Housen model used to characterize people into different stages of cognitive processing based on their actions as they view ERs (De Santis & Housen, 2000, p. 13). Stage I is the least cognitively demanding whereas stage V is the most demanding.

STAGE	ACTIONS	DEFINITION
I	**Accountive**	Use senses, memories, emotions and personal associations, to make concrete observations about the work which get woven into a narrative
II	**Constructive**	Use logical and accessible tools: their own perceptions, knowledge, values of their social, moral and conventional world. If work does not look the way it is “supposed to”—if craft, skill, technique, hard work, utility, and function are not evident— then work is “weird,” lacking, and of no value.
III	**Classifying**	Analytical and critical. Identify work as to place, school, style, time and provenance. Decode the work using library of facts and figures that they are ready and eager to expand.
IV	**Interpretive**	Seek a personal encounter with a work. Let the meaning of the work slowly unfold; appreciate the subtleties of line and shape and colour. Critical skills are put in the service of feelings and intuitions; let underlying meanings of the work—what it symbolizes—emerge. Each encounter with a work of art presents a chance for new comparisons, insights, and experiences. Knowing that the work of art’s identity and value are subject to reinterpretation, these viewers see their own processes subject to chance and change.
V	**Re-creative**	Have established a long history of viewing and reflecting. A familiar painting is like an old friend who is known intimately, yet full of surprise. Combines personal contemplation with views that broadly encompass universal concerns.

For "classifying" viewers (see Table 2.1), everything in the image must fit a certain category as they attempt to classify everything seen in rigid mental categories (De Santis & Housen, 2007; 2000; Housen, 1992). On the other hand, "interpretive" viewers (see Table 2.1) allow the meaning of the work to unfold (De Santis & Housen, 2007; 2000; Housen, 1992). And finally, "re-creative" (see Table 2.1) viewers allow an establishment of varying meanings each time they view an image (De Santis & Housen, 2007; 2000; Housen, 1992). In this regard prior knowledge is used to make new discoveries about the image at hand.

Most researchers (e.g. De Santis & Housen, 2007; Anderson *et al.*, 2001; De Santis & Housen, 2000; Housen, 1992), agree that all stages of cognitive processing, such as the five stages given by De Santis and Housen (2007; 2000), are equally important, as people will tend to move from one stage to the next based on factors such as gain of new knowledge and experience in the field (De Santis & Housen, 2007; 2000). This gradual development in the way people view ERs is in agreement with Piaget's theory of cognitive development which states that development is a methodical and logical process that occurs in distinct stages (Feldman, 2004; James & Nelson, 1981). The overall process is influenced by the quality of experiences in the physical and social world, together with the drive for equilibrium. Equilibrium is the balance between the process of assimilation and accommodation, where assimilation is the fitting of new information into an existing mental structure and accommodation is the creation of new schemata (knowledge structures) or modification of an existing schema (Thompson, 1999).

Since visual literacy can be learned (21st Century Literacies, 2002[6]), it can be suggested that the manner in which cognitive development occurs is similar to that of visual literacy development. In this regard, the current author argues that viewers will develop their visual literacy for MLS progressively in stages such as described by the Housen model (Table 2.1; De Santis & Housen, 2007; 2000; Housen, 1992). Such a gradual development is influenced by a number of central factors such as experience and existing knowledge.

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[6] http://www.kn.sbc.com/wired/21stcent/visual.html

2.4.2.2.2 Cognitive processing of ERs – visual imagery 2

In the second type of cognitive visual processing (Visual Imagery 2, see Figure 2.4), no visual stimulus is required to instigate an individual as they respond to situations (Mast *et al.*, 2003). In this instance, all responses are stimulated by "thought" and "imaginations". For instance, a protein model designer may not necessarily have to see a protein in order to diagrammatically represent it, but may only use knowledge of other similar protein structures. Hence, this kind of cognitive processing of visual images relies solely on prior knowledge stored in the LTM, and the access of this LTM into WM. One account of such cognitive processing is explained by Bloom's taxonomy (Mayer, 2002; Anderson *et al.*, 2001). According to this taxonomy, there are six levels of complexity of cognitive processing, starting from the simplest behaviour to the most complex. Bloom's taxonomy classifies the manner in which people think and can be considered a hierarchy, starting from the "lowest" level and progressing to the "highest" level (Figure 2.6).

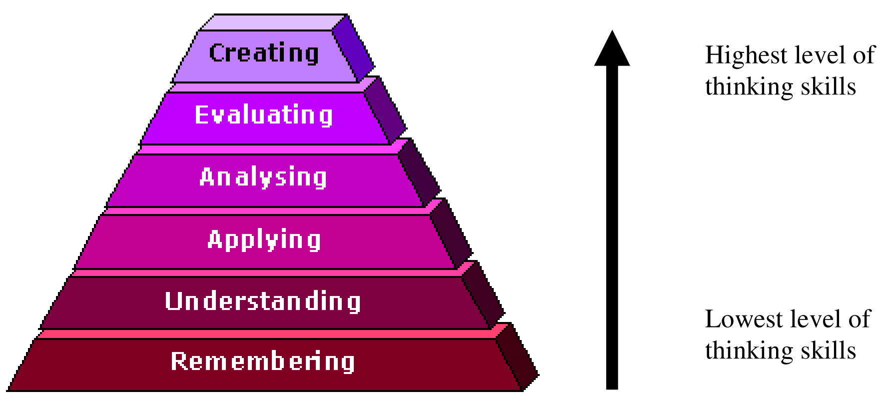

Figure 2.6: Bloom's taxonomy indicating the six levels of cognitive processing[7].

Bloom's taxonomy, as revised by Anderson *at al.*, (2001; Figure 2.6), consists of six levels i.e. remembering, understanding, applying, analysing, evaluating and creating. At the "remembering" level (see Figure 2.6), learners would be expected to retrieve information from LTM (Forehand, 2005; Mayer, 2002; Anderson *et al.*, 2001). Should

[7] www.learningandteaching.info/.../ bloomtax.htm

such learners be subjected to new information, they should be able to recognise it by recalling relevant information from prior knowledge. Concerning “understanding” (see Figure 2.6), learners should be able to construct meaning from given information by interpreting it based on what is known already (Forehand, 2005; Mayer, 2002; Anderson *et al.*, 2001). Furthermore, at the “applying” level (see Figure 2.6), learners would be expected to use their knowledge and understanding in new situations (Forehand, 2005; Anderson *et al.*, 2001). At the “analysing” stage (see Figure 2.6), learners are expected to be able to “break down” new information and rely on the prior knowledge to determine how all the parts are related to one another (Forehand, 2005). Learners at the “evaluating” level (see Figure 2.6) would be expected to rely on prior knowledge to make judgements by criticizing situations (Forehand, 2005). The last level is that of “creating” (see Figure 2.6) where learners are expected to “put elements together” to form functional whole structures that are novel (Forehand, 2005; Anderson *et al.*, 2001). As one progresses up the levels, the processing becomes more challenging and demanding.

Therefore, based on levels of Bloom’s taxonomy (Mayer, 2002; Anderson *et al.*, 2001), one would expect a visually literate molecular life scientist to be able to perform task at each of the levels as detailed above. To perform the tasks in each level of the Bloom’s taxonomy, viewers would rely greatly on already existing scientific knowledge of MLS, a similar phenomena as in Visual Imagery 2. This would help them be able to remember, understand, apply, analyse, evaluate and create new ERs in their field of expertise. As a result, the current author proposes that Visual Imagery 2 is guided by similar levels as those presented in the Bloom’s taxonomy. In this regard, a molecular life scientist who is able to effectively perform the visual cognitive processes relying only on the scientific information in LTM alone, would be able to remember, understand, apply, analyse, evaluate and create new ERs. This may be true for most retired molecular life scientists, who are no longer actively involved in knowledge development. The ability to progress with levels is, however, not automatic and may be limited by lack of necessary skills such as VS as well as experience in a relevant field.

Developing the skills necessary for performing tasks corresponding to Visual Imagery 2 is in line with Piaget's theory of cognitive development which argues the gradual development of the cognitive structures (Feldman, 2004; James & Nelson, 1981). Hence in relation to visual literacy, it is feasible to suggest that learners may gradually move from one level of the Bloom's taxonomy towards the top level over time, provided they are well guided. It follows that, to perform the tasks corresponding to Visual Imagery 2, such processes have to be developed gradually.

As per literature account on visual imagery, it emerges that this stage of visualization involves visual imagery 1 and 2. Here, people's visual literacy can be defined by their ability to generate vivid, high-resolution mental images, compose mental images from separate parts, inspect patterns in mental images, mentally rotate patterns in images, work at Bloom's six levels of complexity of cognitive processing i.e. remembering, understanding, applying, analysing, evaluating and creating.

2.4.2.4 Cognitive processing of ERs – Integration of information

As outlined in the preceding sections, visualization is a process that is influenced by the environment, as well as other factors and in large comprises of an orderly and effort demanding process (Feldman, 2004; James & Nelson, 1981). In this section, the current author argues that following Visual Imagery is an "integration process" (Figure 2.4), which determines the manner with which mental processes influence each other for the production and revision of ERs. In this regard, it is important to review two fundamental theories that reflect this phenomenon, namely, the dual coding theory and the constructivist theory.

The dual coding theory and the constructivist theory both suggest that learning is influenced by prior knowledge which is stored in the LTM (Wastelinck *et al.,* 2005; Thompson, 1995; Clark & Paivio, 1991). According to the constructivist theory (von Glasersfeld, 1995; Figure 2.3), once certain aspects of new information have been selected, human cognitive processes transform it to storable mental forms (see 5 on

Figure 2.3). New information is integrated with already existing knowledge (see Figures 2.2 and 2.3) in order to create new mental schema that can then be stored in the LTM and/or expressed (Wastelinck *et al.,* 2005, Mayer, 2001b).

According to the Dual Coding theory (Wastelinck *et al.,* 2005; Clark & Paivio, 1991), the human cognitive structure has two mental processing systems associated with it, a verbal and non-verbal system (also called auditory-verbal and visual-pictorial channel respectively; see also Figure 2.2). The theory states that human cognition is capable of dealing with verbal or linguistic and non-verbal knowledge as knowledge structures "in their own right" (Wastelinck *et al.,* 2005; Clark & Paivio, 1991). Through referential connections, the two systems work together to construct and integrate mental models which are then memorized and stored as schemata (Clark & Paivio, 1991). Similarly, other authors (e.g. Mayer, 2001) have argued that, upon cognitively processing ERs, the information is integrated into new mental forms.

Related to the dual coding theory is the limited capacity assumption which argues that in humans, WM has a limited capacity for holding and manipulating information in that only a limited number of items of knowledge can be stored at any one time (Mayer & Anderson, 1992). This limited capacity assumption suggests that if the visual-pictorial channel is presented with too many pictures or visual stimuli, it can be overloaded and will fail to integrate information properly (Whelan, 2007; Mayer & Anderson, 1992). The resulting overload leads to an inability to process new information effectively and hence, the cognitive ability of a learner is compromised. Therefore, effective integration of information depends very much on the amount of information presented to each of the cognitive channels.

As a result, it can be deduced that before mental visual models are created, stored or expressed, an integration process occurs, the effectiveness of which depends on the manner in which information is delivered to the systems (see perception). Once a mental schema has been created it can then be stored or expressed depending on the related requirements.

Given the literature review of integration, it emerged that to be visually literate mean one is able to integrate knowledge from different parts of memory, deal with verbal or linguistic and non-verbal knowledge, utilize various intelligences, adapt, to the dynamic world of science and ascertain information from ERs in specific contexts. Due to the complexities related to visualization, it is important that at this stage, we look at the factors that influence visual literacy – before we look at the last stage the actual "production of visual images".

2.4.2.5 Factors influencing visual literacy

Observations indicate that people's visual literacy status varies from individual to individual (e.g. Aanstoos, 2003; Yenawine, 2003). This implies that in addition to cognitive constraints, other factors also determine the visual literacy of individuals. In this regard intelligence plays a central role, because according to the theory of multiple intelligences, there are different intelligences that exist which include spatial intelligence, bodily-kinesthetic intelligence, logic-mathematical intelligence, linguistic intelligence as well as interpersonal intelligence (García *et al.*, 2007; Visser *et al.*, 2006; Gardner, 1983). In this thesis only four of these are discussed as they are viewed as of the most relevance with respect to visual literacy.

A critical intelligence in relation to interpreting visual images is visual/spatial intelligence. Gardner (1983) suggests that visual/spatial intelligence is the ability to perceive and mentally manipulate a form or object, and to perceive and create tension, balance and composition in a visual or spatial display. Such intelligence determines whether people will be able to properly ascertain and make sense of information from given visuals in a coherent manner. Hence, acquiring such intelligence would go a long way towards defining whether one is visually literate or otherwise.

The bodily-kinesthetic intelligence defines one's skills concerning bodily motions (Armstrong, 1994; Gardner, 1983). Such bodily motions involve the way individuals are able to organise the movements of their organs such as eyes, hands and legs, in a well timed and positioned manner (Gardner, 2000). At the same time, in relation to computer based ERs, bodily-kinesthetic intelligence would refer to motor skills associated with moving a computer mouse and rotating a protein molecule on the computer screen. Altogether, such skills involve the ability to regulate the entire motor mechanism that may involve multiple organs and senses simultaneously. Therefore, in MLS, one may need to move multiple organs (or even the entire body) at once in order to position themselves in a manner that maximises their ability to work with for instance physical or computerized models of nucleic acid, amino acid, protein structures, just to mentioned a few. In this instance, bodily-kinesthetic intelligence would play an important role in defining one as visually literate.

Another important intelligence with regards to visual literacy is logical-mathematical intelligence. This intelligence defines the ability to detect patterns, categories and relationships in given ERs by manoeuvring items or symbols in a controlled and orderly way (Armstrong, 1994; Gardner, 1983). As a result, one's ability to perform such tasks defines the way one visualizes, patterns in diagrams, the ability to manipulate information from a given source and be able to extract, select and formulate sound hypotheses as per subject matter for instance. In this way the availability of logical-mathematical intelligence improves molecular life scientist's ability to differentiate between, for example, proteins by observing differences between alpha helices and beta sheet patterns.

Another important intelligence is linguistic intelligence (Gardner, 2000). A number of science educators have suggested that visual literacy is a language in its own right (e.g. Emery & Flood, 1998). However, as Schönborn and Anderson (2003) have suggested, the vocabulary of this language is often inconsistent in contexts such as the Biochemistry. In relation to multiple intelligences theory, linguistic intelligence encompasses the ability to use language to stimulate, entertain, convince or convey information within a certain subject (Armstrong, 1994; Gardner, 1983). As a result, this also affects visual literacy in a sense that it determines one's ability to "read", "interpret" and "express" information in the visual language. Furthermore, the linguistic intelligence would relate to understanding the textual symbols associated with the pictorial part of the ER, e.g. captions and narrations or on-screen text in animation.

When considering the above presented intelligences, it is important to note that, visual literacy involves a number of different mental abilities and does not stand alone as "one intelligence" *per se*. It has been suggested that all intelligences can be acquired through proper mental development strategies and hence, it can be further suggested that visual literacy can be developed and learnt (Gardner, 1983). At the same time, a person's level of visual literacy will be influenced greatly by their multiple intelligence status.

Other factors that contribute to visual literacy include knowledge and age (Bamford, 2003). In this instance, Bamford (2003) suggests that from an early age (where little knowledge is present, e.g. at university entrant), students develop VS in relation to their gain of conceptual knowledge in a relevant field about different systems. Students will develop cognitive abilities where they are able to visualize and create mental pictures which are constantly improved as they ascertain more conceptual knowledge through their university training. Bamford (2003) further suggests that this development varies from different levels. As a result, it is safe to suggest that for instance, students at different academic levels, with "different" level of conceptual understanding, may view the same molecule differently and will have different abilities with respect to characterising such a molecule. This finding correlates well with the notion of constructivism which suggests that humans will interpret ERs in unique ways depending on their already existing knowledge and experiences (Mayer, 2001; Thompson, 1995; von Glasersfeld, 1995)

2.4.2.6 Production of External Representations

In addition to the previous stages of visualization, visual literacy also involves the element of expressing one's thoughts via ERs, in the form of diagrams and pictures for example (Figure 2.4). According to Bamford (2003), this is the last stage of visualization and is a result of both visual perception and cognitive processing of ERs. Producing ERs is a result of developing mental schemata through visual imagery 1, 2 and integration.

Therefore, this may be after one has perceived a visual stimulus and in response, create a new ER and may include the re-production of what is perceived. At the same time, the production of a visual representation may not necessarily be as a response to a visual stimuli but may be instigated by a thought.

Stokes (2002) suggests that people think more in words than in pictures. In this instance, the production of an ER would be a transition where a person converts a verbal mental expression into an ER. As a result, some researchers have suggested that people use the same format in perception, mental processing and expression (e.g. West, 1997). For instance, in Mathematics, West (1997) suggests that learners *do* rather than *watch* Mathematics. In this instance, West's (1997) findings imply that "words go into an idea only after the idea has already settled in our mind" (West, p. 275). In this regard, a visual mental model is expressed easily as an ER rather than a verbal model. At the same time, the increased favour of using pictures rather than words (Dunsworth & Atkinson, 2007; Mayer, 2001) is indeed in line with the famous saying, "a picture is worth a thousand words".

Again, the success in expressing one's thoughts as ERs would greatly rely on the multiple intelligences that a person may possess. For instance, when drawing a diagram, the bodily-kinesthetic intelligence would play a role as it determines the way one moves his/her hand and fingers. Also, logical-mathematical intelligence would play a role in the expression of mental visual models in numerical format. At the same time, spatial/visual intelligence as well as linguistic intelligence is the major role player in the expression of visual mental models in the verbal form. As a result, it may be suggested that the manner in which people express ERs depends highly on their cognitive and physical abilities that they have with which they express a certain model i.e. an artist may have better skills at expressing thoughts as diagrams or pictures. Furthermore, the question of knowledge possessed in the field is a crucial one. For instance, when one has enough knowledge in a certain field, it is likely that the person will express their thoughts in a suitable manner. Hence, the combination of a number of factors defines whether one is able to produce ERs successfully or not.

Another factor that needs consideration concerning the production of ERs is that of the various types of expression that are possible, with regard to ERs. For instance, some people may be able to express their mental visual models verbally better than they would graphically. Expression may depend largely on the manner with which people integrate prior knowledge with new information during cognitive processing such as perception, selection, integration, and on previous experience.

The previous sections have shown why visual literacy is important, the NoER as well as the NoVL. The question at this stage would be, how can one use this knowledge to test for or improve visual literacy through VS? As a result, the next section highlights other researchers' perspective concerning measuring visual literacy.

2.5 Measuring visual literacy

Even though a number of researchers have investigated the learning process with ERs (e.g. Dunsworth & Atkinson, 2007; Lewalter**,** 2003; Mayer, 2001; von Glasersfeld, 1995; Clark, & Paivio, 1991), so far, there have been only limited attempts to define the "levels" of visual literacy with the aim of explicitly measuring it (Bamford, 2003). Besides tests that are used to measure individuals' cognitive and spatial abilities such as IQ tests, it still remains a mystery to determine the degree of visual literacy that individuals possess, particularly in the MLS. Nevertheless, the literature suggests that people can either be visually literate or otherwise, in relation to a particular area of study (Aanstoos, 2003; Bamford, 2003).

In an attempt to quantify visual literacy, Burton (2004) suggests that there are at least three factors which serve to describe the process of visualization namely, visual perception, visual imagery and visual communication. This formulation of the three factors that pertain to visual literacy suggest that there are different levels at which visual literacy can be measured, either at the visual perception, visual imagery or visual communication level. However, for such measurements to be possible, one would first be required to understand and define relevant VSs for each level before each can be measured within a specific context such as the MLS.

In addition to the above mentioned three levels, a number of other factors contribute to an individual's visual literacy. Burton (2004) mentions age, level of cognition, social and cultural disposition, media skills and knowledge of the viewer as factors that further complicate the construction of tools to measure the degree of visual literacy of an individual. It is logical to acknowledge that the environment in which people interact has a significant influence on what and how phenomena are visualized (Burton, 2004). As a standard requirement for visual literacy, people need to possess a number of cognitive abilities. However, if visual literacy could be characterized, then perhaps measuring it can be done. While MLS lacks context specific understanding of visual literacy (i.e. NoVL in Biochemistry), it is difficult to provide an instrument with which to measure visual literacy in a particular context. However, at this stage this review has provided understanding of the NoVL that can be used as a first step towards measuring visual literacy.

2.6 Summary and conclusion

The above sections indicate that visual literacy combines a number of cognitive activities in the form of visual perception, visual imagery and visual communication. The success of these activities is influenced by a number of factors such as age, level of cognition, social domain, culture and knowledge of the viewer in a particular field. Hence, in order to define visual literacy (in response to research question 1; see section 1.3), and its levels in a MLS context, all these factors need to be explored and their contribution thoroughly examined.

From the current account of visual literacy in relation to the process of visualization, it emerges that visual literacy involves a number of abilities that may occur in different stages of visualization. These the current author refers to as the facets of visual literacy that can be used to define the NoVL as well as to test for visual literacy for the MLS.

Below is a table (Table 2.2) presenting the list of these facets (emerging from a synthesis of the above reviewed literature) as abilities required for an individual to be visually literate.

Table 2.2: The facets of visual literacy as they occur in different stages of the visualization process.

Component of visualization	**Ability to:**
Perception	perform preattentive tasks
	extract information from complex environment(s)
	cope with the pace at which concepts are presented
	detect speed
	differentiate symbolism based on colour and/or texture
	detect first and second order stimuli
	recognise items in motion ERs that are presented at different speeds
	chunk information with respect to the Gestalt principles
Visual imagery	generate vivid, high-resolution mental images
	compose mental images from separate parts
	inspect patterns in mental images
	mentally rotate patterns in images
	work at Bloom's six levels of complexity of cognitive processing i.e. remembering, understanding, applying, analysing, evaluating and creating
Integration	integrate knowledge from different parts of memory
	deal with verbal or linguistic and non-verbal knowledge
	utilize various intelligences i.e. visual/spatial intelligence, bodily-kinesthetic intelligence and logical-mathematical and linguistic intelligence
	adapt, to the dynamic world of science, expressed as the ability to work with and generate models that will satisfy the understanding of scientific knowledge as it progresses
	ascertain information from ERs in specific contexts

As seen also in this literature review, Table 2.2 shows that visual literacy cannot be defined according to any one ability. Furthermore, from table 2.2, some of the facets are interrelated and some are very broad. For instance, performing “preattentive tasks” (Table 2.2) includes target detection, boundary detection, region tracking and counting and estimating, while “extracting information from complex environments” (Table 2.2) includes target detection, perceiving luminance, perceiving depth cues and so on. Therefore, the list above on its own, is not enough for the development of an instrument with which visual literacy can be measured. As a result, in the following Chapter, the current author provides research methods employed in this study. Following the research methods are the results used to develop and use the instrument with which to gather data for measuring visual literacy as reviewed in the current chapter.

3. Chapter 3: General methods

3.1 Introduction

Concerning synthesising research, Cooper (1990) suggests that the pursuit of knowledge with the tools of science is a cooperative and interdependent enterprise. Any one scientific research endeavour depends on, and contributes to an array of other research endeavours in a particular field (Cooper, 1990). As a result, for a researched piece of information to be well integrated into the broader world of scientific knowledge, a specific research methodology needs to be adhered to.

Because of the nature of the study, specific methods used in collecting and analysing data in different sections of this project are given in each chapter. In this chapter background knowledge to specific methods are given. In this regard, a vast number of research methods exist and the choice of any one method depends entirely on the nature of the research being conducted at a given time. However, according to Cooper (1990), a great deal of researchers fail to use proper methods when finding, evaluating and integrating past research methods into their studies. As a result, most researchers' work tends to lack proper synthesis procedures. To ensure that the current research avoids this shortfall, a number of issues were considered upon designing and conducting this research, particularly with regards to data collection. This involved using a range of different research methods, testing for validity and reliability of the instrument, and reviewing data to determine the best methods for the current study.

3.2 Qualitative and quantitative approaches

There are two major types of methods that can be used for collecting and analysing data, namely, qualitative and quantitative approaches (Creswell, 1994). The value of the two approaches is a source of great debate among researchers. However there is a clear distinction between the two methods and based on this, researchers find value in whichever method they prefer for a particular study based on the research questions being addressed (Patton, 1990).

According to Hoepfl (1997), phenomenological inquiry or qualitative research, uses a realistic approach in search of understanding a phenomena in context-specific settings. In human and social sciences such as science education, qualitative research involves enquiring about participants' opinions, behaviors and experiences from the informant's points of view (Zucker, 2001). Such qualitative methods are often used in educational studies with the aim of describing and discovering events, phenomena and situations of theoretical significance (Zucker, 2001).

Researchers (e.g. Hoepfl, 1997; Strauss & Corbin, 1990) agree that qualitative methods are best suited for situations where little is known about particular phenomena. In such cases, the qualitative method is used to define certain variables that can later be tested through quantitative methods (Hoepfl, 1997), even though quantitative methods may not always follow qualitative methods. In this regard, qualitative researchers follow what Patton (1990) calls "non-absolute characteristics, but rather strategic ideas that provide a direction and a framework for developing specific designs and concrete data collection tactics" (p. 59). This means the researcher remains "objective" as an instrument where they only make observations, descriptions and interpretations of the given data (Patton, 1990). As a result the research is interpretive in the sense of discovering meanings of the events (Hoepfl, 1997). At the same time, qualitative researchers "pay attention to the idiosyncratic as well as the pervasive, seeking uniqueness of each case" (Hoepfl, 1997, p. 3).

In science education research a number of qualitative methodologies, for collecting and interpreting data, are employed. Nonetheless qualitative research is very much dependent on the researcher's subjectivity (Bogdan & Biklen, 1992). This poses a threat to the validity and reliability of the data as these will depend heavily on the logic of the approach (Libarkin & Kurdziel, 2002). As a result conclusions in such research are often applicable to very limited circumstances and contexts (Libarkin & Kurdziel, 2002).

In contrast to qualitative methods, quantitative methods refer to research methods where findings are observed through the use of statistical means of quantifying information (Strauss & Corbin, 1990). According to Hoepfl (1997), "quantitative researchers seek causal determination, prediction, and generalization of findings" (p. 2). In this instance, quantitative researchers instead seek illumination, understanding, and extrapolation to similar situations. With respect to quantitative studies, already-defined methodologies for collecting and interpreting data are used (Libarkin & Kurdziel, 2002). During the use of these methods, a well structured approach is followed in which case divergence from such methods needs to be backed up by sensible arguments. Hence, the reliability and validity of quantitative methods is governed by established statistical techniques (Creswell, 1994).

3.3 Mixed method approach

Because of the nature of individual approaches in qualitative and quantitative approaches, a mixed methodology approach has been explored and successfully used. According to Bazeley (2003), a mixed method of research generally refers to the combined use of different qualitative and quantitative methods to investigate a particular phenomenon (Bazeley, 2003). In the 1980s, it was rather unacceptable to combine methods in research as it was viewed as "creating a conflict in ontology and epistemology" (Bazeley, 2003, p. 1). This "paradigm war" however faded away in the 1990s as an increase in the use of mixed method approaches emerged (Bazeley, 2003).

According to a number of researchers (e.g. Libarkin & Kurdziel, 2002), the mixed method incorporates both the qualitative and quantitative methods. The argument is that the combination of both methods strengthens the research findings. The researcher may perform one method and follow it up with the next as a substantial tool for his or her findings (Bazeley, 2003). Derry *et al.* (2000) used the mixed method approach in their study and argued that the findings of such an approach are applicable to both a local setting (the context of the study) and in more general terms. Other authors (e.g. Leahey, 2006; Denzin, 1988) agree that mixed method designs enhance the validity and reliability of results compared to if each method is used on its own. Furthermore, it is believed that the simultaneous use of both methods reduces the limitations posed by the weaknesses of individual methods alone (Derry, 2000). As a result of such arguments, a large volume of researchers favour mixed method designs to conduct their studies as they ensure a high degree of validity and reliability (e.g. Leahey, 2006; Tashakkori & Teddlie, 2003; Alford, 1998).

3.4 Validity and Reliability in Science Education Research

According to Morse *et al.* (2002), the usefulness of research relies heavily on reliability and validity of the research methods. Because of this, a number of statistical methods have been developed to measure validity and reliability in quantitative studies. Such a rigorous approach has fuelled the adaptation of various criteria for pursuing validity and reliability in qualitative research (Morse *et al.*, 2002). In this regard, Morse *et al.* cite Guba and Lincoln (1981) who suggested that, due to the variations in the nature of quantitative and qualitative research methods, each paradigm requires its own criteria for addressing reliability and validity.

3.4.1 Triangulation

Validity and reliability in research have propelled the subject of triangulation. Guion (2002) suggests that triangulation is a method used to pursue and ensure validity and reliability of a research study. Other authors define triangulation as the use of multiple methods to validate data or research findings (e.g. Hyrkäs *et al,* 2003). A number of approaches can be followed in triangulation in an attempt to eliminate the bias that may be caused by the use of only one particular method (Hyrkäs *et al.*, 2003; Derry, 2000). In this respect, when a combination of qualitative and quantitative methods is used to explore the same phenomenon, data may be collected and analysed using both methodologies (Creswell, 1994). If the two methods reach a similar conclusion, data may be perceived as “valid” (Creswell, 1994).

Besides triangulation that involves a combination of qualitative *and* quantitative methods to validate research, Guion (2002) has highlighted four other triangulation methods. These are data triangulation, investigator triangulation, theory triangulation and environmental triangulation. In the data triangulation approach, different *sources* of information are used (Guion, 2002). In this instance, data may be collected at different times using different data–generating instruments i.e. interviews and questionnaires. In investigator triangulation, different *researchers* use the same method of data collection and analysis (Guion, 2002). For instance, different interviewers may interview the same set of students about a given phenomena. With theory triangulation, a *single* set of data is interpreted by *different investigators* (Guion, 2002). This method differs from investigator triangulation in that the focus is on interpreting the data or methods used by interpreters who may be outside of the field of the primary researcher. Finally, environmental triangulation relates to the use of different *places*, and other environmental *settings* e.g. culture, to collect data (Guion, 2002). Overall, by using such approaches, the researchers hope to minimize or eliminate any bias that may invalidate the research findings.

Reliability and validity are both important concepts, where validity is more important in qualitative approaches and reliability is more important in quantitative approaches (Hyrkäs *et al*., 2003; Guion, 2002; Derry, 2000; Creswell, 1994). As a result, reliability is well understood in the context of quantitative researches and validity is well defined under the qualitative context. Because of this, in the following section the current author discusss validity in detail under the qualitative context and reliability under the quantitative context.

3.4.2 Qualitative Validity

In qualitative approaches of research validation, there are a number of methods that are used to maintain logic. Amongst others, the current author will outline two types of triangulation (namely, theory triangulation and data triangulation) and different types of validity namely, content validity, concurrent validity, face validity and criterion–related validity. As highlighted in section 3.4.1, theory triangulation relates to the use of "multiple professional perspectives to interpret a single set of data" (Guion, 2002 p. 2). The professionals may be in the same field as the researcher or be in a different field. The latter is important when the researcher wants to make general inferences about the research findings. Data triangulation on the other hand refers to the use of different sources of data Guion, 2002). In this instance, the data collected from the different sources is compared and consensus observations are made. Only if the results from the data show similar findings, will validity be pronounced.

In the case of qualitative research, there is a range of instruments available that can be used to collect and or analyse data. As in any empirical investigation, instrument validity requires careful attention. Content validity refers to the instrument's ability to represent clearly and appropriately all of the content of a particular construct (Heffner, 2004). In this regard, content experts define the content domain that the instrument is representing and then define how well it is able to cover such content domain. On the other hand, concurrent validity relates to the comparison of two different instruments that measure the same variable on two different occasions (Heffner, 2004). For example, a sample of people may be given a test, and later be given a new test. The differences between the tests are compared to determine how well the second test reflects the findings of the initial test. Should findings of the first and second tests be similar, then validity is achieved.

Another type of validity is face validity which is concerned with the appearance of the procedure or instrument. Face validity tells the researcher whether or not the instrument is well designed and is a reasonable tool for gaining information (Golafshani, 2003; Simner, 1989; Nevo, 1985). Criterion–related validity is a measure used to demonstrate the precision of an instrument by way of comparison with other validated instruments (Carmines & Zeller, 1979). For example criterion–related validity can be gained by comparing a test under study with a well established test such as a psychometric test. Finally, like criterion-related validity, concurrent validity tests the correlation of two instruments' results where one has been previously validated and the other is being tested (Carmines & Zeller, 1979). Such instruments may presumably be related. In all cases, validity may only be established if the results of the instrument under study are similar to those of the previously validated instrument.

3.4.3 Quantitative Reliability

In order to have confidence in the research methodology and its findings, the measure of reliability is of importance. This refers to the estimated probability of consistency of given measurements over time (Libarkin & Kurdziel, 2002; Creswell, 1994). In other words, reliability predicts the probability of obtaining the same results if the research method is repeated under same conditions on a different occasion. However, reliability does not answer whether the research or its method is valid, while it does not cater for changes in humans over time.

The two basic processes of single administration and multiple administrations can be used to pursue reliability (Libarkin & Kurdziel, 2002; Creswell, 1994). Single administration estimation of the reliability involves administering the investigation once and then estimating the reliability from findings thereof (Libarkin & Kurdziel, 2002; Creswell, 1994). In this regard, there are two methods that can be followed to obtain single administration reliability, namely, split-half and internal consistency (Libarkin & Kurdziel, 2002; Creswell, 1994). In split-half method, the sample of subjects or items is divided into two alternate forms, but the test is administered in the same way. Thereafter, the instrument reliability is estimated by comparing the total score from one half of the items to the total score from the other half by calculating reliability using the Spearman-Brown formula (Libarkin & Kurdziel, 2002; Creswell, 1994). In multiple administrations, reliability can be estimated using the internal consistency method where Cronbach's alpha is measured (Libarkin & Kurdziel, 2002; Creswell, 1994). Cronbach's alpha measures how well variables measure a single unidimensional (consistent) latent construct. Hence, if data have a multidimensional (inconsistent) structure, Cronbach's alpha will usually be low (below 0.8) and vice versa for unidimensional structure (Libarkin & Kurdziel, 2002; Creswell, 1994).

Another measure of reliability is internal consistency. Internal consistency is the degree to which different instruments assess the same skill or characteristic (Carmines & Zeller, 1979). In this regard, internal consistency determines the accuracy of an instrument used in a study by way of comparing scores through correlation determination. Instrument accuracy can also be measured through a measure called test – retest reliability. In this case, a single test may be performed by the same group of respondents at different times. If the correlation coefficient between such tests is close to 1.0, the tests are regarded as reliable (Carmines & Zeller, 1979).

Often, quantitative research deals with relationships between multiple items or events. In this regard, a number of assumptions can be made about the data. For instance, in each event such as a test, each subject has a true score which is the actual degree of particular characteristics e.g. conceptual understanding (Libarkin & Kurdziel, 2002; Creswell, 1994). The second assumption is that while testing particular characteristics in a given event there are random measurement errors (Libarkin & Kurdziel, 2002; Creswell, 1994). In this regard, the actual true score is obtained by calculating the average scores (mean score), which in a way, considers all the measurement errors (standard deviation from the mean score). If the standard deviation is too high (close or equal to the mean score), the results are regarded as having a low reliability (Libarkin & Kurdziel, 2002; Creswell, 1994). Furthermore, statistical tools using the mean score and the standard deviation can calculate a component called the reliability coefficient which ranges from 0 to 1.0. If the coefficient is close to 1.0, the results are regarded as reliable (Libarkin & Kurdziel, 2002; Creswell, 1994).

3.5 Summary of methods used in this study

As given in figure 1.1, the second phase of this study focuses on data collection and analysis for the development of the taxonomy of visual literacy. Below (Figure 3.1) is a summary of the research methods used to gather and analyse data as detailed in the following Chapters.

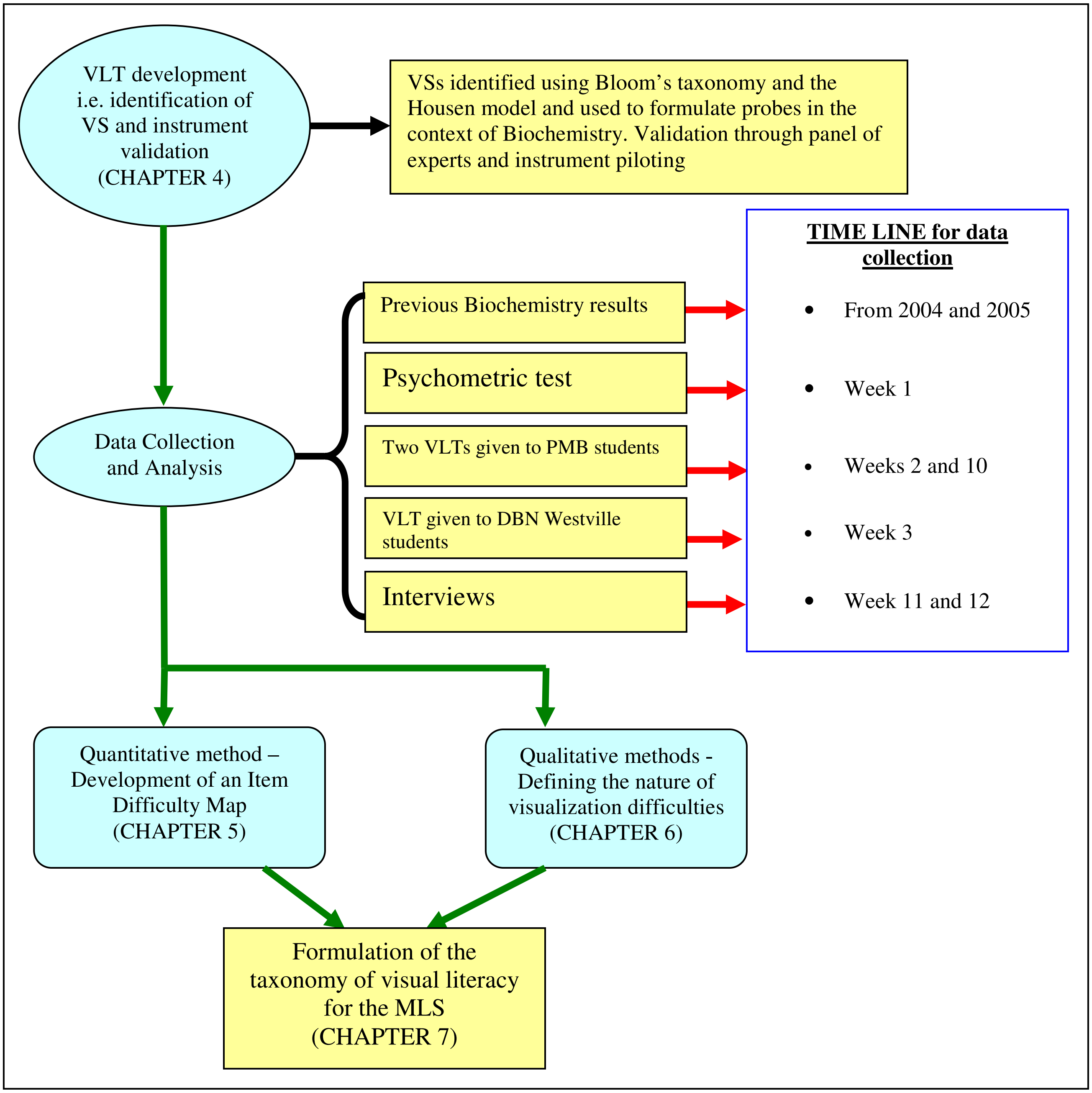

Figure 3.1: A summary of the research methods employed in this study

3.6 Ethical clearance

To conform with ethical care, ethical clearance was obtained from the University of KwaZulu-Natal's Research Ethics Committee. This clearance required that the researcher provides details of the research in relation to ethical protection of the participants. These included the project description, background to the study, the key questions to be addressed, the participants (or subjects) and research site, including a full description of the sample, and the research approach/ methods.

Concerning the participants, the researcher clearly indicated the type of subjects to be involved in the study as well as their medical related history. In this regard, the researcher indicated how the autonomy of respondents will be protected to prevent social stigmatization and/or secondary victimization of respondents. In cases where confidential information is used the researcher indicated what steps would be taken to minimize potential stress or harm to the respondents. Concerning instruments used (e.g. interviews and psychometric tests), the researcher indicated the nature of such instruments and provided evidence that the measure is likely to provide a valid, reliable, and unbiased estimate of the construct being measured. In the case of interviews, topics covered were also presented. Regarding the autonomy of participants, a consent form (appendix 1) was signed by the respondents and the researcher, in the language that the respondents understand. This consent form indicates the following:

- The nature and purpose/s of the research
- The identity and institutional association of the researcher and supervisor/project leader and their contact details
- The fact that participation is voluntary
- That responses will be treated in a confidential manner
- Any limits on confidentiality which may apply
- That anonymity will be ensured where appropriate (e.g. coded/ disguised names of participants/ respondents/ institutions)
- The fact that participants are free to withdraw from the research at any time without any negative or undesirable consequences to themselves
- The nature and limits of any benefits participants may receive as a result of their participation in the research

The researcher also indicated how the research data was to be secured, stored and/or disposed of. All the above stated information was included in an ethical clearance form which was signed by the researcher and the project supervisor and then submitted to the University Research Ethics Committee for authorization. Following relevant processes, the University deemed the research ethically cleared (ethical clearance number HSS/0150/07).

4. Chapter 4: Development and validation of the Visual Literacy Test

4.1 Introduction

As stated in Chapter 2, visual literacy is multifaceted and involves several cognitive processes that work together to achieve specific goals in the visualization stages. It was further observed in Chapter 2 that the current literature defines visual literacy according to the cognitive processes involved. In order to test for visual literacy, it is imperative that the components related to the cognitive processes and the stages of visualization are identified. In the current Chapter the author identifies such components as cognitive skills. These are then used to formulate a test for visual literacy.

4.2 Identification of VS for MLS.

Knowledge of the Housen model (Table 2.1) and Bloom's taxonomy (Figure 2.6), enabled the current researcher to propose a list of facets of visual literacy (Table 2.2). It was further argued that each facet may contain one or more VS of relevance to the context of MLS. To identify these skills, the current author used Bloom's taxonomy and the Housen model to argue for the stages of visualization (Figure 2.4). From these stages, the current author uses Bloom's taxonomy in an attempt to identify relevant VS.

As shown in Figure 2.4, there are five stages of visualization. Each stage is unique in that the cognitive processes undertaken are different from other stages. According to Bloom's taxonomy (Anderson *et al.,* 2001 and Bloom, 1956) each stage of the process of learning (e.g. visualization) has learning objectives (the learning goals intended to be attained). Because of this, the current author suggests that each stage of visualization has a learning goal or an objective. The Housen model (Table 2.1) accounts for these by defining the actions taken by viewers when looking at an ER. For visual literacy, such objectives are fulfilled by correctly carrying out specific VSs that may be unique or shared between different stages. For example, if the objective is being "accountive", viewers will "use senses, memories, emotions and personal associations, to make concrete observations about the work which get woven into a narrative" (De Santis & Housen, 2000, p. 13; Table 2.1). In line with this, Bloom's taxonomy suggests that if the objective is "remembering", learners will "retrieve (recall) information" (Forehand, 2005; Mayer, 2002; Anderson *et al.*, 2001).

Literature has also shown that visual literacy is multifaceted (Table 2.2). Given this, to achieve a certain objective at a given stage of visualization, a number of skills are required. These VSs are therefore performed in a collective manner. This was also evident in section 2.4.2.5 where several factors were found to influence visual literacy. Based on this, it is difficult to identify any one VS as being performed uniquely at a visualization stage. Nonetheless, from Bloom's taxonomy as well as the Housen model, VSs have been identified (Table 4.1). Because our study is in the MLS, these VSs have been defined in the context of the current study

Table 4.1 The list of VS that formed the probes as derived from Bloom's taxonomy and the Housen model

VS Code	Related VSs and definitions
T01	Analyse; Interpret; Assess; Evaluate; Examine; Investigate *To break down into components or essential features by making sense of or assigning a meaning to or give explanation and to examine and or assess carefully and observe or inquire into in detail by examining systematically to observe carefully or critically.*
T02	Arrange/order/organise/classify *To put into a specific order or relation through a methodical or systematic arrangement or to arrange in a coherent form or pattern based on specific features*
T03	Compare; relate *To examine and note the similarities or differences of and bring into or link in logical or natural association and establish or demonstrate a connection between*
T04	Complete *To make whole, with all necessary or normal elements or parts*
T05	Critique *To critically examine and judge something*
T06	Depth perception/ Recognition of depth cues *To perceive spatial relationships and distances between objects, in multi-dimensions*
T07	Describe/discuss/explain *To make plain or comprehensible by adding details or to justify or offer reasons for or a cause and give a description of, by conveying an idea or impression in speech or writing; characterize*

T08	Discriminate *To recognize or perceive the difference*
T09	Find; locate *To come upon or discover by searching or making an effort; to discover or ascertain through observation, to determine or specify the position or limits of by searching, examining.*
T10	Focus *To concentrate attention energy on something*
T11	Ground perception *To detect or perceive the part of a scene (or picture) that lies behind objects in the foreground*
T12	Illustrate; sketch *To clarify, as by use of examples or comparisons and to use drawings to describe roughly or briefly or give the main points or summary of*
T13	Imagine *To form a mental image of something that is not present or that is not given*
T14	Infer; Predict *To conclude by reasoning; in logic or reason or establish by deduction or state, tell about, or make known in advance, on the basis of special knowledge*
T15	Judge *To determine or declare after consideration or deliberation; to form an opinion or evaluation*
T16	Manipulate/Mental rotation; recognise orientation; Recognition; Identify; identify shapes *To move, arrange, operate, or control cognitively in a skilful manner for examination purposes and then to perceive multiple items with different orientation and/or shape to be the same if orientation and/or shape is rearranged*
T17	Outline *To give the main features or various aspects of; summarize*
T18	Perceive Luminance/Identify colours *To detect or perceive a visual attribute of things that result from the light they emit or transmit or reflect*
T19	Perceive motion *To recognize, discern, envision, or understand change of position in space and assign meaning to*
T20	Perceive speed *To recognize, discern, envision, or understand a rate of movement and meaning thereof*
T21	Perceive texture *To recognize, discern, envision, or understand the characteristic visual and tactile quality of the surface and meaning of such*
T22	Propose; Develop; formulate; devise; construct; create; produce; invent *To cause to exist in a new or different form through artistic or imaginative effort*
T23	Recall/retrieve *To remember by retrieving information from memory*
T24	Use *To put into service or apply for a purpose*

At this stage, it was observed that some skills have the same objective as a result, those skills that have a similar objective were given the same definition (see column 2, Table

4.1). For the purpose of the study, each skill was coded from T01 to T24, such codes are arbitrary. Table 4.1 lists only 24 VSs, however, it is acknowledged that given the multifaceted nature of visual literacy, more skills may exist but for the purpose of the current study, these were selected. To test for visual literacy, the currently available skills were used to develop probes.

4.3 Probe design[8]

To address the critical research questions a series of probes were designed (see "probe design" in Figures 1.3). Probes are defined as devices or instruments designed to investigate and obtain information on, in the case of the present project, the degree of difficulty of VSs. Because of interdependence of the skills (e.g. to "interpret" ERs, one has to be able to "perceive" visual cues), each probe is made up of more than one VSs (Table 4.1) that collectively aid the students to effectively respond to the probe. Furthermore, students' ability to respond to the probe depends on their ability to perform the individual VSs that make up the probe. Each VS was defined so that it was clear what was being addressed (Table 4.1). As a result, VSs that address the same cognitive process (Mayer, 2002) were given the same meaning, even though these may be tested differently and may fall in different levels of the Bloom's taxonomy (see Figure 2.6 in Chapter 2). For the purpose of the study, the probes covered propositional knowledge is the context of Biochemistry[9].

4.3.1 Background conceptual knowledge of the probes

As explained by Schönborn (2005, also see Schönborn & Anderson, 2005), students' ability to respond to any one VS related to an ER depends on at least three factors namely, students' conceptual understanding (C), their reasoning ability (R) as well as the mode (M) in which the ER is presented (Figure 4.1). In this regard, availability of all three factors (R, C and M) working together as C-R-M improves students' performance.

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[8] All the probes are also given in the booklet entitled "A Visual Literacy Test For Molecular Life Sciences" where the protocol for tests administration and assessment is also given.
[9] The "context of Biochemistry" referred to here and after is propositional knowledge of amino acid and protein structures, nucleic acid and protein synthesis, cellular structures as well as protein binding and for the lack of a term, the author refers to the probes as being in the context of Biochemistry

Therefore, for students to respond adequately to the probes under study, this model framed the overall nature of the probes and their suitability for the study as follows:

i) The probes had to be able to represent concepts clearly (“mode” in figure 4.1);

ii) Students had to have sufficient conceptual understanding (“conceptual” in figure 4.1); and

iii) Students had to have reasoning skills in order to respond to the probes and interpret ERs appropriately (“reasoning” in figure 4.1).

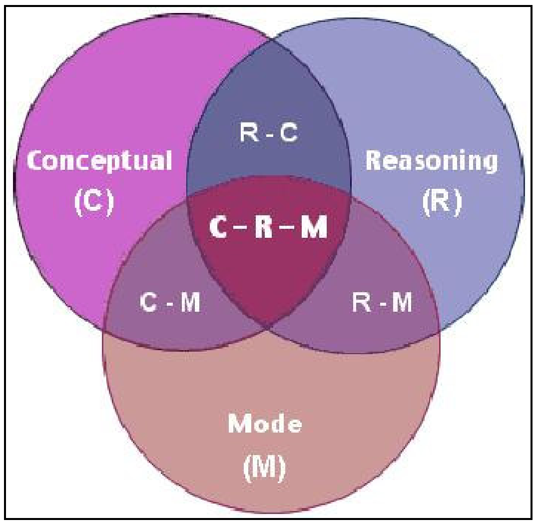


Figure 4.1: A model of factors that determine students' ability to interpret ERs in Biochemistry (Schönborn, 2005). In the figure, C = Conceptual knowledge, R = Reasoning skills, M = Mode of presentation.

Students’ conceptual understanding refers to prior knowledge that students bring (from prior knowledge) to the probe and reasoning ability refers to the total reasoning skills the students have for interpreting the probe and reasoning with the ER (Schönborn & Anderson, 2006). Using the model and its constituent factors to guide probe design (see Figure 4.1):

i) Each probe was context specific in that the terminology and the ERs used, modelled that used in the MLS (i.e. Biochemistry) as given in the propositional knowledge (see section 4.3.1.1).

ii) The concepts underlying the probes were specific to the above stated field in that all the probes were designed around the concepts taught and learned in the final year Biochemistry courses.

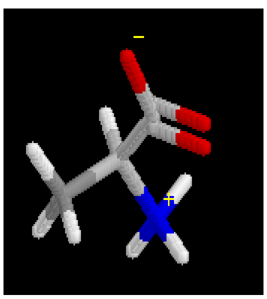
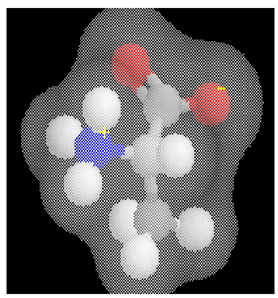
Biochemistry courses used to model the probes under study were those learned at the University of KwaZulu-Natal (Protein Structure and Function, BIOC304 and Advanced Protein Chemistry and Dynamics, BIOC306[10]), and the University of California Santa Barbara (Structure/Function Biochemistry[11]). The probes used in the study are given below[12].

4.3.1.1 Probes used in the current study

PROBE 1

- **Time allocated: 3 minutes**

a) Compare the following two diagrams with respect to the amino acid features represented.
b) Do the two diagrams represent the same amino acid or different amino acids? Explain.

- **Propositional knowledge:**

The ERs are representations of an amino acid. This is shown by the presence of a carbon molecule at the centre joined to an amino group (the blue attached to three white sticks that represent carbon) and a carboxyl group (the grey attached to three red stick that represent oxygen molecules). The other group (one grey carbon and three hydrogens) attached to the centre carbon is a side chain. In the notation, the two sticks that are close to one another and point to the same direction represent a double bond – single oxygen. The positive and negative signs indicate positive and negative charges respectively. On the diagram on the right hand side, is a "greyish" cloud that represents the electron cloud. Both the ERs have 3 carbons (grey), 7 hydrogens (white), 2 oxygens (red) and 1 nitrogen (blue) molecules, hence in both cases the molecular formula is $C_3H_7NO_2$. The amino acid represented by the molecular formula $C_3H_7NO_2$ is alanine. Since the ER on the left uses sticks only, it is a stick model of alanine, and because the ER on the right uses sticks and balls, it is a ball and stick model of alanine.

- **Visual Literacy Skills:**

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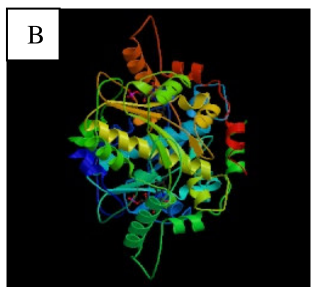
[10] http://www.ukzn.ac.za/handbooks/2006/SCAG%20Handbook%202006.PDF
[11] http://tutor.lscf.ucsb.edu/instdev/sears/biochemistry/
[12] For the convenience of the reader, all probes are also given in the booklet entitled "A Visual Literacy Test For Molecular Life Sciences" where the protocol for tests administration and assessment is also given.

VLS number	VLS name
1	Analyse; Interpret; Assess; Evaluate; Examine; Investigate
3	Compare; relate
6	Depth perception/ Recognition of depth cues
10	Focus
11	Ground perception
16	Manipulate/Mental rotation; recognise orientation; Recognition; Identify; identify shapes
18	Perceive Luminance/Identify colours

PROBE 2

- **Time allocated: 3 minutes**

Fully explain any differences between the structural features of the proteins represented in the following two diagrams.



- **Propositional knowledge:**

The two ERs represent proteins which are made up of beta pleated sheets and alpha helical structures. Diagram A is made up of almost the same amount of beta pleated sheets as alpha helices, while diagram B is made predominantly of alpha helices. Different colours are used to represent different units of the proteins; hence the structural make-up of the proteins is different. Since proteins are made up of amino acids, the different colour-coding indicates that the amino acids making up the two proteins represented are different.

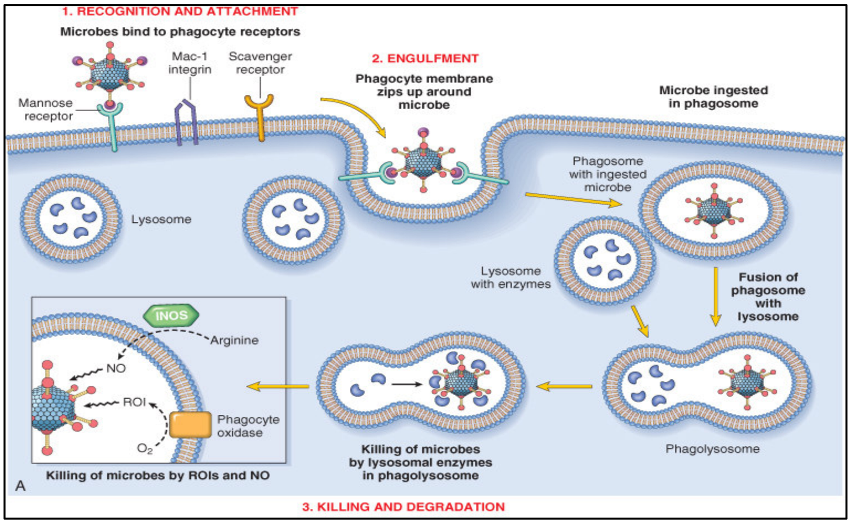
- **Visual Literacy Skills:**

VLS number	VLS name
3	Compare; relate
6	Depth perception/ Recognition of depth cues
8	Discriminate
11	Ground perception
18	Perceive Luminance/Identify colours

PROBE 3

- **Time allocated: 4 minutes**

Use the following diagram of microbial degradation in the cell to explain the role of the "lysosome" in the process that is represented.



- **Propositional knowledge:**

The ER above shows the process of phagocytosis. In the diagram, a microbe attaches to receptors called mannose receptors (1). This is followed by the engulfment of the microbe by the cell (2), to form a phagosome. This phagosome joins the lysosome (which carries proteolytic enzymes) to form a phagolysosome. In the phagolysosome, the lysosomal enzymes degrade the microbe (3) through protoelytic processes by ROIs and NOs.

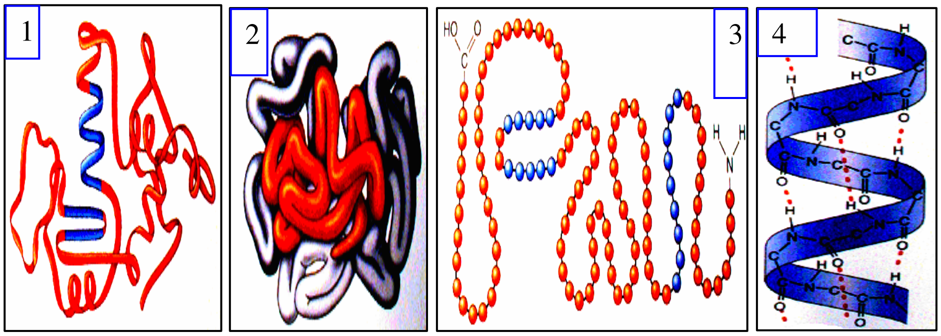
- **Visual Literacy Skills:**

VLS number	VLS name
1	Analyse; Interpret; Assess; Evaluate; Examine; Investigate
7	Describe/discuss/explain
9	Find; locate
10	Focus
16	Manipulate/Mental rotation; recognise orientation; Recognition; Identify; identify shapes
24	Use

PROBE 4

- **Time allocated: 2 minutes**

Use your knowledge of protein structure to arrange the following representations in order of increasing complexity. Give reasons for your chosen arrangement.



- **Propositional knowledge:**

The four ERs indicate different structural arrangement of a protein molecule. In this regard protein folding starts with the primary structure, the secondary structure, the tertiary structure and the quaternary structure. The primary structure is concerned with the arrangement of amino acids in terms of the number of amino acids and sequence to form a polypeptide chain through covalent bonding. This chain then forms a secondary structure through adoption of structural shape that forms alpha helices and beta pleated sheets. The helices and sheets form the tertiary structure through formation of globular structures and fibres. When globular structures and fibres of one polypeptide chain interact with others from other chains, they form larger proteins consisting of quaternary structure.

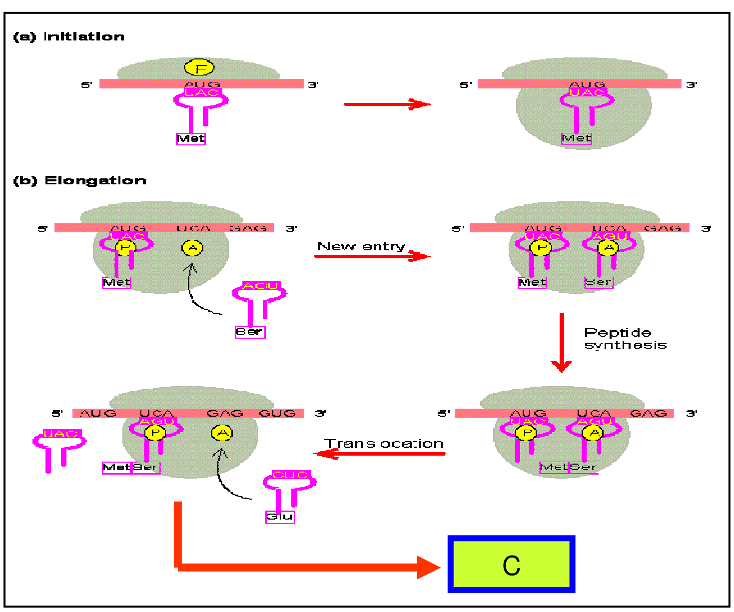
- **Visual Literacy Skills:**

VLS number	VLS name
2	Arrange/order/organise/classify

<u>PROBE 5</u>

- **Time allocated: 4 minutes**

Use the following diagram to predict step(s) "C", assuming there are no stop codons. Draw an appropriate diagram to illustrate your answer.



- **Propositional knowledge:**

The above ER indicates how the RNA codons are translated by enzymes to form proteins. Here the process starts with initiation which requires a start codon (AUG). An enzyme joins a coded amino acid to the start codon (Met where Met is the only amino acid that is coded by the start codon AUG) at the P site. Thereafter, another amino acid (e.g. Ser) is joined to the following RNA codon at the A site. Once this has taken place the two amino acids are joined through the formation of a peptide bond. After this another amino acid (e.g. Glu) is then joined to the following codon, and later joined to the two amino acids. This continuous joining of amino acids is called elongation.

- **Visual Literacy Skills:**

VLS number	**VLS name**
1	Analyse; Interpret; Assess; Evaluate; Examine; Investigate
4	Complete
13	Imagine
22	Propose; Develop; formulate; devise; construct; create; produce; invent
24	Use

PROBE 6

- **Time allocated: 2 minutes**

Do you think the following model is a good representation of a eukaryotic cell and its different components? Carefully explain your answer.

- **Propositional knowledge:**

The ER is a representation of a cell since it consists of organelles. Among other things, these organelles include a nucleus (large blue in the middle) and mitochondria (in pink). All the organelles including the nucleic acids in the nucleus are membrane bound structures which is a feature of eukaryotic cells.

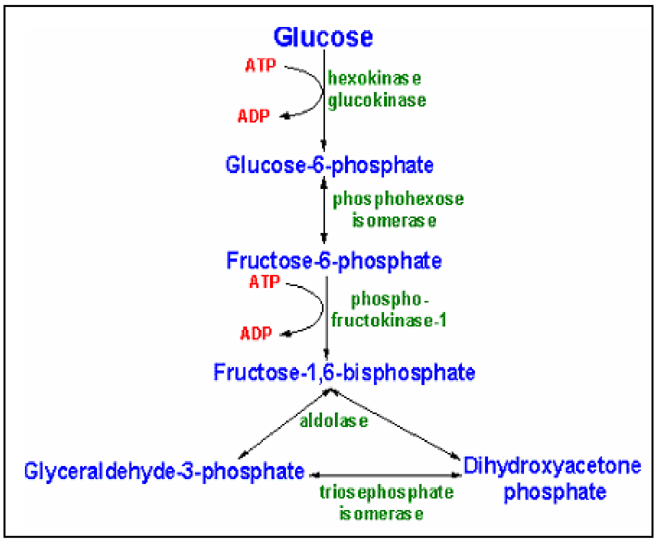
- **Visual Literacy Skills:**

VLS number	VLS name
1	Analyse; Interpret; Assess; Evaluate; Examine; Investigate
5	Critique
15	Judge
16	Manipulate/Mental rotation; recognise orientation; Recognition; Identify; identify shapes
23	Recall/retrieve

PROBE 7

- **Time allocated: 3 minutes**

Use the following diagram to describe the details of the process represented.



- **Propositional knowledge:**

This ERs shows the process of glycolysis. In this regard, Glucose is converted into Glucose – 6 – phosphate by hexokinase glucokinase by utilizing ATP which is reduced to ADP. Glucose – 6 – phosphate is reversibly converted to Fructose – 6 – phosphate by phosphohexose isomerase. Thereafter, Fructose – 6 – phosphate through the use of ATP is converted to Fructose – 1, 6 – bisphoshate, again yielding ADP. Fructose – 1, 6 – bisphoshate is then converted reversibly to either Glyceraldehyde – 3 – phosphate or Dihydroxyacetone phosphate by aldolase. Glyceraldehyde – 3 – phosphate and Dihydroxyacetone phosphate are also reversibly converted to one another by triosephosphate isomerase.

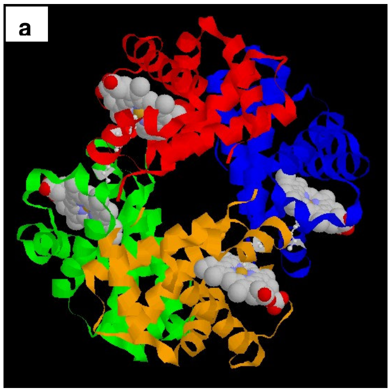
- **Visual Literacy Skills:**

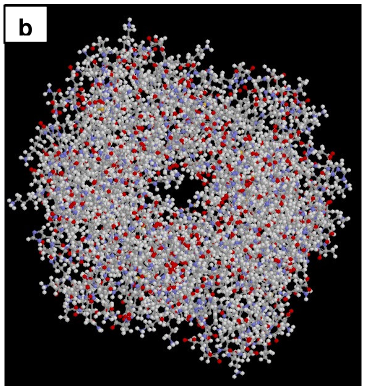
VLS number	VLS name
1	Analyse; Interpret; Assess; Evaluate; Examine; Investigate
7	Describe/discuss/explain

PROBE 8

- **Time allocated: 2 minutes**

Do you think the following two diagrams represent the same or different protein(s)? Carefully explain your reasoning by referring to the structural features that are represented.





- **Propositional knowledge:**

The two ERs depict protein structures. ER number A, uses balls (in grey) as well as alpha helices while B uses only ball representations. In comparison to B, ER number A clearly shows the different components i.e. the four grey units, and differently coloured units that make up the alpha helices. On the other hand, the molecule in B, does not have much detail except the redish and greyish balls. Both the structures have a pore in the middle.

- **Visual Literacy Skills:**

VLS number	VLS name
9	Find; locate
15	Judge
16	Manipulate/Mental rotation; recognise orientation; Recognition; Identify; identify shapes
18	Perceive Luminance/Identify colours

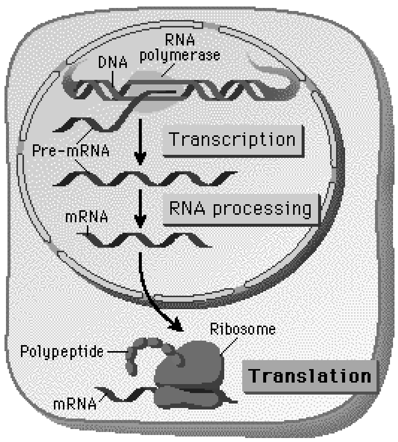
PROBE 9

- **Time allocated: 4 minutes**

Use you **own** drawings to outline the process of protein synthesis.

- **Propositional knowledge:**

The process of protein synthesis is called translation as the RNA molecule gets translated into an amino acid chain by enzymes. In translation, messenger RNA (mRNA) is decoded to produce a specific polypeptide according to the rules specified by the genetic code. Translation is necessarily preceded by transcription. Similarly to transcription, translation proceeds in four phases: activation, initiation, elongation and termination (all describing the growth of the amino acid chain, or polypeptide that is the product of translation). Activation - involves the joining of the correct amino acid to the correct tRNA, The AA is joined by its carboxyl group to the 3' OH by an ester bond. Initiation - Small subunit of ribosome binds to 5' end of mRNA with the help of initiation factors (IF). Elongation - Next AA in line will form complex with elongation factor and GTP. Termination - When A site faces a nonsense codons (UAA, UAG, UGA) no tRNA can recognize it, but releasing factor can recognize nonsense codon and causes the release of the polypeptide chain. The following diagram shows how this process takes place:



- **Visual Literacy Skills:**

VLS number	VLS name
2	Arrange/order/organise/classify
12	Illustrate; sketch
17	Outline
23	Recall/retrieve

PROBE 10

- **Time allocated: 4 minutes**

Suggest any molecular alteration(s) that can be made to change enzyme – substrate specificity? Use simple drawings to show your reasoning.

- **Propositional knowledge:**

An example of a process to alter molecular arrangements to change the enzyme – substrate specificity is mutation induction. This is because enzymes have an active site which is the region which facilitates their functioning by attaching substrates. The active site is only able to recognize and bind to a specific substrate molecule due to structural complementarity between the substrate and binding site. Other molecules with a variant structure can not be bound, similarly, other enzymes with a differently structured active site can not bind none complementary substrates. As a result, changing molecular structure (e.g. at DNA level) by mutation would alter the conformation and therefore the tertiary structure of the protein. This is because protein synthesis is brought about by DNA being *transcribed* into RNA which is then *translated* into a protein.

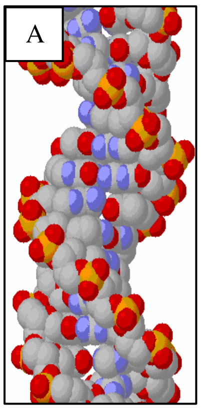
- **Visual Literacy Skills:**

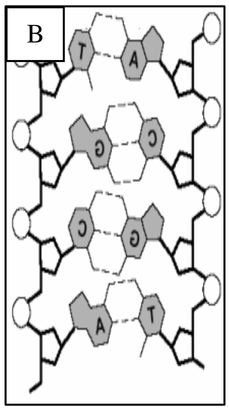
VLS number	VLS name
12	Illustrate; sketch
13	Imagine
22	Propose; Develop; formulate; devise; construct; create; produce; invent

PROBE 11

- **Time allocated: 2 minutes**

List the different features of nucleic acid structure that:
a) Are represented by each of the following two diagrams.
b) Are **not** represented by each of the following two diagrams.





- **Propositional knowledge:**

The two ERs show DNA molecules. ER number A shows a ball structure representation that does not show individual nucleic bases and sugars. This structure shows the helical appearance of a double stranded DNA molecule. ER number B shows a primary structure with nucleotide bases and sugars clearly shown. The helical appearance of DNA is not depicted.

- **Visual Literacy Skills:**

VLS number	VLS name
1	Analyse; Interpret; Assess; Evaluate; Examine; Investigate
9	Find; locate
10	Focus
16	Manipulate/Mental rotation; recognise orientation; Recognition; Identify; identify shapes

PROBE 12

- **Time allocated: 10 minutes**

See animation on *"Rolling adhesion"* in DVD included. The animation is played three times after which students are given the questions

Study the following animation and answer the following questions:

a) List the components of the animation that are:
i) stationary
ii) moving

b) Explain how the binding of the ligand to the selectin is facilitated.

c) What do you think would happen if leukocyte movement did not occur? Explain.

- **Propositional knowledge**:

See animation on *"Rolling adhesion"* in DVD included.

- **Visual Literacy Skills:**

VLS Number	**VLS name**
1	Analyse; Interpret; Assess; Evaluate; Examine; Investigate
7	Describe/discuss/explain
11	Ground perception
14	Infer; Predict
16	Manipulate/Mental rotation; recognise orientation; Recognition; Identify; identify shapes
19	Perceive motion
20	Perceive speed
21	Perceive texture

Before one could collect empirical data with these probes, instrument validity was investigated (Figure 3.1). The following section indicates what methods were used for instrument validation, what results were obtained and what knowledge was obtained from such results.

4.4 Validation of the VLT

Instrument validation was pursued in two ways namely, through the use of a panel of experts and by instrument piloting (Figure 3.1). The panel of experts' method was employed first in which expert recommendations were used to, in some cases, revise probes. Following this, the revised set of probes was piloted, and the results used to inform any further revisions of the instrument. Details of the methods employed are provided and discussed below.

4.4.1 Instrument validation employing a panel of experts

To ensure validity of the data in the current study, the instruments (or probes) were validated by utilizing qualitative and quantitative methods (see section 3.3 and Figure 3.1). In this regard, qualitative validation was conducted through a panel of nine experts consisting of: three 4th-year Biochemistry students (4YS); as well as two Biochemist Professionals (BPs), and four Non-Biochemist Professionals (NBPs) (see "instrument validation" in Figure 3.1). The BPs were Biochemistry lecturers at tertiary level and the NBPs were secondary school educators. This panel was given a questionnaire (see Table 4.2) requiring them to scrutinize each probe and determine its legitimacy and appropriateness for the research. This enabled the content and face validity of the probes to be measured (Section 3.4.2).

The questionnaire given to the panel of experts (Table 4.2) was designed to address two fundamental questions, through which the validity of the probes would be established. These questions were:

a) Do the probes question what they ought to be? Given that each probe was meant to assess specific skills (as given in section 4.3.1.1), the panel was meant to determine therefore whether the probes meet the specified standards. As a result, validation of the probe meant the confirmation of the probe's design as a valid instrument for addressing each of the stated VSs (See Section 4.3.1.1).
b) Is the probe suitable for the purpose it is designed for? In this instance the main focus was on the conceptual background of the probe as per propositional knowledge given in Section 4.3.1.1. Given that each probe was designed within the context of Biochemistry, it used terminology and ERs of relevance to that field, which also needed to be checked for accuracy by the panel. The experts were also asked to check whether, in their view, the probes were pitched at the appropriate educational level, namely for those students in final (3rd) year Biochemistry.

Table 4.2: Questions used in the questionnaire given to the experts and reasons for their inclusion.

Questions	*a) The ERs used in the probes are similar to those used in the MLS*
	b) The terminology used in the probes is similar to that used in the MLS
Reason for inclusion	Questions 1 and 2 above were concerned with the background conceptual knowledge of the probe (see also "Conceptual" in figure 3.4). In this regard, question 1 was designed to validate the probes ability to use ERs that exist in the MLS. Question 2 focused on evaluating the terminology used whether it is the same as that used in the MLS.
Questions	*c) The symbols used are easy to follow*
Reason for inclusion	This question focused on the probes ability to convey information. Given the different symbols used in the probes, question *c* attempted to validate the probes' understandability. In this regard, the panel had to determine whether they thought that students will be able to follow, perceive and understand the symbols used in the probes.
Questions	*d) The time allocated to each question is appropriate*
Reason for inclusion	Since each question was to be performed over a specified period of time, the panel had to give their opinion as to whether the time allocated for each probe was adequate. Given the different VSs attached to each probe, the panel had to scrutinize each probe and determine if students will be able to perform all the VSs in the given time without compromising understanding.
Questions	*e) The questions are easy to understand*
Reason for inclusion	Like question *c,* questions *e* focused on the probes ability to convey information. Here the panel had to determine whether the overall language used in the probes was suitable for the students.
Questions	*f) There is a good balance between text and pictures*
Reason for inclusion	Most probes were made up of the combination of ERs and text, it was then important that the amount of the ERs and text in each probe be balanced. This was determined by the panel by answering the above question so that students do not get overwhelmed or underwhelmed by lack of proper balance between ERs and text.
Questions	*g) The test is appropriate for 3rd year biochemistry students*
Reason for inclusion	The panel also had to assess the content of the probes and suggest in their experience whether they thought that typical 3rd year biochemistry students would have enough conceptual knowledge to respond to the probes.
Questions	*h) There are special skills required to interpret the pictures*
Reason for inclusion	Should the probes require any additional skills (except the VSs listed in Table 4.1, which was supplied to experts), the panel of experts were requested to indicate such. These could include any generic or non-MLS skills and/or those not directly linked to visual literacy.
Questions	*i) Other positive comments*
	j) Other negative comments
Reason for inclusion	The panel of experts was also asked to forward any other inputs by critiquing the probes. This was to cover any loop-holes that the questions in the questionnaire were not covering.

Table 4.2 lists the questions (in *italics)* used in the questionnaire given to the panel of experts and motivates for their inclusion. For each question, the panel had to give a closed response on a 4-point Likert scale (i.e. strongly agree, agree, disagree and strongly disagree), as well as an open response where they had to justify their choice in the closed responses.

Concerning the panel of experts, the author especially chose a wide range of different expertise in order to minimize any biasness amongst panel members due to knowledge backgrounds. The 4YS were chosen to be on the panel so that they could give the researcher an indication of what level of conceptual knowledge and experience was most appropriate for the VSs. Furthermore students' opinion would provide information that other panel experts could not because of lack of knowledge about students' true feelings about the probes. At the same time, the BP members of the panel, might use their experience to verify, the proper questioning ability of each probe, the use of the terms and diagrams in the field and their suitability for the students. To further limit subjectivity, NBP would provide objective knowledge about the questioning ability of each probe and its suitability. In combination, the responses from the different experts were intended to give the researcher confidence about the validity of the probes as suitable tools for the research under study.

The four-point rating scale stated above i.e. strongly agree = 3, agree = 2, disagree = 1 and strongly disagree = 0 (Hyrkäs *et al*, 2003) was used to calculate an inter-item correlation, t-test as well as content validity index (CVI) (see section 3.4.3; Hyrkäs *et al*, 2003). The inter-item correlation was calculated using the *Statistical Programme for Social Sciences* (SPSS) to determine the correlation between each panel member's overall score in relation to the next member's. The t-test was done to determine the relationship between the groups (i.e. NBP; BP and 4YS). The CVIs were calculated for each question according to the following formula:

$$\text{CVI} = \frac{\text{number of raters giving a rating of '2' or '3'}}{\text{Total number of raters}}$$

Where raters are the panel members and ratings ‘2’ or ‘3’ are generated from four-point rating scale.

As suggested by Hyrkäs *et al.* (2003), for the CVIs obtained, those questions in relation to the probes in the questionnaire that scored above 0.79 were regarded as acceptable, those between 0.7 and 0.78 as in need of attention and those below 0.69 as requiring revision or elimination. As a result, some probes were reviewed and some were substituted and/or adjusted. Furthermore, the correlations between the panel’s scores were calculated to determine the consistency of the scores, and hence reliability (section 3.4.3).

The experts were further asked to indicate from a list of VSs (Table 4.1), which ones best fitted each probe. In this regard the VSs allocated to each probe in Section 4.3.1.1 were also validated. This was such that for each probe, the VSs that were chosen at a highest frequency were regarded as best tested in the probes. As a result, from the list of probes that were generated using the Bloom’s taxonomy some VSs were eliminated and some combined based on the meaning and relevancy of each.

4.4.2 Instruments validation results and discussion

The face validity and content validity (section 3.4.2) of the probes was measured by analysing the responses from the panel of experts. In formulating these two forms of validity, inter-item correlations (the measure of relationship between two different items) were measured, where a high correlation indicated agreement among the panel regarding the appropriateness of each probe. Table 4.3 presents the inter-item correlation matrix of the panel. It was observed that in all cases there was a correlation. In this regard, had the results shown a significant lack of correlation between the experts’ responses, the instrument would have been rendered invalid and not reliable, in which case a significant improvement of the probes would have been necessary.

From the results, displayed in Table 4.3, it was noted that expert P2 showed a high number of negative correlations in comparison with the other experts. Analysis of this expert's open responses showed that he/she had a substantial number of questions unanswered due to "lack of relevant knowledge". This could be because this expert is not from the field of MLS and hence lacks the relevant conceptual knowledge. As a result this expert's overall conceptual input in the research was considered more in comparison to the statistical figures as given in Table 4.3.

Table 4.3: Inter-item correlation matrix generated for the panel of experts. P1 to P4 represent the non-biochemist professionals (NBP), P5 and P6 are the biochemist professionals (BP) and P7 to P9 are 4th year students within the field (4YS).

Panel members		NBP				BP		4YS		
		P1	P2	P3	P4	P5	P6	P7	P8	P9
NBP	P1	1.000								
	P2	.102	1.000							
	P3	.628	.522	1.000						
	P4	.870	-.065	.462	1.000					
BP	P5	.114	.213	.424	-.218	1.000				
	P6	.522	-.195	.647	.333	.655	1.000			
4YS	P7	.628	-.486	.385	.647	-.061	.647	1.000		
	P8	.853	.000	.679	.612	.535	.816	.679	1.000	
	P9	.566	-.258	.501	.361	.552	.843	.768	.885	1.000

Another point with regards to these correlations is the high correlation between the students' responses. This trend was also seen with respect to the BP. This indicates that these two groups of experts have a rather common background (within the field of MLS) and hence, share the same ideas regarding how the probes should be designed. However, the views of the NBP were not so consistent with each other's as well as with the other experts. Here, it was observed that probably due to inconsistent backgrounds, these professionals did not share the same views on the nature, aim and content of probes. This could be because they use their backgrounds (e.g. knowledge of Biology, Chemistry, Mathematics and Physics) to judge the probes.

Based on the correlation observed within the "groups" of experts (Table 4.3), it was implied that the probes were valid and reliable, with respect to the correlations. As a result, to further validate the instrument, Cronbach alpha (see section 3.4.3) was calculated values using the panel of experts' overall scores. This was done to determine the reliability of the probes. In this regard, if the Cronbach alpha value scored was below 0.80, the probes would be regarded as requiring careful review. In this regard, the Cronbach alpha value observed was 0.868. Hence, it was deduced that the probes were reliable. The high inter-item correlations (Table 4.3) and the high Cronbach alpha value, gave confidence that the probes were statistically reliable (section 3.4.3) from an expert perspective. Nonetheless to gain further confidence, we also looked at the t-test. In this instance the current researcher intended obtaining statistical definition of the relationship between groups. In this regard, the researcher tested for the null hypothesis that the mean scored by any one group is not the same as that of another group (Ho: $\mu_1 \neq \mu_2$). An ideal situation would be where all the group means are equal i.e. rejecting the null hypothesis. This is so because if all the experts had the same responses, then we have a consensus view in terms of the validity of the probes. The t-test results are given in Table 4.4.

Table 4.4: Results from the paired samples t-test comparing the mean scores of the three different groups. NBP denotes non-biochemist professionals, BP indicates the professional biochemist and 4YS indicates the 4th-year biochemistry students.

	NBP vs. BP	**NBP vs. 4YS**	**BP vs. 4YS**
Mean difference	0.000	0.1038	0.1037
SD	0.9083	0.9940	0.5100
95% CI	-0.7594 to 0.7594	-0.7273 to 0.9348	-0.3226 to 0.5301
DF	7	7	7
Test statistic t	0.000	0.295	0.575
2-tailed probability (P)	1.000	0.7764	0.5830
Conclusion	Reject Ho	Accept Ho	Reject Ho

The results in Table 4.4 show a significant difference between the means of NBP and that of the 4YS. This again could be explained by differing academic background knowledge. In spite of this case (NBP vs. 4YS), rejecting the hull hypothesis in more cases (i.e. NBP vs. BP and NBP vs. 4YS) provides confidence that there was a general consensus with regards to the nature, aim and content of the probes. This was further shown using the CVIs.

Concerning the CVIs, the current researcher suggests that the CVIs would serve to support the inter-item correlations, Cronbach alpha values and t-test results previously determined. In this instance, the researcher used the CVIs range values used by Hyrkäs *et al*. (2003) to determine whether the current probes require revision, elimination or retention. Figure 4.2 presents the CVI values observed from the questionnaire analysis for *each* question (see Table 4.2).

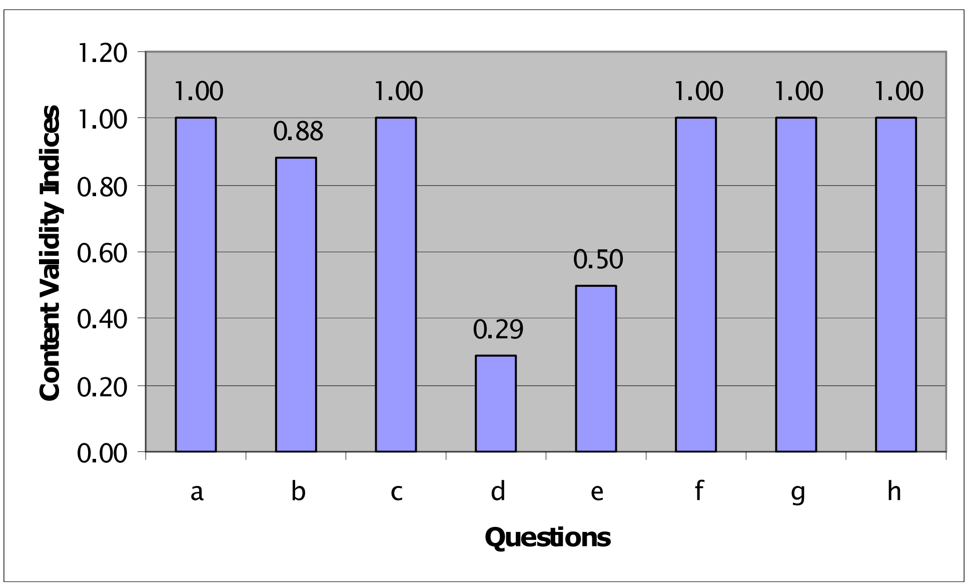


Figure 4.2: CVIs obtained from the panel of experts.

Analysis revealed that the panel of experts had two major concerns with the probes (see *d* and *e* in Figure 4.2) namely, the "insufficient amount of time allocated" for the probes and the "clarity of some of the probes". In this instance, the experts agreed that for some probes, the time allocated was very short in relation to the "cognitive effort" required to respond to the probe. Also, for some probes, the terminology used was not clear and hence rendered the probe “overwhelming” to respond to.

Given the CVIs in Figure 4.2, it was necessary to study each question in order to determine the qualitative nature of the concerns raised by the panel of experts. According to the results from the panel of experts, the probes (see Section 4.3.1.1) were considered valid but required minor adjustments, particularly with respect to *d* and *e* in Figure 4.2. In this regard, relevant examples in relation to the CVIs are discussed below.

a. ERs used in the probes are similar to those found in the MLS field

The questionnaire respondents generally agreed that ERs that are used in the probes were similar to those used in Biochemistry. For instance, expert P7 (a 4YS) suggested that he/she has:

> *“[Seen] the pictures in [books] before, even if they were not exactly the same…so interpretation of the test pictures was easy”.*

In this regard the 4YS suggested that they were familiar with the ERs from conceptual knowledge taught in the first to third year Biochemistry courses. This was supported by the BP who agreed that the ERs are similar to those taught in the undergraduate Biochemistry courses. In probe 1 (see Section 4.3.1.1) is an example of ERs representing an amino acid, such is taught in the Biochemistry course that teaches Protein Structure and Function at undergraduate level at the PMB and Westville campuses.

b. Terminology used in the probes is similar to that used in the MLS

With respect to the terms used in the probes, the respondents suggested that they were similar to those used in biochemistry. For instance, in the following probe:

> *“Fully explain any differences between the structural features of the proteins represented in the following two diagrams”,* (Probe 2).

The panel agreed that students in the MLS field would probably be able to understand terms such as “structural features” in the relevant context. However, it was suggested that some non-context specific terms that have ambiguous meanings may mislead the respondents. For instance, it was suggested that the terms such as *"'explain' and 'describe' have similar meanings" (P2)* and hence, when used ambiguously, students may not be able to respond to the probes as the researcher expected but have a different understanding of the probe.

c. Symbols used are easy to follow (i.e. read or interpret)

Concerning the interpretation of symbols, one of the experts suggested that:

> *"[The symbols] are large enough and spaced comfortably. I can work through the diagrams and notice differences" (e.g. P1)*

Given this, it was also suggested that careful attention needs to be paid to the clarity of ERs as lack of clarity may affect students' ability to respond to the VSs

d. Time allocated for each question is appropriate

Concerning time allocation, all respondents were satisfied with limiting the amount of time allocated to each question. It was suggested that this would ensure that students do not spend too much time responding to any one probe which might result in other probes not being responded to. However, one expert said;

> *"Some questions need careful observation and consideration before answers can be developed" (P4).*

For instance, it was suggested that for probes requiring "drawing" and "writing", more time should be allocated as it takes longer to perform such VSs. Some questions were also labelled by experts as having too little allocated time yet others were considered as incorporating too much time.

e. Questions are easy to understand

The panel of experts found that it was difficult to understand some of the questions with some probes being considered "*vague*" (P2). For instance, one probe had the following statement:

> *"From your knowledge of protein structures, arrange the following protein structure representations in order of complexity"*

In this regard, phrases such as "order of complexity" are rather ambiguous. Hence, the *"students may not [necessarily] know what is meant in scientific terms" (P5).* Also, it was indicated that the focus of the questions needed to be narrowed so as to help student understand the requirements of the question.

f. Good balance between text and pictures

The ratio of text to pictures was regarded as acceptable and well balanced. In this instance, the amount of text did not 'dominate' over the number of ERs. For example, expert P9 suggested that:

> *"Pictures were accompanied with some text (not a lot) so the picture and the text were relevant to one another, i.e. there was not too much text…"*

In this manner students would not be "overwhelmed" or "underwhelmed" by either the amount of text or the number of ERs.

g. VLT is appropriate for 3rd year biochemistry students

The respondents, particularly the 4YS, suggested that the VLT requires conceptual knowledge that students normally acquire during their first three years of studying Biochemistry. However, one expert (P8) cautioned that:

> *"The test is appropriate for 3rd year biochemistry students, but not for lower levels as it was quite a challenging test".*

Hence, the VLT would be suitable for the 3rd year Biochemistry students. However, the BP suggested that depending on the concepts learned in such undergraduate courses, and the emphasis thereof, some students may not be able to do certain questions. Nonetheless, the general consensus was that the probes were appropriate for 3rd year students.

h. Special skills required to interpret the pictures

All respondents agreed that there are different skills required to respond to the probes. These include mainly VSs that will enable students to *"perceive"* the graphical components of the probe, *"cognitively process"* information as well as *"communicate"* knowledge (quotes from P4). In this regard, there is no one specific skill that is required but a combination of different skills- hence the multifaceted nature of visual literacy (see section 2.6). For instance, in probe 5 (see Section 4.3.1.1), students would have to be able to *perceive* the different graphical components of the probe. Once they have perceived such, they need appropriate skills to *understand* and make sense of the probe by cognitively processing the probe. Thereafter students need to be able to use their cognitive skills to predict the outcome as denoted by "C" where they are expected to *communicate* such an outcome through drawings.

Given the above concerns, relevant changes were made to the probes (the probes presented in this thesis i.e. section 4.3.1.1 are those that were revised). These included:

- Excluding ambiguous terms that give vague understanding of the probe;
- Clarifying questions that had ERs and text where the meaning was not clear;
- Re-adjusting the amount of time allocated to each probe so that time would not be a factor when students were responding to the probes; and,
- Clarifying those questions that contained vague phrases.

After this was done, the revised probes (as given in Section 4.3.1.1) the experts were asked to determine what VSs are required to perform such probes.

4.4.3 Allocation of VLSs to probes

As indicated in section 4.3, probes were designed in such a way that each probe would require in some cases several different skills in order to perform it (see Section 4.3.1.1). Such VSs originated from the revision of the literature, particularly the Blooms taxonomy (Figure 2.6) and the process of visualization (Figure 2.4). Like the probes, the allocation of skills to individual questions needed to be validated. In this regard, a list of skills composing visual literacy was given to the experts so that they could independently indicate the skill(s) which they felt were being addressed in each given probe. Definitions of these skills (Table 4.1) were also reviewed by the panel who agreed on what each skill meant (the list in Table 4.1 was reviewed and approved by the panel of experts). Those skills allocated more frequently by experts to each probe were the ones designated to each probe (see Section 4.3.1.1).

Table 4.5: Indicating the skills allocated to each probe by the panel of experts. VS code is the arbitrary codes used in the research and probe numbers 1 to 12 correspond to the probes in section 4.3.1.1. The "#" indicates the VS allocated to the probe by experts.

VS Code	Probe Number											
	1	2	3	4	5	6	7	8	9	10	11	12
T01	#		#		#	#	#				#	#
T02				#					#			
T03	#	#										
T04					#							
T05						#						
T06	#	#										
T07			#				#					#
T08		#										
T09			#					#			#	
T10	#		#								#	
T11	#	#										#
T12									#	#		
T13					#					#		
T14												#
T15						#		#				
T16	#		#			#		#			#	#
T17									#			
T18	#	#						#				
T19												#
T20												#
T21												#
T22					#					#		
T23						#			#			
T24			#		#							

In the course of this process, the probes obtained a varying number of VSs (see Table 4.5). This is because some VSs form the basis of the visualization process, for example, in order to respond to the probes, students often need "to break down the probe into components or essential features (text and ERs) and make sense of the different parts thereof". Such an activity is a definition to VS *T01* i.e. "Analyse; Interpret; Assess; Evaluate; Examine; Investigate", and hence this VS appeared more frequent than the other VSs (Table 4.5). At the same time, it was rare for student "to make whole, with all necessary or normal elements or parts" which is VS *T04* (Table 4.5). This inconsistency in the number of VSs per probe however did not jeopardise the research. This is because, for those VSs that appeared more frequently, an average score was calculated so as to eventually have a single score for each VS.

Following the instrument validation process, it was decided that the probes were suitable for the research. Nonetheless, since validation was done purely from an expert perspective, it was necessary to still validate the probes from a student perspective by administering them to a pilot group of students so as to fully test their usefulness for actually measuring visual literacy.

4.4.4 Piloting of the instrument

After validating the instrument through the panel of experts, probes were further validated through piloting them on postgraduate Biochemistry students (see "instrument validation" on Figure 3.1). Here all variables applicable to administering the VLT were implemented (see section 4.4.4.1 below). Overall, the VLT administration procedure was similar to that stipulated in the Aptitude Tests administered by the South African HSRC[13], namely, announcing all relevant instructions; providing an example or practice question, controlling time for VLT performance and collecting of the scripts soon after the allocated time has elapsed. The full protocol followed in this exercise is given in below.

4.4.4.1 The VLT administration and score allocation protocol[14]

a. Administering the VLT

- Instructions concerning completing the VLT must be handed out first. The tester must ensure all students understand the instructions clearly.

[13] Due to ethical concerns, details of the relevant documents remain confidential to the Human Sciences Research Council

[14] The The VLT administration and score allocation protocol is also given in section 4.4.4.1

- All students are to complete the VLT in a specified time limit as it appears next to each question.
- Students must work independently, no open book or sharing of information.
- Students must not prepare for the VLT prior to writing
- The VLT should be given to students as a Microsoft PowerPoint presentation.

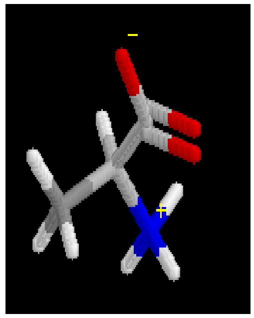
b. Allocating scores

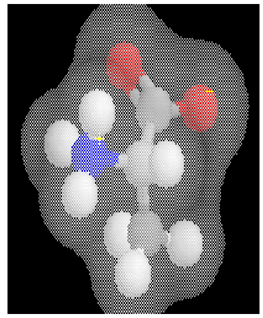
- Scores should be allocated for each *VLS* per *probe*
- The procedure for allocating the scores is based on Schönborn & Anderson (2005) model of seven factors that determines students' ability to interpret ERs (see figure 3.4). In this regard the three areas of concern that were used to determine the student’s score were their reasoning skills (R), conceptual knowledge (C) and mode of representation (M), all with regards to the use of conceptual (propositional) knowledge and visual skills to respond to the probes. Therefore the score ranged from 0 to 3 on a 4-point Likert-type scale as follows:

Grading	Score	Definition, i.e. reason for a score
Correct	3	High degree of conceptual (propositional) and visual knowledge used to provide a relevant response with high amount of detail i.e. C – R – M.
Acceptable	2	An average amount of conceptual (propositional) knowledge, where one uses mainly conceptual knowledge and ER based knowledge to respond to the probe i.e. C – M, with little evidence of in depth reasoning e.g. student regurgitate answers from conceptual knowledge.
Partially correct	1	Response based on reasoning with ER, little or no evidence of conceptual understanding i.e. R – M, or response based by reasoning only with regard to conceptual knowledge and no evidence of ER based reasoning i.e. R – C. (i.e. R-M or R-C not both)
Incorrect	0	No response or incorrect response based on lack of, or incorrect conceptual knowledge and/or reasoning ability in relation to the ER

For the purpose of clarifying the scoring procedure used in allocating the scores, below is an example using Probe:

Probe 1:
a) Compare the following two diagrams with respect to the amino acid features represented.
b) Do the two diagrams represent the same amino acid or different amino acids? Explain.



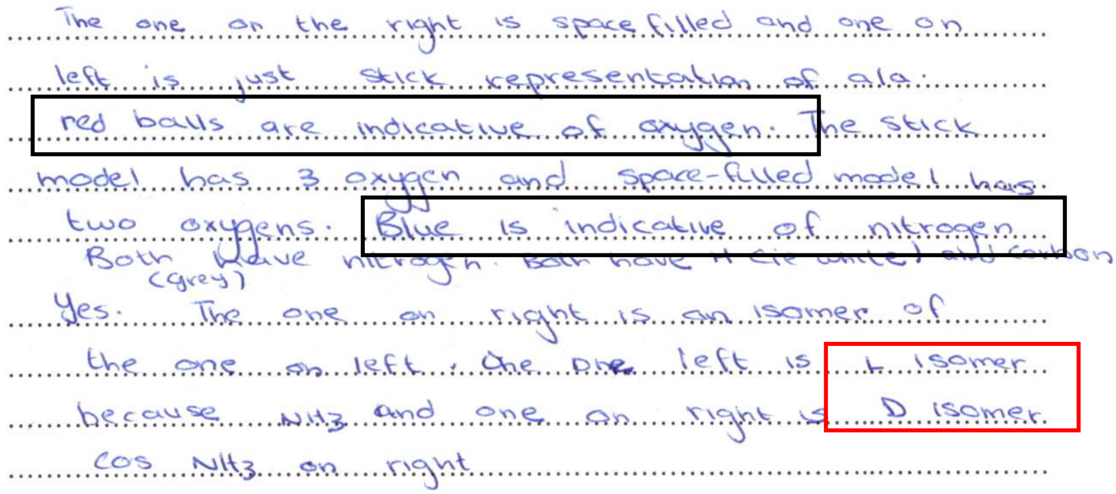


The ERs are representations of an amino acid. This is shown by the presence of a carbon molecule at the centre joined to an amino group (the blue attached to three white sticks that represent carbon) and a carboxyl group (the grey attached to three red stick that represent oxygen molecules). The other group (one grey carbon and three hydrogens) attached to the centre carbon is a side chain. In the notation, the two sticks that are close to one another and point to the same direction represent a double bond – single oxygen. The positive and negative signs indicate positive and negative charges respectively. On the diagram on the right hand side, is a "greyish" cloud that represents the electron cloud. Both the ERs have 3 carbons (grey), 7 hydrogens (white), 2 oxygens (red) and 1 nitrogen (blue) molecules, hence in both cases the molecular formula is $C_3H_7NO_2$. The amino acid represented by the molecular formula $C_3H_7NO_2$ is alanine. Since the ER on the left uses sticks only, it is a stick model of alanine, and because the ER on the right uses sticks and balls, it is a ball and stick model of alanine.

The following were some of the skills being tested:

VS number	**VS name and definition**
T06	Depth perception/ Recognition of depth cues i.e. "*To perceive spatial relationships and distances between objects, in multi-dimensions*"
T18	Perceive Luminance/Identify colours i.e. "*To detect or perceive a visual attribute of things that result from the light they emit or transmit or reflect*"

Below is a response that was given by student 2P25:



The one on the right is space filled and one on
left is just stick representation of ala.
red balls are indicative of oxygen. The stick
model has 3 oxygen and space-filled model has
two oxygens. Blue is indicative of nitrogen.
Both have nitrogen. Both have H (ie white) and carbon
(grey)
Yes. The one on right is an isomer of
the one on left. The one left is L isomer
because NH_3 and one on right is D isomer
cos NH_3 on right

To score the students response with regards to the two skills (T06 and T18) the following was done:

- *VS 06 - Depth perception/ Recognition of depth cues*

As indicated in the red box on the student response, the student is able to detect that the arrangement of the atoms on the ER are not on the same plane, which is denoted as either “L and/or D form” in Biochemistry. This student’s response shows that the student is able to perceive the spatial relationships between the elements of the ER and perceive the different dimensions as given in the ER. Furthermore, the student is able to use conceptual knowledge to define the spatial arrangement within the ER by using correct terminology which is context specific. In this regard the student shows a fair amount of conceptual knowledge by using relevant knowledge and ER based knowledge to respond to the probe i.e. C – M (see Figure 3.4). However, the student in this regard does not explain thoroughly what is meant by the terms “L isomer” and “D isomer” and how she came to conclude that the “one on the left is L isomer” and the “one on the right is D isomer”. With this analysis, this student was scored as “**Acceptable or 2**” for Depth perception/Recognition of depth cues.

- *VS 18 - Perceive Luminance/Identify colours*

Looking at the information in the black boxes in the student's response above, he/she is able to tell the different colours displayed by detecting visual attributes of elements that result from the light they "emit". In this regard, the student fulfils the requirements of perceiving luminance or identifying different colours correctly. Given this ability, the student then uses conceptual knowledge to give meaning to this colour coding. In this case, as taught in Biochemistry, in the ER "red balls are indicative of oxygen" and "blue [balls are] indicative of nitrogen". In this instance, the student is able to use conceptual knowledge to reason with the ER. As a result, for the skill "Perceive Luminance/Identify colours" the student was scored as "**Acceptable or 2**".

Given that a number of probes would be testing the same skills, the scores would be averaged out to get a mean score for the skill. In this regard, a score sheet like the one below is typical of what would be obtained for a student. The average score would then be entered into the Rasch model for analysis.

Probe number	**1**	**2**	**8**	**Average (rounded off)**
Score for VS 06	2	3	N/A	3
Score for VS 18	1	2	2	2

Following the completion of the pilot test by the students, the results were analysed utilizing the Rasch model to determine the students' ability to respond to the questions with a view to excluding probes that were either too easy or too difficult, as well as to verify the procedure to be followed in administering the VLT. In this regard, to determine the students' ability to perform the VSs, answers were graded with reference to the researchers' propositional knowledge as stated in Section 4.3.1.1 as well as the Schönborn and Anderson model (Figure 4.1). Thereafter, the students' responses in relation to this propositional knowledge were regarded either as correct (graded 3), acceptable (graded 2), partially correct (graded 1) and incorrect (graded 0) as per protocol given in section 4.4.4.1, the results are given in Table 4.6 below.

As seen in Table 4.6, the reliability value of 0.60 was observed. Even though such a value is not very close to 1.0 (highest possible reliability index), with the sample size of four participants such a value was acceptable. Furthermore, the process was able to identify potential problem questions as it indicated four difficult questions as well as four very easy questions. Such questions had to be revisited and the problem areas which were also identified and rectified. Another important finding of this exercise was the ability of the students to perform all the probes and relevant VSs. In this instance, the researchers gained evidence that the probes were doable. In this regard, it was acknowledged using empirical method that the conceptual knowledge gained at undergraduate levels of Biochemistry was sufficient for students to respond to the probes under study.

Table 4.6: The summary of the results obtained from the pilot, these results were generated using the Rasch model

	Input	**Measured**
No of items (VSs):	24	24
Mean	5	3
S.D.	1	
Reliability index	0.60	
No. of most difficult probes	4	
No. of most easy probes	4	

4.5 Summary and conclusion

At this stage, the researcher had obtained instrument validity through quantitative and qualitative methods. Concerning the quantitative methods, the inter-item correlations, Cronbach alpha values and the CVIs were determined. These were substantiated by inductive analysis of the panel of experts concerns as well as the allocation of VSs by the panel of experts. All these methods showed that the instrument was valid and reliable provided some minor adjustments were made, which was done prior to using the VLT for data collection with respect to the research questions under study. The piloting of the probes further gave confidence that the instrument was valid and reliable for the research. Therefore, at the end of this process the researcher was confident that the instrument was valid and suitable for the research. At this stage, data for the formulation of the empirical taxonomy was collected.

As indicated in Figure 3.1, following instrument validity as discussed in this Chapter, the researcher then proceeded to collecting data for the synthesis of an empirical taxonomy of visual literacy. From such data the research questions as stated in Chapter 1 were to be responded to. Chapter 5 of this thesis provided such data and the analysis thereof.

5. Chapter 5: An Item Difficulty Map for Constructing a Taxonomy of Visual Literacy

5.1 Introduction

Following the instrument development and validation process presented in Chapter 4, which sought to provide a VLT (probes and VLSs), the current Chapter describes how the VLT was used to gather data with which to respond to the research questions stated in Chapter 1. This data was used particularly to determine whether "specific levels of visual literacy can be defined in the MLS" and whether "a taxonomy is a useful way of representing the levels of visual literacy for MLS" (see section 1.3). Such an understanding was also be used to crystallize a definition for visual literacy for the MLS (see sections 1.3 and table 2.2).

5.2 Sampling of students

According to Webster (1985), "research" is an attentive investigation aimed at exploring, by way of discovering, interpreting and revising non-existing or existing truths about the nature of particular concepts. Such actions are used to provide new understanding of the global systems of knowledge. Due to the impracticability of studying large-scale systems, samples are usually taken in which findings are used to make sensible conclusions and generalizations about populations through the use of statistical inferences (Taylor - Powell, 1998).

In order to appreciate the usefulness of samples in scientific research, one needs to understand what a sample is and how sample data can be used to infer to larger population. By definition a sample is a small part of a whole, selected using specific methods, with the intention of using it to represent the whole (e.g. Dytham, 1999). Such samples are used to test hypotheses about the whole (e.g. population) (e.g. Dytham, 1999). As a result, clearly defined sampling methods need be followed when a research investigation is being conducted, so that the sample is a good representation of the population, and such methods should suit the purpose and nature of a given study.

In research, sampling methods vary and the choice depends entirely on the aims, research questions and nature of the research (Dytham, 1999; Taylor - Powell, 1998). There are two major types of sampling, namely, probability sampling and judgement sampling (Dytham, 1999). Probability sampling refers to randomly selecting units in a given population (Taylor - Powell, 1998). This means every individual unit in the population has an equal chance of being selected. As a result, the information collected has a likelihood of representing the entire population (Dytham, 1999; Clarke, 1980). With non-probability or judgement sampling, there is no expectation that each unit has an equal chance of being selected (Taylor - Powell, 1998). This may be due to a limitation of the availability of participants or, the sampler is more interested in discovering in-depth information about a particular section of the population (Taylor - Powell, 1998), which is what is often done in interviewing where selections have been made on the basis of prior student responses to written probes. Another example of judgement sampling is quota sampling where a large population is divided into subgroups based on specific information (Kitchenham & Pfleeger, 2002). Nevertheless, in both the probability and judgement sampling methods, a well defined number of participants, also known as sample size, are chosen (Clarke, 1980).

Sample size is an important factor a researcher needs to consider when sampling. Depending on the needs of the research, samples must be appropriate reference studies through which inferences about a population can be made (Dytham, 1999). For instance, if a sample is too small, the results thereof may be statistically insignificant (Kitchenham & Pfleeger, 2002). Also, with inadequate sampling, the ability to compare or contrast between different sets of the population may be limited (Kitchenham & Pfleeger, 2002). As a result, the effect of sample size is important when comparisons between groups are to be made, for example, when sampling two groups that vary in sizes may negatively affect the comparison.

Once a sampling method has been chosen for the research, researchers then consider the type of data (i.e. qualitative and/or quantitative) to be used in the research. This may be done prior to, or after deciding on the sampling method to be followed. However, a sampling method, and the type of data to be used often go hand in hand in that each sampling method is suitable for particular type of data (Taylor - Powell, 1998).

5.2.1 Sampling method employed in the current study

For the purpose of the present study, a non-probability (or judgement) sampling (Taylor – Powell, 1998) approach was undertaken. Here, a specific group of students was selected based on specific conditions. In this regard, from data collected from instrument validation and piloting, final (3^{rd}) year students in Biochemistry were best suitable for the study, given the propositional knowledge required to respond to the probes (see Section 4.3.1.1). As a result, quota sampling was done where a large population of university students was divided into smaller groups as per students' background of studies (Kitchenham & Pfleeger, 2002). At the end, a specific proportion known to best suit the aims of the study i.e. students in the field of MLS at the University of KwaZulu-Natal (Pietermaritzburg (PMB) and Westville Campuses), where the study was based, were selected. The selected students were undertaking courses Biochemistry 304 and 306 (taught in PMB and Westville Campus, respectively). In the PMB campus, 31 students participated and in the Westville Campus, 75 students participated resulting in a total of 106 students. The difference in number of participants from each campus was because of student availability. This, however, did not jeopardize the validity and reliability of the data because; item calibration studies using the Rasch model require at least a sample size of 16 to 36 and 27 to 61 (Nijsten *et al.*, 2007; Linacre, 1994). Such samples sizes provide item calibrations stable (i.e. standard deviation) within $\pm$ 1 logit at 95% and 99% confidence[15] (e.g. Nijsten *et al.*, 2007; Beltyukova & Fox, 2002; Linacre, 1994). These studies include scale purification and taxonomy fixation as is the case in our current study. Thus our sample size of 106 was considered suitable for the present study.

[15] http://www.rasch.org/rmt/rmt74m.htm

However, if in the study the intention was to generalize the results to a larger population, the sample size would have required revision. Once a specific group of students was selected for the study, prior knowledge was measured (before they did the VLT) as such knowledge would affect the manner with which students would respond to the VLT (see Figure 3.1).

5.2.2 Participants' prior knowledge and reasoning skills

Before the VLT was administered, students' prior knowledge factor was measured (Figure 3.1). As discussed in section 2.4.2.5, lack of relevant prior knowledge may cause students not to be able to respond to the probes accordingly. According to the constructivist theory of learning, knowledge is constructed by integrating new knowledge with already existing knowledge (Lowe, 2003; Thompson, 1995). Therefore, at any given point, students have a certain degree of knowledge in their cognitive structures that is either scientifically acceptable or otherwise, depending on the nature and context. For instance, students entering the 1st year at tertiary level have multiple forms of information from social life, primary and secondary education. It is upon this existing knowledge that new knowledge will be constructed.

Since the current research aimed at formulating a measure of students' visual literacy, it was important to first determine the students' prior knowledge as it would affect visual literacy. Such a measure was crucial as it would assist the researcher in determining if students' visual literacy ratings only reflected VS as desired or were "tainted" by variations in students' prior conceptual knowledge and reasoning skills. Such prior knowledge was then divided into two major components i.e. conceptual knowledge of Biochemistry and generic visual reasoning ability (Figure 3.1). Conceptual knowledge was determined by assessing students' previous Biochemistry results and generic visual reasoning ability was assessed by administering a Psychometric Visual Test (PVT), details of which are given in the following sections. Due to logistical difficulties, such prior knowledge was only measured on all the PMB students (N = 31) and not on the Westville students.

5.2.2.1 Conceptual knowledge in Biochemistry

As a control measure to ensuring that students had sufficient conceptual knowledge to be able to perform the VLT, their current conceptual knowledge of relevance to concepts covered by the test, was measured (Figure 3.1). In the context of the current research, prior conceptual knowledge refers to students' state of understanding of the interrelationships of basic Biochemistry concepts before the administration of the VLT. Such knowledge covers the propositional knowledge required to respond to the probes as given in Section 4.3.1.1. As a result, it is important to ensure that students have sufficient conceptual knowledge before they are subjected to the VLT.

As stated above, students participating in the current study were enrolled in either the Protein Structure and Function course (BIOC304, in PMB) or Advanced Protein Chemistry and Dynamics (BIOC306, in Westville). Even though these courses are taught at different campuses, they were similar since they are taught in the same School of the University of KwaZulu-Natal (Department of Biochemistry), which aims to achieve the same outcomes in their students. In these courses students are taught about the "concepts and methods for the determination of primary, secondary, tertiary and quaternary structures of proteins; methods for the representation of the 3-D structure of proteins and the families of proteins which have thus been identified; mapping of enzyme active sites and enzyme reaction mechanisms"[16]. The propositional knowledge required to respond to the probes under study (see Section 4.3.1.1) is covered in these courses. Furthermore, the courses are designed not only to teach students technical skills but also visual skills. During this period, coursework tests are administered as part of assessment.

In determining students' prior knowledge, results from preceding Biochemistry courses (i.e. percentage obtained in the 2nd year examinations) were collected (Figure 5.1) from the PMB students. The results presented in Figure 5.1 are the average percentage marks obtained by each student from PMB in two previous Biochemistry courses, as well as one assessment quiz for a Biochemistry course that students were undertaking at the same time of the research.

[16] http://www.ukzn.ac.za/handbooks/2006/SCAG%20Handbook%202006.PDF

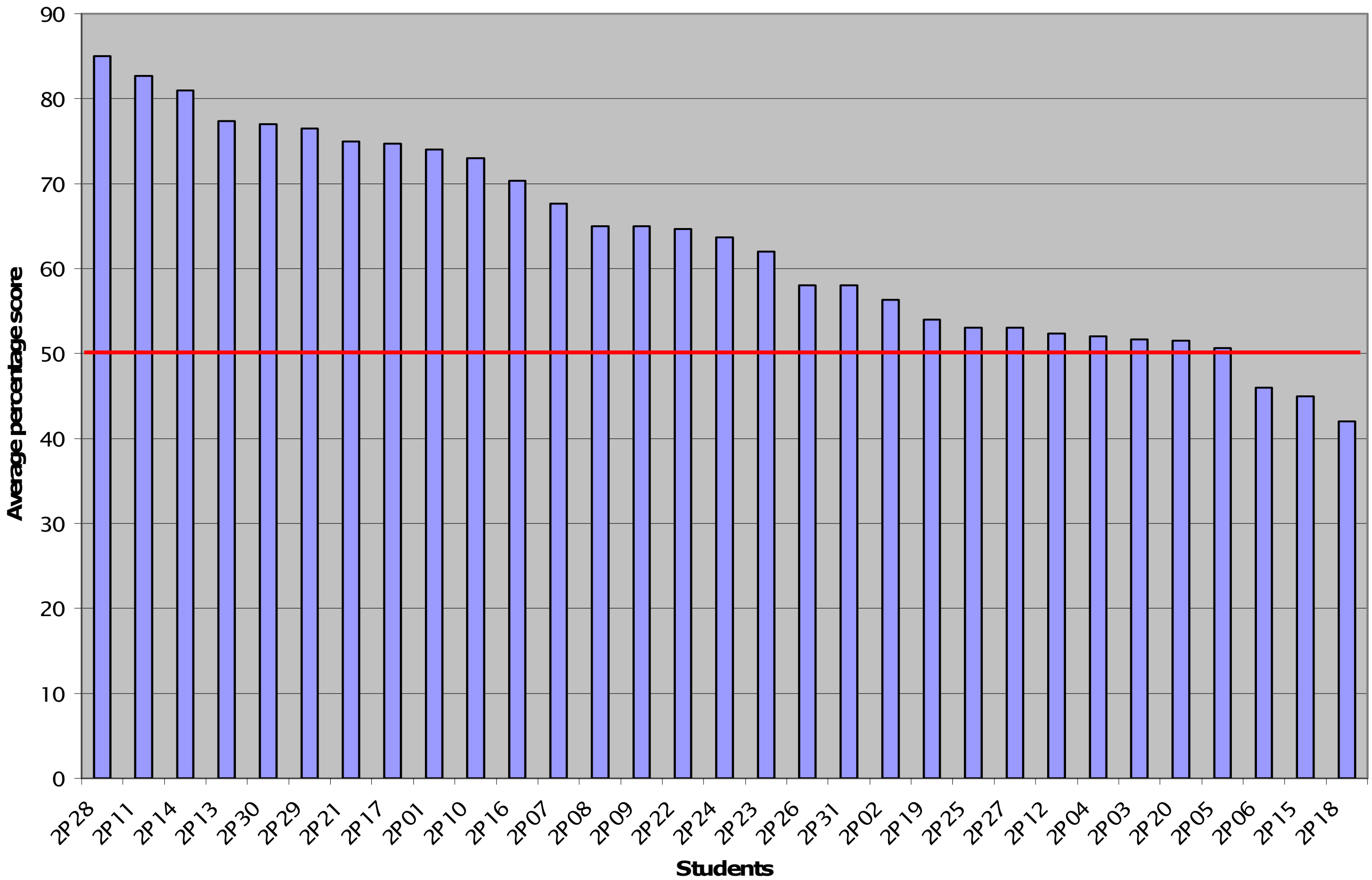


Figure 5.1: The average percentage score obtained by the students in two previous Biochemistry courses and one assessment quiz. The codes used, e.g. 2P28, 2P11 etc are student IDs used for the purpose of the study

From Figure 5.1, it can be seen that only three students were unable to achieve a pass mark (i.e. scored below 50%). The variations in conceptual knowledge (Figure 5.1) served as a good control measure as it would indicate whether visual literacy is linked to conceptual knowledge. In this regard, the average score for all the students was found to be 63%. Such a mark was sufficient to give the researchers confidence that the students participating had enough conceptual knowledge to enable them to participate in the VLT. In relation to the 4YS (Chapter 4), an average above 60% was a good finding, because students at the UKZN need to obtain an average mark above 60% to qualify for the fourth year of study in Biochemistry. In this regard, the results indicate that the 4YS who participated in the pilot study (Chapter 4) and the instrument validation were a good indicator of 3rd year students' ability to participate in this study.

5.2.2.2 Generic visual literacy

In line with the panel of experts' recommendation of VS as one of the most important prerequisite for students to respond to the VLT, students' current generic visual skills were measured (Figure 3.1). Here, students' ability to perform spatial and visual reasoning was measured using a Senior Aptitude Test designed by the Human Sciences Research Council (HSRC).

Aptitude tests are commonly used by psychologists as a tool in vocational assessment, either in career counselling or in organizational contexts as a predictor of job / occupational performance. Unlike tests of general intelligence which produce a global or general score ("IQ"), aptitude tests can evaluate potential related to *specific* abilities and are often designed for specific categories of occupation. Aptitudes are defined by the South African Human Sciences Research Council (HSRC) as "the potential a person has which will enable her / him to achieve a certain level of ability with a given amount of training and / or practice. In vocational counselling, aptitude test results are used to assess the extent to which an individual, usually a learner in a secondary or tertiary institution, has the potential to successfully undergo education or training in a specific type of discipline, and to perform successfully in a related occupation thereafter. Such tests would normally be administered as one of a battery of tests, and such a battery would include interest and personality inventories.

In the current study, specific aptitudes, described by the researcher as visual literacy, and more broadly in psychological terms as visual-spatial reasoning (VSP) or spatial visualization were dealt with. In this regard, the following tests were selected for use in this project:

a) The Trade Aptitude Test Battery (TRAT): Patterns Test

The Trade Aptitude Test Battery was designed to assess the aptitude of persons anticipating a career in technical fields such as mechanics, technical drawing or construction. Such occupations require the ability to perceive, interpret and manipulate spatial relationships, and spatial visualization is considered a key aptitude for any person to study and perform successfully therein. The test was developed in South Africa and has been validated using a sample of first-year students at technical institutes. Validity coefficients for the subtests of the TRAT range between .60 and .98, the latter pertaining to the Patterns subtest to be used in this research project. The test is commonly used in organizational settings to select employees into technical positions at skilled and supervisory levels. Normed scores are presented on a stanine (1-9) scale with 1 = very poor performance and 9 = very good performance. Scores of 4-6 are in the average range.

The following subtests were selected for this study:

i) Patterns

The Patterns subtest requires a testee to copy mirror images of specific geometric patterns and is considered a valid predictor of the ability to read and interpret plans or graphic designs in a technical work environment.

ii) Spatial Perception 2-D

This is a measure of two-dimensional visual-spatial reasoning and requires testees to perceive and mentally rotate geometrical figures on a plane surface. Based on their rotations, they are required to distinguish similarities and differences between a range of options and a pre-defined figure.

b) The Senior Aptitude Test Form L (SAT-L)

The SAT-L is a general aptitude test, used in career counselling to evaluate learners and adults who have completed Grade 12 and who wish to undergo tertiary education or work in professional or “high-level” disciplines. The test was developed in South Africa and has been standardised using multicultural samples (N = 3541). Separate norm are available for males and females and according to education level. As with the TRAT, normed scores are presented in a stanine scale. Subtest correlations produce co-efficients of between .60 and .81, with the correlation between the two subtests selected for this study being .67 (p = .01)

The following subtests of the SAT-L were selected for use in this study:

i) Non-Verbal Reasoning: Figures

This subtest measures General Reasoning (R) in relation to non-verbal material. Testees are required to perceive the relationship between figures presented and manipulate these to form logically sequenced material.

ii) Spatial Visualisation -3D

This is a measure of three-dimensional visuo-perceptual and spatial visualisation. Testees are presented with a series of geometric images which have to be rotated, folded or rolled mentally to form required shapes. The test primarily evaluates the Visualization factor but also loads on the Reasoning factor.

When used in combination, performance on these two subtests, along with mechanical insight, are considered valid predictors of technical aptitude and performance in related occupations. All of the abovementioned tests are classified as C-grade tests with the HSRC. This means that they may be administered only by a registered psychologist. For this study, the tests were administered by a registered Industrial Psychologist (see acknowledgements) of the School of Psychology from the University of KwaZulu-Natal who has considerable experience in aptitude assessment in organisational and educational contexts. The test was administered in accordance with the Health Professions Council of South Africa's guidelines for psychological testing.

This standardized test was administered to the students a week prior to the VLT (Figure 3.1), results of the PVT are given in Figure 5.2 below.

Regarding students' ability to perform generic visual skills, a varying ability amongst students was observed (Figure 5.2). In this regard, some students performed below the norm average (poor and very poor) while some other students performed above such a norm average (Figure 5.2). This shows that whilst the students have a satisfactory degree of conceptual knowledge (Figure 5.1), they do not possess the same degree with regards to VSs (Figure 5.2). At this stage the current researcher did not engage in an inductive analysis of any qualitative data pertaining to this issue, but this was done after the students had performed the VLT. Nonetheless, given that only four students performed below average, the researcher was confident that the students would be able to perform the VLT. In this regard the researcher's confidence was further enhanced by the fact that, unlike the PVT, the VLT requires both science conceptual knowledge and visual literacy.

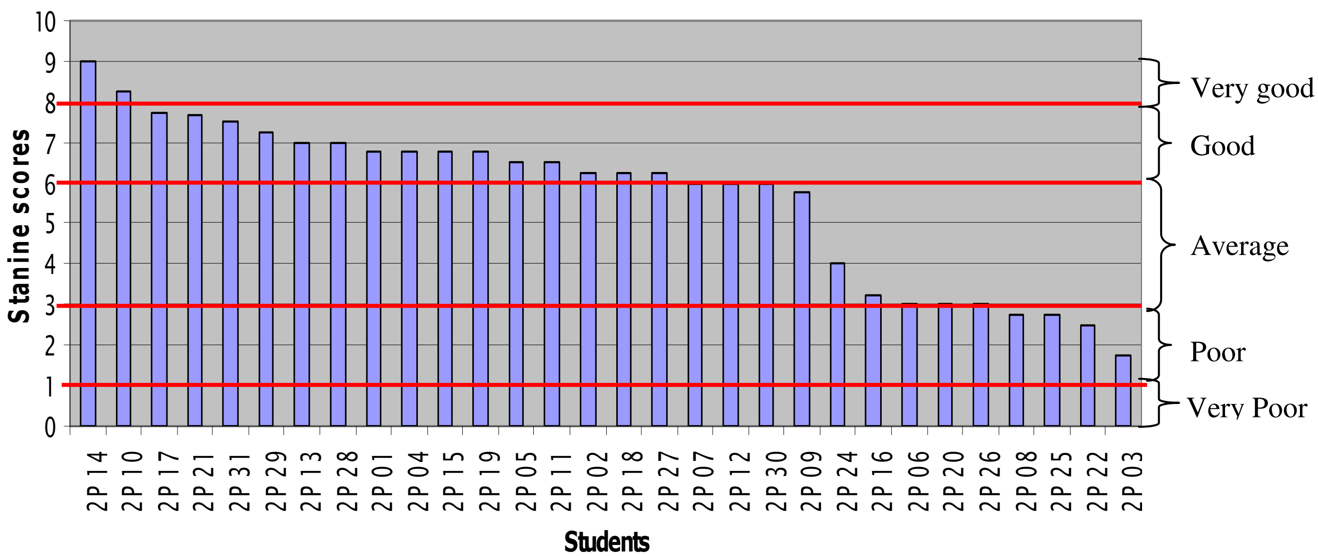


Figure 5.2: The results of the PVT administered to students. The codes used, e.g. 2P28, 2P11 etc are students' ID used for the purpose of the study.

At this stage the researcher was confident that the students had enough conceptual knowledge of relevance to the propositional knowledge required to respond to the probes. Also, it was evident that students had sufficient skills to understand ERs used in the probes. As a result, data for the formulation of the taxonomy for visual literacy for the MLS using the VLT was collected and analysed.

5.3 VLT Data Collection and Analysis – Taxonomy computation

The VLT (as described in Section 4.3.1.1) was then given to the students a week after the PVT (i.e. Week 2 of data collection, Figure 3.1), following the procedure outlined in section 4.4.4.1. This included calculating the students' scores per VS for each individual probe following the same procedure as in the pilot study (described in section 4.4.4.1).

As indicated in section 4.4.4.1the scores were allocated for the skills and not the entire probe. The scores were further used to determine validity and reliability, and also to formulate the item difficulty map. All statistical procedures were done using the SPSS and through use of the Rasch model (Bond & Fox, 2001). Qualitative data was also obtained through the analysis of student responses to determine the nature of any difficulties. The identical VLT was administered, under controlled conditions, to both groups of students (PMB and Westville), with only the dates and times of test administration being different. Due to logistical constraints, the students in PMB performed the test about four weeks before the Westville students (Figure 3.1). In both cases, students performed the tests after midday which assumed similar levels of tiredness. Furthermore, students were not told about the test prior to its administration, so that they were unable to prepare for it in any way. As stated above, analysis of the data mainly involved the utilization of the Rasch model. Thus, it is important at this stage to look at some key features of the Rasch model and why it was considered an important tool for the current study.

5.3.1 Important features of the Rasch Model

According to Nijsten *et al.* (2007), the Rasch model assumes sample-free measurements. Explaining this condition, Wright (1967) suggests that if a learner says "he[/she] is at the ninetieth percentile in math ability" such a statement may not necessarily be understood unless the score is explained in terms of the group and the test that the learner was involved in (p. 1)[17]. But if the same learner says he/she is 1.45 metres tall, one does not "ask to see his[/her] yardstick" (Wright, 1967). This is because, we tend to assume that the scale of the "yardstick" is independent of factors such as colour, weight and so on, but

[17] http://www.rasch.org/memo1.htm

such an assumption can not necessarily be made about a test that measures cognitive ability (Wright, 1967). Hence, when one measures cognitive ability, such as visual literacy, factors such as prior knowledge, experience and social background cannot be ignored, in which case an instrument that will standardize the findings is required. In this regard, the Rasch model is able to calibrate students' score for item difficulty indices. This means that even if the students who perform the VLT were to be changed, the sequence of difficulty (SoD) for the items would not be altered (Nijsten *et al.*, 2007; Wright, 1967).

Like other psychological test models that use the dichotomous scoring rule i.e. marking a response as either "right" or "wrong", the Rasch model also represents the conditional probability of a binary outcome i.e. marking as either "right" or "wrong" (Kubinger, 2005; Kim & Hong, 2004). In this regard, the model is fundamentally based on the following expression (Kim & Hong, 2004; Bond & Fox, 2001):

$$P\,(x = 1) = \frac{P(Bn - Di)}{1 + P(Bn - Di)}$$

According to Kim and Hong (2004) and Bond and Fox (2001), here:

> "$P(x = 1)$ is the probability of an endorsed response, that is an answer that is marked as correct);
>
> B*n* is the ability of the person *n* (on a given item *i*);
>
> D*i* is the difficulty of the item;
>
> *P* is the probability such that P(B*n* – D*i*) refers to the relationship between person *n* interacting with (or responding to) test item *i*".

Hence, when "$Bn > Di$, $Bn = Di$ and $Bn < Di$, the chance of an endorsable (correct) response is greater than 50%, equal to 50%, or less than 50%, respectively" (Kim & Hong, 2004)

The original Rasch model is based on what Kubinger (2005) calls "scoring the hits" (i.e. the response being either "right" or "wrong" which is a binary outcome). However, this kind of scoring has limitations as was shown in an example used by Kubinger in the German version of the Wechsler Adult Intelligence Scale – Revised (cited in Tewes, 1991). In this example, two students A and B, scored 18 and 17 respectively, but the scores fail to reflect the difficulty differences of the items and hence the students ability with respect to the items. Therefore, the scoring "seems to be distorted" with regards to determining difficulty differences and students' abilities (Kubinger, 2005).

As mentioned in Chapter 2, since visual literacy is multifaceted in nature, a number of variables influence it. As a result, there are possibilities that while a researcher hopes that the study addresses visual literacy only, the results may be reflective of other variables. Hence, a measure called "unidimensionality" is determined, which determines whether or not the results are reflective of a single indicator (Cohen, 1969). If data is proved multidimensional, it means such data is reflective of more than one indicator. Unidimensionality can be measured using, amongst other tools, Cronbach alpha or factor analysis (Cohen, 1969).

With regards to the above argument, another important feature of the Rasch Model is its basic assumption of unidimensionality (Kim & Hong, 2004). For this purpose, the Rasch model calculates the Item Mean Square (MNSQ) fit statistics (Smith *et al.*, 2007; Kim & Hong, 2004). In this regard two fits statistics namely, the item fit (weighted mean square) and outfit statistics (unweighted mean square) are determined (Smith *et al.*, 2007; Kim & Hong, 2004). According to Smith *et al.* (2007) "the outfit statistic is sensitive to anomalous outliers for person or item parameters, whereas infit statistic is sensitive to residuals close to the estimated person abilities" (p. 3). In this way, these statistics determine whether or not MNSQ fall within a certain expected range. In this regard, Smith *et al.* (2007) suggests that fit statistics are expected to have a value of 1.0 for which significant excess range is regarded as lack of fit between items and the model, and below which is regarded as item redundancy.

Kim and Hong (2004) highlight that the infit and outfit statistics do not provide complete dimensionality of the test but they are able to provide important information about dimensionality. In this instance, if the statistics are in a certain numerical range they are regarded as an acceptable reference of unidimensionality (Kim & Hong *2004*). However the cut-off for these values is a subjective issue as it depends on the objectives of the study, determined by the researcher. For example, in their study, Kim and Hong (2004) set values between 0.8 and 1.2 as the acceptable range for determining dimensionality, while Velozo *et al.* (1999) suggested that reasonable ranges of MNSQ fit values are between 0.5 and 1.7. At the same time Smith *et al.*, (2007) worked with a range of 0.7 to 1.3 and Kjellberg *et al.* (2003) suggested a range of 1 $\pm$ 4. Nonetheless, as per Rasch specifications, MNSQ values of about 1.0 are ideal (Kim & Hong, 2004).

In essence, the Rasch model converts non-linear raw scores (i.e. 0, 1, 2, 3) to linear logit scores (Bond & Fox, 2001). The reason behind this is that unlike raw scores, when logit measurements are compared between items or tests, their probabilistic meaning is maintained (O'Neill, 2005). For instance, if a student *x* scores 50%, and student *y* scores 25%, it is not true to conclude that student *x* is twice as good as student *y*. Regarding non-linear raw scores, the Rasch model calculates mean and standard deviations. The mean raw score, as per the Rasch model, is the average scored by the total students for all VSs calculated as per model below.

	S_1	S_2…	S_n	Total
T_1	x_1	x_2…	x_n	T_x
T_2	y_1	y_2…	y_n	T_y
⋮				
T_n	z_1	z_2…	z_n	T_z
Average				T_{xyz}

T is the VS number 1 to 24 (Table 4.1), S the student number and x, y, z are the scores per VS per student and T_{xyz} the average scores (Bond & Fox, 2001). For instance:

X_1 = student S_1's score for VS T_1

Y_1 = student S_1's score for VS T_2 etc.

Based on the above model for calculating the mean raw score, the mean (and hence standard deviation) will be dependent on the number of students and the number of VSs in a test. As a result, the position of each VS in terms of "item difficulty" will be relative to the number of students *and* VSs.

Given the above arguments concerning the Rasch model, the researcher saw fit to employ this model for the analysis of data for the current study. The following sections present results generated by this model.

5.3.2 PMB vs. Westville data

Following the data collection, different statistical measurements were calculated using the Rasch model. The first variable measured was dimensionality which, as discussed in 5.3.1, is an important measurement when one intends using the Rasch model. In this regard, the current study adopts a similar approach to that of Velonzo *et al.* (1999)'s study by focusing on test construction and psycho-diagnostic studies. As a result unidimensionality was assumed over the same range as in Velonzo's study i.e. from 0.5 to 1.7. The current data in this instance revealed that regarding dimensionality, items ranged from 0.56 to 1.6 for infit statistics and 0.58 to 1.66 for outfit statistics, which are both within the range suggested by Velonzo *et al.* (1999). This suggested that the data was unidimensional which further justified the use of the Rasch model in the current study.

To gain further confidence in the results generated by the Rasch model, it was important to determine reliability coefficients (Section 3.4.3). These coefficients would indicate whether or not the: *i)* items or VSs under study (which were identical for the PMB and Westville groups) are reliable; for instance that the items are not measuring unintended variables such as generic visual skill only and, *ii)* participants (or persons) undertaking the VLT are reliable such that if the test was re-administered, same results would be obtained. The reliability coefficients also indicate the stability of the results in terms of the test being "sample-free" (Section 3.4.3), so that if the test was re-administered to a different group of students, the same results would be observed. Table 5.1 presents the summary statistics obtained for the two student groups. This table presents data that had already been corrected from raw scores into logit scores.

Important to note in Table 5.1 are the reliability coefficients. These were computed for both student groups (PMB and Westville). The maximum obtainable reliability coefficient is 1.0, and any value above 0.8 indicates a good reliability (Section 3.4.3). In all four cases i.e. item reliabilities and person reliabilities, the reliability coefficients were above 0.8 (Table 5.1). As discussed above, these findings indicate that *i)* the items were reliable *ii)* the persons were reliable and *iii)* the test was "sample-free".

Table 5.1: The summary statistics for the PMB and Westville data.

	PMB	Westville
Mean	0.00	0.00
Standard deviation	1.33	1.06
Number of students	31	75
Item reliability	0.93	0.96
Person reliability	0.80	0.86

Even though data from both samples was reliable, the effect of the sample sizes was such that the Westville data reflected a higher reliability coefficient than that of PMB (Table 5.1). The PMB data was obtained from a smaller sample of participants with a corrected standard deviation of 1.33 whereas, in Westville, where a higher number of participants were recorded, a lower standard deviation was obtained. This suggests that, even though according to Linacre (1994) and Nijsten *et al.* (2007) the current sample size was suitable for the research; a larger group is best suitable to generate a more stable result.

Regarding the data being "sample free", Figures 5.3 indicates the general trends from the PMB and Westville data. It can be observed from this figure that even though a similar trend of item difficulty was obtained for both groups, the exact difficulty value or difficulty index changes in relation to their standard deviations (see Table 5.1). Nonetheless the results show that, the item difficulty trend is not relative to the students and a similar trend (in terms of order of difficulty of VSs) is obtainable even if the participants are different. This is also shown by the high item reliability coefficients presented in Table 5.1.

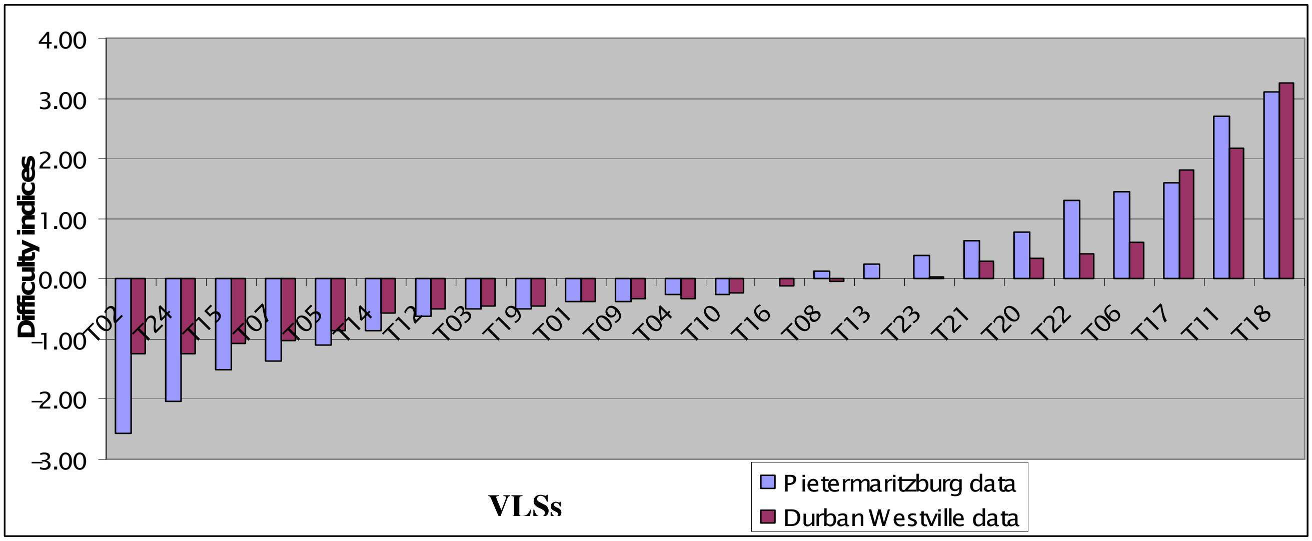


Figure 5.3: Comparison of the item difficulty trends for the PMB and Westville data. In the figure, labels on the x-axis refer to the VLS codes used in the current study.

Figure 5.3 also indicates the SoD for the individual VSs. In this instance, VS *T02* is the easiest and VS *T18* is the most difficult. Such a sequence was observed both in PMB and Westville data by scoring each VS. This constitutes one of the most important findings of the current research as it indicates that the identified VSs for the MLS vary quite widely in terms of their level of difficulty. Thus by utilizing the Rasch model, each skill can be placed at a specific level of difficulty as shown in Figure 5.3.

One of the objectives of the current study was to determine whether visual literacy in the context of Biochemistry, and as defined by the range of identified skills, can be represented by means of a taxonomy. At this stage, the research has shown that there are specific VSs (Table 4.1) that are used to process ERs in Biochemistry (Section 4.3.1.1). Furthermore, the research has shown that these VSs can be ranked in terms of difficulty from the least to the most difficulty (Figure 5.3) by administering the VLT to groups of students and analysing the data using the Rasch model. As discussed in section 5.2.1, to normalize or calibrate a scale of item difficulty (e.g. Figure 5.3), Linacre (1994) suggests that the sample size should range between 16 to 36 and 27 to 61 such that the standard deviation may lie within ± 1 logit at 95% and 99% confidence, respectively. Furthermore, our data (e.g. Table 5.1) showed that with a larger sample size, the reliability coefficient increases thus making data more dependable.

With this in mind, the current researchers then opted to combine the two student groups (PMB and Westville) to form a single group from which an empirical taxonomy of visual literacy for MLS in the context of Biochemistry would be computed. Such a taxonomy would arrange different VSs in a hierarchical order from least difficult to most difficult. Because each skill would have its distinct "item difficulty" level, each would be in its own taxon. Below are the results obtained upon combining data.

5.3.3 Combined data

As mentioned above, to obtain a normalized set of difficulty indices or an item difficulty map, the two groups of students were combined to form a larger sample of 106 students. Given this sample size, the combined item difficulty map was regarded as calibrated (Nijsten *et al.*, 2007; Beltyukova & Fox, 2002; Linacre, 1994) and thus a norm for determining visual literacy in the context of the designed probes and associated VSs. From this combined sample, raw scores were again converted to logit scores and item measures computed using the Rasch model. Thereafter, an item map (Figure 5.4) was deduced which serves to indicate the sequence of difficulty indices for each of the VSs under study.

In the part of the study presented in this chapter, we did not analyse data qualitatively to determine whether the SoD was valid based on meaning of the text from the scripts. In other words, methodological triangulation (combination of quantitative and qualitative methods, section 3.2) is not detailed in this Chapter as we look only on the quantitative account and give the qualitative account in the next Chapter.

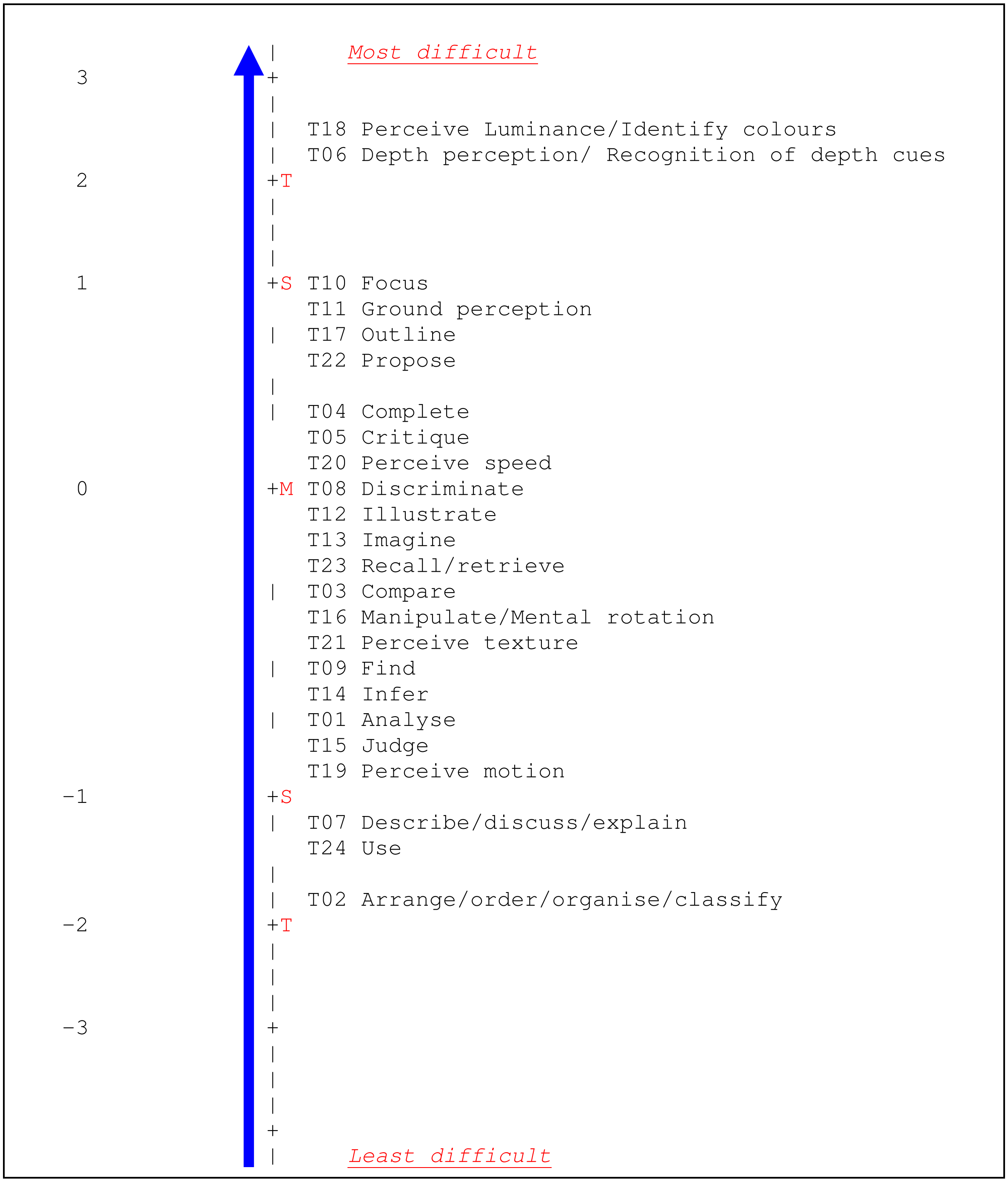


Figure 5.4: VS difficulty map obtained from combining the data from two samples. In the diagrams, VLSs are labelled as T01, T02, T03…T24.

The right hand side of Figure 5.4 indicates the level of difficulty of the VSs, i.e. the VS *"perceive luminance/identify colours"* was the most difficult for the students and the VS *"arrange/order etc"* was the easiest. Those VSs that scored similarly to one another do not have a separating line (“ | ”) on the left. For instance the VSs T07 (Describe/discuss/explain) and T24 (use) had scores that were close to one another. This was also observed with VSs T08, T12, T13 and T23. The difference between the scores of these VSs was below one logit. The letter M indicated the average difficulties. VSs that score at this level are half as difficult as they are easy, such that there is 50% chance of getting them correct and 50% chance of getting them incorrect. Thus, those VSs that are below this level have a more than 50% chance of being responded to correctly while those above this level have a more than 50% chance of being responded to incorrectly. Letters S and T indicate the one and two standard deviations respectively, from M.

However, given the difficulty indices presented in Figure 5.4, the relationship between the combined data and that of the individual samples (PMB and Westville) was measured. Thus by combining the qualitative and quantitative data, we hypothesise that this would provide an indication of validity and reliability. Such a finding would indicate whether or not combining data was necessary to improve the results as obtained for individual samples.

5.3.4 Validity and reliability – sample comparison

The relationship between combined data and single sample data was measured by computing correlation coefficients. In this regard, a negative correlation between the combined sample and the original individual samples would indicate a disagreement between the data (section 3.4). This would mean that the combined data would not reflect the individual samples and therefore would lack reliability. The results presented in Table 5.2 below indicate that there was a high correlation between the data obtained from each of the individual samples (PMB and Westville) and the overall combined sample. This further supports the reliability values obtained in the individual samples (see Table 5.1). As a result, the researcher was confident that the item map (Figure 5.4) is a reliable measure for representing the item difficulties for VSs as tested in PMB and Westville. The combined data is closely related to the Westville data since over 70% of the participants in the combined group are from this campus.

Table 5.2: Correlations between the data from the different samples. In the table, * refers to correlation significant at the 0.05 level (2-tailed), ** Correlation significant at the 0.01 level (2-tailed) and N the number of VSs per group of students

		Combined	PMB	Westville
Combined	Pearson Correlation	1		
	Sig. (2-tailed)			
	N	24		
PMB	Pearson Correlation	0.440(*)	1	
	Sig. (2-tailed)	.032		
	N	24	24	
Westville	Pearson Correlation	0.927(**)	0.486(*)	1
	Sig. (2-tailed)	0.000	0.016	
	N	24	24	24

Also important to note was the correlation observed between the PMB and Westville samples. Such a correlation is also reflective of the findings presented in Figure 5.3, such that there is consistency between the findings of these samples. At this stage, data validity and reliability had been shown through triangulation methods (i.e. environmental triangulation, section 3.2) where different groups gave a similar trend of results (Table 5.1, Figure 5.4 and Table 5.2). The current researcher further measured whether there would be consistency of results (Figure 5.4) if the VLT was repeated by any one group. This is important as it would indicate whether the results obtained in any one group are reliable and valid in relation to validity obtained through triangulation i.e. data triangulation (collection of data at different times).

5.3.5 Test – Retest reliability and internal consistency

To gain further reliability of the difficulty map, as provided in Figure 5.4, the same VLT was given to the PMB students for a second time (test-retest, section 3.4.3). The test was not re-administered at Westville due to logistical difficulties. Regarding the PMB group, the two were administered 8 weeks apart i.e. the first VLT was administered at the beginning of the semester and the second one towards the end of the semester (Figure 3.1). Even though the second VLT was identical to the first one, students were not told about the test prior to its administration. Test-retest reliability was measured using SPSS software to determine the relationship between the two tests. Here the researcher wanted to determine, *i)* if the mean scores would be the same, *ii)* if the SoD (e.g. Figure 5.4) would be the same. In other words this re-test would determine if there is internal consistency (section 3.4.3).

Observation in this exercise indicated that, at 95% confidence interval, the correlation was 0.495, which is significant. This indicates the two means (test 1 and 2) were similar, i.e. $\mu_1 = \mu_2$. The results also gave a Cronbach alpha value of 0.798. These findings indicate that the results obtained in the first test are consistent with those obtained in the second test, which is indicative of internal consistency (section 3.4.3).

Looking at the actual mean scores, it was observed that in the second test the mean score increased from 42% (raw score of the first test) to 51% (raw score in the second test) with the same students participating. This improvement could be associated with an increase in students' conceptual knowledge and/or improvement in their VSs during the ongoing Biochemistry courses that they were attending. Also, as implied by the Cronbach alpha value, there were some changes in the difficulty indices for some VSs, at a standard deviation of 1.47 logit score. Here, changes that occurred in the second test were expected as the item reliability value of the first test was 93%. In the same vein, the second test's item reliability value was found to be 94%.

With the internal consistency observed through the above presented process, it was deduced that the item map (Figure 5.4) was indeed a true reflection of the difficulty levels of the VSs. Given that students' prior knowledge (i.e. conceptual knowledge and generic visual literacy) was measured (Figures 5.1 and 5.2), the researcher then measured the correlation between these three tests. Because prior knowledge data was only obtained from PMB, the correlations in this regard were measured using data from this campus (the initial test data for the VLT was used). Also, because some students did not participate in the previous Biochemistry courses, this exercise meant only data from those students who participated in all three experiments would be considered. Here we intended to determine criterion-related validity and concurrent validity (section 3.4).

5.3.6 PMB results' correlation

As mentioned in section 5.2.2.1, results from two, 2nd-year Biochemistry courses (Bioc A and Bioc B[18]), and those from an assessment quiz taken by Bioc 304 students, were used to determine correlations with the VLT. Also, results from the PVT (Figure 5.2) were used. The main purpose of this exercise was to determine whether the current VLT was reflecting students' visual literacy in the context of Biochemistry. In this instance, the researcher intended measuring the degree to which the different tests were related by measuring the Spearman correlation, r (Clarke, 1980). Spearman's correlation was chosen because our data was nonparametric, which means the current sample (of students) is not assumed to fit any parameter in terms of distribution (Mann, 2004). In this instance, the current study had three different data sets i.e. Biochemistry results, PVT results and the VLT results, all assumed to be independent of one another. Furthermore, the current researcher's intention was to determine the nature of the relationships that may exist between the students' scores in the three tests. In this regard the null hypothesis was that there is no correlation between the tests ($r = 0$) and the alternate hypothesis was that there is correlation between the tests ($r \neq 0$) (Mann, 2004).

An ideal situation with regards to the three tests would be for the VLT to lie halfway between the Biochemistry and the PVTs in terms of correlation. For instance, if the VLT correlates highly with the Biochemistry scores and poorly with the PVTs, then the VLT would perhaps be testing predominantly Biochemistry knowledge and minimal visualization skills. Similarly, if the VLT correlates highly with the PVT and poorly with the Biochemistry scores, then the VLT would be testing predominantly generic visual skills. Nonetheless, as discussed in section 2.6, a number of other factors such as language, age, experience and knowledge from other fields such as chemistry would influence visual literacy. However, as shown in the instrument validation process (Chapter 4), the current study focused on prior knowledge in Biochemistry and generic visual literacy.

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[18] Named arbitrarily

Table 5.3 below presents the results obtained in determining the correlation between the VLT and the other two assessment tests. The results reflect the data obtained from 30 students who participated in all three tests. In Table 5.3, the relationship (correlation) between the tests is indicated by the correlation coefficient, where the lower the correlation (i.e. close to zero), the less related the tests are (section 3.4.3). For instance, the correlation between the Biochemistry test (which tests minimal "pure" visualization skills) and the PVT (which tests minimal "pure" Biochemistry knowledge) is 0.434* which (as expected) is the lowest between the three tests (Table 5.3).

Table 5.3: Indicating the correlations between the Biochemistry, PVT and VLT given to students. * indicates a correlation significant at the 0.05 level (2-tailed) and ** denotes a correlation significant at the 0.01 level (2-tailed).

		Biochemistry	Psychometric
Psychometric	Correlation Coefficient	.434(*)	
	Sig. (2-tailed)	.016	
	N	30	
Visual literacy	Correlation Coefficient	.684(**)	.484(**)
	Sig. (2-tailed)	.000	.007
	N	30	30

The results indicate that, even though there is some relationship between these particular tests, it is relatively minimal. This was probably because the tests had minimal corresponding content. In contrast, the correlation between the VLT and the Biochemistry tests is highest and significant, which means the VLT requires students to have more Biochemistry knowledge in order to do well in the test. Furthermore, the correlation (0.484**) between the VLT and the PVT, although quite low is still significant and indicates that generic visual literacy knowledge is important for one to do well in the VLT. The lower correlation might be due to the requirement of Biochemistry conceptual knowledge in the case of the VLT. Hence, one can infer from all this data that the VLT measures visual literacy in the context of Biochemistry. Also that it might not be possible to design a VLT for the context of Biochemistry (or any other area of science) that exclusively measures visual skills while at the same time being unaffected by Biochemistry knowledge.

5.3.7 Validity of the VLT

Another important finding of the research concerns the validity of the VLT. As stated in section 5.3.1, the Rasch model is able to detect items in a test that are either too easy or too difficult. Such items tend to shift the overall score to one direction as students either perform them too well or too poorly. In such cases, the test fails to determine students' true abilities in a given area. To prevent this, tests are usually compared to other established tests e.g. psychometric tests where the correlations are measured (Guion, 2002). Should correlation be low, the tests under study are regarded as invalid.

In the case of the VLT, it was observed that there was a significant correlation between the VLT and the PVT, thus giving confidence that the current test is valid. Furthermore, as proposed by the panel of experts (Chapter 4), students' ability to perform the VLT without having major difficulties in any one question indicates that the test was suitable for the study. The variation in students scores, some doing well and some having difficulties in the test also indicates that the test was valid (Figure 5.3). For instance, if all students failed or passed the test, one would assume that the test was too difficult or too simple. Therefore, the current data shows that the VLT used in the study was valid

5.4 Summary and Conclusion

At this stage, the results analysed quantitatively have shown that:

- The degree of difficulty of different VS can be tested. These skills can be ranked from the least to the most difficult by using the Rasch model (Figure 5.4).
- The SoD of the different VS, as presented in Figure 5.4 is sample free (i.e. independent of the nature of the student sample as long as Biochemistry students are used). This was shown in Figure 5.3 where results from different setting showed a similar trend.
- As was indicated by the panel of experts (Chapter 4), the results represented in this Chapter reflect visual literacy in the context of Biochemistry and possibly generally in the MLS (Table 5.3).
- The VLT used in the test was suitable and valid for the study

Given these findings, it was crucial that inductive analysis of the student data be conducted so as to qualitatively describe what makes other VSs more difficult than others. The results of this analysis are given in the next Chapter.

6. Chapter 6: The Nature of Visualization Difficulties Revealed By the VLT

6.1 Introduction

The quantitative data presented in Chapter 5, indicated that there is a variation in the degree of difficulty of the VSs. Since, various researchers (e.g. Bazeley, 2003; Libarkin & Kurdziel, 2002; Derry *et al.*, 2000) have recommended that, to achieve good triangulation and high validity, it is advisable to use more than one research method to reinforce results, the current researcher decided to collect qualitative data in addition to the quantitative data. This would also afford the researcher the opportunity to identify the nature of any visualization difficulties that might be affecting students' visual literacy. This Chapter details the results of inductive analysis of the students' responses to the VLT with regards to the research questions addressing the levels and a taxonomy of visual literacy for the MLS (see sections 1.3 and 5.1).

6.2 Data collection and analysis methods used

To conduct a qualitative analysis in order to validate the quantitative findings, the basic question that was to be addressed was, "what makes one VS more, or less difficult than another?" For example, why is *VS "VS T18: Perceive Luminance/Identify"* the most difficult? By answering this question it would be possible to tell whether "it makes sense" for any one VS to be more difficult than another and would also serve to validate difference in students' visual literacy levels. To respond to this question, the following methodology was followed.

6.2.1 Script analysis and interviews

Given the VS difficulty map (Figure 5.4), obtained through the Rasch model which indicates VSs from the least to the most difficult, each script (all 106 scripts) was analyzed. In this analysis, the focus was on determining trends that define the visualization difficulties that the students have. Here, an inductive analysis was done to determining meaningful patterns that emerged (Thorne**,** 2000; Anderson & Aresenault, 1998). However, in some cases, more questions arose in terms of what was meant by the students responses which would clarify the trends observed as well as the meaning of such. As a result interviews were also conducted.

For the interviews, the researcher used clinical interviews where the interviewee was expected to express his/her views openly (Schönborn, 2005). Here the role of the interviewer was to pose questions that provide deeper understanding of what the interviewee is saying by progressively following up on the responses until clear meaning is obtained (Schönborn, 2005). Because the interviews were structured to obtain deeper understanding of each student's responses, each interviewee had a specific set of questions asked to them. However, a standard protocol for all interviews was used. Such a protocol involved an introduction where the researcher explained to the interviewee the aims of research and the interview, the specific terms (e.g. probe) used as well as the rights of the interviewee in responding to the questions. Following this, specific questions for obtaining the data were posed. In such questions, ERs used in the VLT were used. Students' responses in the interviews resulted in verbal, textual and graphical responses. All responses were recorded through audio and video format and the textual and graphical responses were collected for analysis.

The interviews took place in the PMB campus where only PMB students participated due to logistical limitations that did not allow Westville students to participate. The choice of students in PMB was based on, *i)* specific questions that needed to be clarified by specific students and *ii)* on the students' average score in the tests. Regarding the latter, students were arranged from the best performing to the least performing student. Thereafter, every third student was selected to participate in the interviews, thereby resulting in 10 participants who comprised about 33% of the PMB group. Results obtained in script analysis and interviews are presented in the following sections.

6.3 Results

Data analysis revealed that factors that influenced students' performance can be categorized into two domains, namely, non-visualization type difficulties and visualization type difficulties. Regarding the non-visualization type difficulties, four themes of responses emerged; these are *a)* poor ability to work with ERs, *b)* a lack of conceptual certainty, *c)* poor ability to multi-task and *d)* a lack of motivation or positive attitude towards probes or part thereof. With regards to visualization type difficulties, it was found that there were difficulties relating to the different stages of visualization namely *a)* visual perception, *b)* visual imagery 1 and 2, *c)* integration and *d)* expression. Specific results, supported by student response data, in relation to the above are presented in the following sections.

6.3.1 Non-visualization type difficulties

6.3.1.1 Poor ability to work with ERs

Regarding the theme of "poor ability to work with ERs", the current author refers to students' lack of *energy* to work with ERs. This may be expressed as *exhaustion* which is the result of students being "overwhelmed" by ERs (Lowe, 2004). In such cases students may apply low effort to high demanding ERs (Healey, 2005) and hence not be able to interpret them correctly. Also, this theme includes students' inability to *give meaning* to unfamiliar symbols. In such cases students prefer not to work with symbols unless they have seen them before. This also includes students' failure to switch between different modes of representations that represent the same Biomolecular concept (Schönborn & Anderson, 2005; 2006).

Typical evidence in support of the above phenomenon was observed in the interviews where, for instance, one student (2P31) was asked “how they feel about working with ERs”. In response, the student said:

> *“[working with ERs is] very challenging…but fun. I could feel my brain getting tired”.*

It is evident from the above quote that students generally enjoy working with diagrams and pictures when studying. However, some students (e.g. 2P31) feel that working with ERs, whether drawing them or extracting information from them, is exhausting. This exhaustion could overwhelm the visual channel of information processing as explained by Lowe (2004) and Robinson (2004). In turn, this “overwhelming” can hinder students’ ability to effectively work with ERs.

In addition to being exhausted, inconsistent symbolism (as discussed by Schönborn & Anderson, 2005) has a huge impact on students’ visual literacy. In this regard, it was observed that because of different forms of representations, particularly of the same concept, students had difficulty, translating between, and “mastering” each mode of representation (Figure 6.1).

Therefore, students may find it difficult to relate one mode to the other, especially those not often used by instructors and textbooks. An example of this problem was encountered when students were asked to give a sketch that illustrated an enzyme–substrate reaction. All (10) interviewees opted to draw a “lock-and-key” model, with little or no variation from one another’s drawing. They justified this approach as something that is often done in textbooks and lecture notes. Also, when asked to draw an amino acid representation in the “ball and stick”, “stick” or “3D” format, six of ten interviewees preferred to draw the stick model, which is the simplest to draw. For example, in Figure 6.1, even though students drew different ERs, none drew a “ball and stick” model. In addition to the above, these students (the four who generated the ERs in Figure 6.1) indicated that they preferred working with models in the format they drew. This they said was due to their experience in different fields of study; for example, the student who drew “C” (Figure

6.1) suggested that she "likes fine arts" and the student who drew "D" indicated that she is a Chemistry major, from where she learnt the symbols.

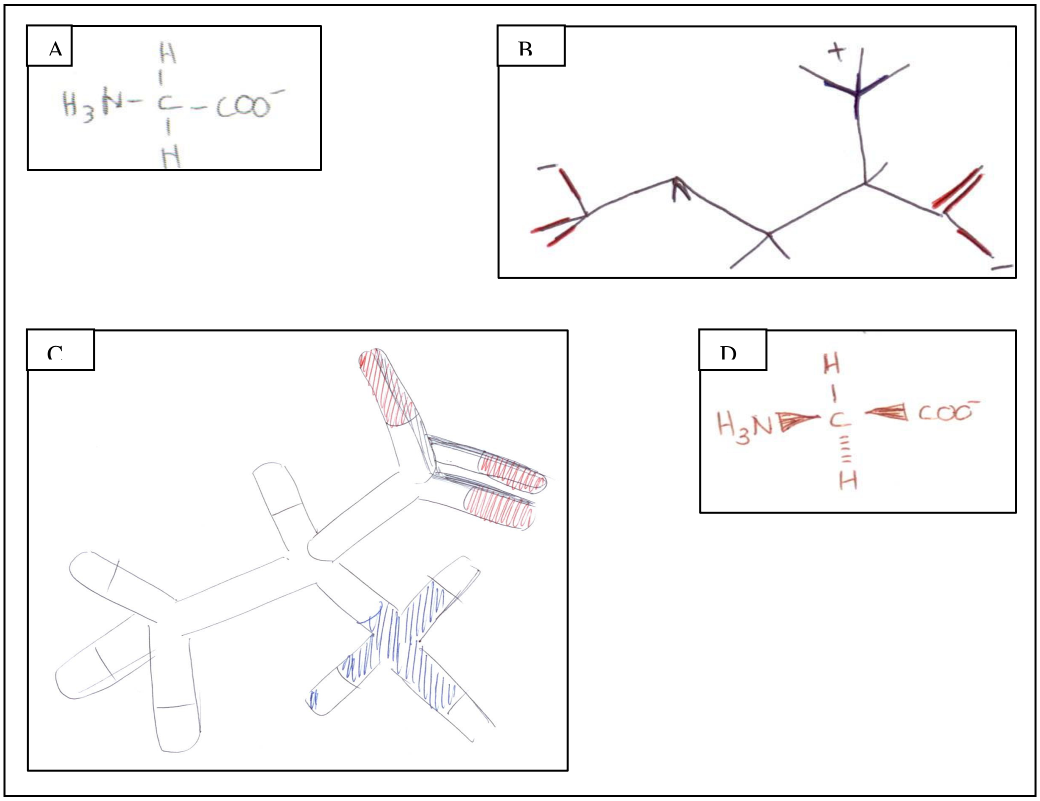
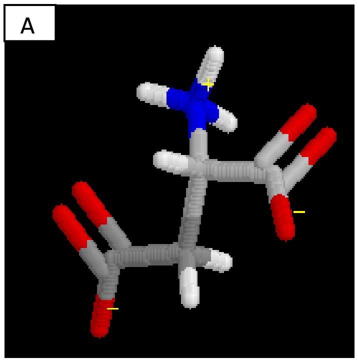
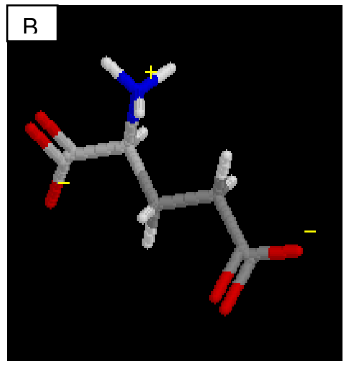


Figure 6.1: Different representations of amino acids generated by students in the interviews.

Another reason for students' poor ability to work with ERs was that they tended to miss important components of the ERs. This is because students tend to pay little effort in studying the ER. At times, students' attention may be focused on some parts of the ER and not the ER holistically. In this regard, students' interpretation of an ER may be limited. For example, when one student (2P17) was asked if "the two ERs below represent the same amino acid":





The student responded by saying:

> *"[they] first looked like same amino acid, but after looking at it for a while you see [that] there is an extra –CH_2 group [in the amino acid on the right, hence they are not the same]".*

In this regard, it is evident that if students "pay little attention" to an ER they may not recognize important parts of the ER and thus misinterpret it. The student in question in this case had to look at the ER "for a while", thereby analyzing the ER in order to be able to identify key components of the ER.

6.3.1.2 Lack of conceptual certainty

By lack of conceptual certainty, the current author refers to a situation where a student fails to be critical and reflective about the ER, because they are unsure of a certain scientific concept, represented by the ER. Under these circumstances, the student fails to judge the ERs correctness in representing a concept (Thompson**,** 1995). In such cases, students rely heavily on what the ER "imposes", without them engaging directly into argument with it, with the purpose of verifying the concept presented. Here, students hardly question the legitimacy of the information represented and end up not being sure or certain of what concepts were represented. As a result, should the ER have inaccuracies in its design, students are likely to feed on the same error.

With respect to the theme of "lack of conceptual certainty", when two students were asked in the interview as to "why they think a particular symbol is used to represent a certain component of a phenomenon", the students said:

> "*That's what we've been taught (2P08)"* and *"that's what we've learnt (2P17)"*.

In this regard, if students doubt the truthfulness of their knowledge, they tend to indirectly give away ownership of such understanding. Consequently, if students lack certainty, they stand a good chance of being confused, particularly when they have different views about the same phenomenon. For instance, one student (2P31) was confused by the different colouring of atoms in an amino acid representation (e.g. Probe 1, Section 4.3.1.1). During this confused state, the student said:

> *"Its quite confusing…we (at lectures) always associate grey with carbon…I am not sure about white (referring to light grey), because I know* ***for a fact*** *that there should be a carbon at those points".*

A similar confusion was observed among five interviewees where students lack certainty and hence doubt their understanding of the concept.

6.3.1.3 Poor ability to multitask

With respect to working with ERs, students may be expected to access different cognitive processes and, therefore, use different cognitive skills, simultaneously (See Table 4.5). To some students, this is very challenging as they tend to be cognitively overloaded and thus unable to properly co-ordinate their mental and physical processes (Robinson**,** 2004; Mayer, 2001). As a result, students end up failing to show understand of concepts as represented in ERs, even though some of the students might show such conceptual understanding when responding to other probes under less demanding conditions.

In the current study, it was observed that students generally tend to fail to multitask. For instance, when asked to look at an ER and then draw what was represented, all interviewees (i.e. ten students) generally failed to draw exactly what was represented. This may be because during the act of drawing, students have to utilize various intelligences, e.g. visuo-spatial intelligence and bodily kinaesthetic intelligence, as well as VSs such as "recalling", "mental rotation" and "focusing". As a result, they tend to find it difficult to utilize all these required processes simultaneously. However, when given the same ER again, after some time, students easily recognized the ER. In this regard, recognizing an ER requires fewer skills, and hence is less demanding (Lowe, 2003).

6.3.1.4 Lack of motivation or positive attitude towards ERs

Another theme that emerged in non-visualization type difficulties was that of a lack of motivation which results in a negative attitude towards ERs (Greene & Hicks, 1984). In such instances, students may prefer other forms of presentation such as text instead of ERs. Nonetheless, students' attitude towards ERs varies with the nature of ER and experience.

In the current investigation at least two interviewees indicated that they dislike working with diagrams and pictures. As a result, the amount of attention paid to what the ER is representing is limited and hence, students may fail to adequately perform VSs. An example of this phenomenon occurred when one student (2P27) was asked if they like using diagrams. The student suggested she did not and supported her reasoning with the following:

> *"Sometimes you get a diagram and you can not really see what's behind it (or what it represents), you can't rotate it, you can't do anything to it…for me that's not right, I don't like that. So it's better for me just to read the notes".*

In this regard, because of the lack of dynamic features in some ERs, students end up losing interest in the ER. As a result of that, they may fail to adequately comprehend the concepts represented.

In the above presented cases, it can be argued that, there were a number of factors that influenced students' performance in the VLT. These are some of the factors that contribute to the manner in which students comprehend information represented by ERs when performing different VSs. As shown above, the above mentioned factors may not necessarily be directly linked to visual literacy or conceptual knowledge, but they cover mainly the mode of presentation and the students reasoning ability (Figure 3.4). In this regard, the mode of representation may for instance affect students' attitude towards ERs. At the same time, students' ability to reason with an ER tends to affect their cognitive processes that occur together in performing certain VSs. Given these factors, it may then be suggested that, students' poor performance in some VSs such as VS *T18*, may be linked to their failure to work with ERs, lack of conceptual certainty, inability to multitask and lack of motivation. Thus it is crucially important to try and minimize such confounding factors as they will interfere in the ability of the VLT to give an accurate measure of a students VL status.

As mentioned in the methods section of this Chapter, we also investigated the visualization type difficulties that affect students' visual literacy. In this regard our focus was to determine the nature of difficulties encountered by the students in performing VSs. In this regard, we looked at each theoretical visualization stage (Figures 2.4), namely, visual perception, visual imagery, integration and expression.

6.3.2 Visualization specific factors

6.3.2.1 Visual Perception

The first area where students struggled to engage was extracting information from an ER, which is the initial stage of the visualization process (Figures 2.4; Healey, 2005; Mayer, 2003; Mayer, 2001). As discussed in Chapter 2, the perception stage consists of two major divisions, namely, perception with low cognitive effort and perception with high cognitive effort (Healey, 2005; van Schoren, 2005). Given that the main objective of visual perception is *accounting* which refers to using different skills to "make concrete observations" (DeSantis & Housen, 2000, p. 13), a number of cognitive skills required for visualization were found to be related to this stage of visualization. While still investigating the NoVL, students' responses relating to each skill, is discussed below to indicate how each skill became allocated to each difficulty level (Figure 5.4) by means of the Rasch model.

a) Depth Perception/Recognition of depth cues – VS *T 06*

Depth perception or recognition of depth cues refers to one's ability to "perceive spatial relationships and distances between objects, in multi-dimensions". In this regard, students were expected to identify and interpret depth cues in the 2-dimentional ERs provided, so that they could recognise spatial relationships between objects. For instance, students were expected to observe the differences between the *cis* and *trans* configurations of amino acids. The results showed that some students had difficulty recognising these cues or the importance thereof. Data supporting this is given below.

In the VLT, for probes requiring the interpretation of depth cues, e.g. Probes 1 and 2, some students used the following terms in their responses:

Student 2P08: "spatial arrangement"

Student 2P11:"stereochemistry"

Student 2P09: "the positions have moved"

Student 2P14: "just viewed differently"

In the above examples, it is clear that although the later two students could see the differences between the amino acid displays, they failed to relate those differences to *depth perception* while the first two students did. An interview question concerning this matter revealed that students thought "*angular rotation*" was the same as *depth*. In this regard, if elements of a compound are rotated in the same plane (2-D), students perceived representations such as different stereoisomers (3-D). In so doing, students fail to comprehend information relating to the dimensional arrangement of the ER (a visual skill), which in turn limits their concept understanding.

b) Focus – VS T10, Use – VS T24

In this section the researcher looks at two different VSs that were found to be related in terms of students' ability to perform. The first of these is "focus" which refers to "concentrating one's attention on something". "Use" refers to "putting into service or applying for a purpose". As discussed below, students were observed to have limited ability regarding probes that required a combination of these VSs e.g. Probe 03.

Concerning the "focus" VS, students (82% of those participating in the VLT from PMB and Westville) answered either *incorrectly* or *partially correctly* as they did not show great ability to focus on a particular part of the ER. It was noted that students' attention can be drawn away from the required target (Mayer, 2001). This is because sometimes students do not really examine or interpret the ER but just use some basic cues from the ER to relate to their conceptual knowledge thereby missing some of the important components of the ER. For example, when students were expected to "use" primarily information given in the ER, students tended to prefer "using" prior knowledge rather than using the ER to aid their thinking. An example of this was observed in Probe 03, where students were asked to use the ER to explain the role of a lysosome in an ER, one student (2P10) suggested that:

> *"[The lysosome] prevents the [lysosomal] enzymes [from] acting on the cell i.e. harming the cell"*

Although this information was not given in the ER, the student only used their knowledge of enzyme proteolytic activity to respond. This is not generally bad, but sometimes students may be expected to only use given information and not prior knowledge as this particular student did, in which case, the student fails to "focus" only on the ER given information and using such.

The data also revealed that complex ERs tended to shift students' focus away from where it ought to be. In this regard, in tertiary and quaternary proteins structures students had difficulty focusing on alpha helices and/or beta sheets. This further enhanced a negative attitude, as the students struggled to re-focus on key elements of the ER. In this instance, some students (e.g. 2P22) tended to disregard other parts of the ER and focused on what they consider as important areas. This phenomenon may be associated with an inability to select relevant parts of the ER when required to do so (Mayer, 2001) and can be linked to poor diagram reading skills (factor R-M in Figure 4.1)

c) Ground perception – VS T11, Perceive texture – VS T21

Ground perception as a VSs deals with one's ability to detect or perceive the part of a scene (or picture) that lies behind objects that are in the foreground or the background. Furthermore, students may be expected to understand the role of the background in an ER (Healey, 2005).

In the current study it was observed that students tended to disregard the background and not see it as part of the ER. An example of this tendency was observed in a probe (Probe 01) where students did not perceive the electron cloud (Figure 6.2) in the ER. Asked about this, student 2P17 said, "*I don't know, I am guessing…it's a way of showing the amino acid…the background*". Similarly, one student (2P31) suggested that the black background (Figure 6.2) represented an *"empty space"* in the cell. In other words, the student perceived this area as part of the cellular matrix and not as a means of enhancing the visibility of the amino acids.

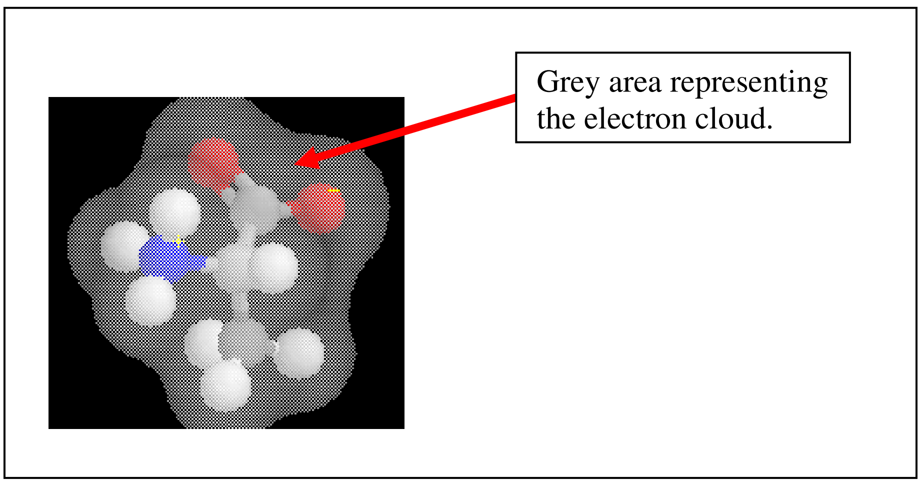


Figure 6.2: ER in which students perceived the electron cloud as a background.

d) Arrange, order, organise, classify – VS T02

The cognitive skills involving the ability to, "arrange, order, organise, classify", are concerned with "putting into a specific order or relation through a methodical or systematic arrangement". In the current study students were expected to use components of an ER to fulfil the above stated VSs. This they would do by using their ability to interpret models and identify specific features.

Results indicated that some students (e.g. W061 and W045) struggled to use diagnostic features based on conceptual knowledge to "arrange, order, organise, classify" ERs in a given probe (e.g. Probes 4 and 9). This may be linked to a limited ability to *extract* information from ERs and *use* such information to make sound decisions about the grouping of ERs in relation to their appearance. For instance, when classifying proteins based on their complexity i.e. primary to quaternary structure (Probe 4), one student (W061) suggested that:

> "*[The] more coiled the protein structure is, the more complex it is"*

and student W045 suggested that:

> a "*nucleic DNA strand [is less complex than a] helical DNA strand"*.

Thus, it can be clearly seen that incorrect conceptual knowledge can limit students' ability to perform certain VSs e.g. arrange, order, organise, classify.

Looking at the above difficulties, it was observed that they played a major role in limiting students' ability to perform VSs. Here it was noted that even though these VSs required low cognitive effort (i.e. pre-attentive tasks), they remain an important component of visualization, particularly in the MLS. Besides these VSs, it was observed that visual imagery VSs were also challenging to some students; these are discussed in the next section.

6.3.2.2 Visual imagery

According to constructivist theory, learners create knowledge based on their already existing knowledge, by integrating new information into their prior knowledge (Thompson, 1995). In this regard, an inability to formulate scientifically correct concepts may be due to erroneous prior knowledge or an inability to interpret new knowledge appropriately thus creating alternative conceptions (Thompson, 1995). In the current study, it was observed that some students, having extracted information from an ER, sometimes failed to correctly interpret such information. In this regard, students tended to construct erroneous meanings and concepts of the phenomena represented. As a result, their ability to perform certain VSs was overshadowed by the incorrect information they constructed. The following are examples of VSs that students could not perform due to incorrect interpretation of the ER.

a) Analyse – VS T01, Compare – VS T03 and Discriminate – VS T08

Another multitasking (Section 6.3.1.3) problem was observed when students responded to VSs *T01, T03* and *T08*. Here the combination of three VSs, i.e. Analyse, Compare and Discriminate was found to be a limiting factor in students' ability to work with ERs. In this regard students were expected to, "break down into components or essential features by making sense of or assigning a meaning to the ER" (analyse), then by way of "examining note the similarities or differences of the different components" (compare) and also "recognize or perceive the difference" (discriminate).

However, when given an ER, it was observed that students tended to ignore some parts of the ER when responding to the probes that require them to perform the above stated VSs. In this regard, students tended to focus on certain parts of the ER and not on the "entire" representation (Todorova & Mills, 2004). The lack of a "holistic" perspective may be due to limited or narrowed conceptual knowledge or limited ER reading skills (Todorova & Mills, 2004). Hence, students only responded in relation to those parts that are more familiar to them. For example, when asked to compare two ERs and indicate if they represent the same amino acid (Probe 01), student 2P38 suggested that:

> "*It is the same amino acid…the other one is L form and the other is D form"*

In the same question, student 2P08 suggested that:

> *"The two are of the same structure…the first is a stick model, the second is a ball and stick model…both have the same charge and spatial arrangement…same number of carbons and hydrogen atoms"*

Clearly, one student presents more supporting evidence for his/her choice than the other and this may be linked to conceptual knowledge the students possesses. At the same time, this indicates how "familiarity" with different conceptual knowledge helps the students respond to probes.

Similarly, the processing of information by some students was filtered by their already existing cognitive structures. In this regard, in an interview one student (2P08) when asked how she reads ERs stated:

> *"I [perceive/process] them to how I'd remember them…textbooks are difficult they do everything in depth, I don't think you really need to know such"*

Evidently, this student risks eliminating crucial parts of the ER because she thinks they are not important. This is more so when there is no instructor to guide the student (Schönborn, 2005). For instance, this student's style of processing information is not informed by what he/she is required to know but rather by what she believes is important. As a consequence, this may have a severe negative impact on learning, especially if the student does so without proper guidance from experts.

b) Perceive motion and speed – VSs *T19 and T20*

In the study, two related VSs were included (in probe 12), i.e. perceive motion and perceive speed. These VSs deal with one's ability to "recognize, discern, envision, or understand change of position in space and assign meaning to" as well as "to recognize, discern, envision, or understand a rate of movement and meaning thereof".

In the current study, change in mobility of the features within an ER was identified as another area of difficulty pertaining to visual literacy (Albright, 1995). Close assessment of this phenomenon revealed that students' understanding of *motion* is a confusing factor. For instance, one student (2P08) failed to recognise that some parts of the animation were moving because to his/her understanding, something is said to be in motion or moving "*when it has covered a distance… [Linearly] away from where it started"*. In this instance, the *rolling* items (i.e. moving by turning over or rotating at the same point e.g. in probe 12- see supplied DVD) were not regarded as *moving*. This was further observed when students were asked to interpret an animation (probe 12). Here students disregarded *rolling* items or the role of such motion in their responses. In this instance, the student (2P08) only referred to linear motion.

Furthermore, even when students could see that certain elements of an ER are moving, and at a particular pace, they still showed a lack of ability to relate such motion to biological processes. When asked about the role of motion and pace (probe 12), students (two of the interviewees) were not able to determine what would happen if the pace and mobility of the components of a process were altered. This inability was also associated with poor conceptual understanding. For instance, student 2P17 in the interview suggested that:

> *"[changing the pace of the reaction in the animation would result in] different products forming and different reactions happening [because] different things happen at different rates"*

Clearly the student is not able to relate properly the rate and the nature of the biological process in question. In most cases students were able to deduce the result of motion inhibition, but found it difficult to relate this to a change in pace.

The above two examples, *a)* and *b)*, show that when students have perceived information from ERs, they may find it difficult to interpret such information accordingly. This difficulty may be due to students' failure to reason properly with the ER or due to a lack of conceptual knowledge (factor R-C in Figure 4.1). Nonetheless, it may also emanate from the mode of presentation. In all cases, however, students' failure to perform VSs like in the above examples may limit their ability to work with ERs. Given this, another observation was that for those students who are able to perceive and interpret information from ERs, integrating the new information with already existing knowledge may also be difficult. Below are examples of this difficulty.

6.3.2.3 Integration of knowledge

As suggested by a number of authors (e.g. Mayer, 2003), visualization also involves a process of integrating new knowledge with already existing knowledge (Figure 2.2; Mayer, 2001; De Santis & Housen, 2000). However, students at times fail to do this, particularly when they have to transfer and use knowledge from other fields such as Mathematics to create knowledge in a different field. As shown in the following examples of VSs, students in the current research had difficulty integrating knowledge from prior knowledge with that represented by the ERs.

a) Perceive luminance/identify colours – Tasks 18, Perceive texture – Tasks 21

In *VS T1*8, students were expected to "make sense" or "give meaning" to the colour coding used in the ERs. This requires understanding of the relevant concepts which must then be integrated with the colour coding in the ER to construct new knowledge. In relevant probes (e.g. probes 1, 2 and 8), it was observed that students had difficulty applying this visualization skill in a MLS context. For example, the data suggested that students had difficulty recognising the role of colours in ERs (Albright, 1995). This difficulty may be due to experience and what they are used to. An example of this was where students perceived colours as a "real" one-to-one indication of how atoms are coloured, e.g. oxygen being actually red and carbon being grey in reality. Changing colours was perceived as "wrong". For instance, student 2P17 suggested that:

> *"From what we (students) have learnt, it would be wrong to say [represent] carbon is [as] red".*

This was also evident when students (e.g. 2P17 and 2P31) failed to recognise carbon when it was represented in grey and light grey in an amino acid (section 6.3.1.2).

In Figure 6.3, students were asked to determine how many carbon molecules were represented and in which positions. As discussed in section 6.3.1.2, student 2P17 was not able to integrate his/her prior knowledge with the colour coding in the ER. This was also observed in one other student (2P31) who participated in the interview. While the student was able to detect that the colour is different and that there "should be" carbons in the labelled positions (see Figure 6.3), the student was not able to formulate a single form of knowledge that integrates the colour coding in the ER with their prior knowledge.

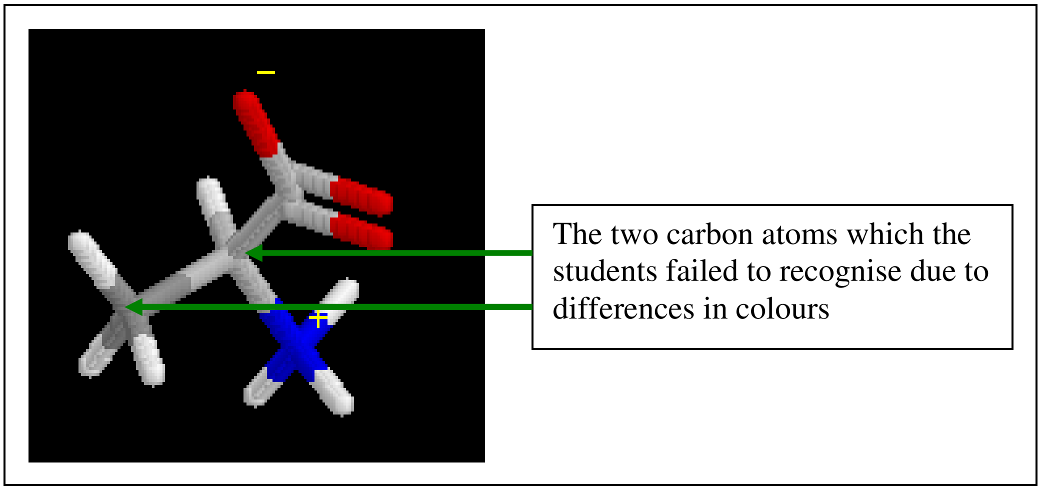


Figure 6.3: ER in which students failed to recognize atoms represented in different colours.

b) Evaluate/Assess – VS T01, Critique – VS T05, Judge – VS T15, Describe/Discuss – VS T07

Regarding integration, another related area of difficulty observed was that where students were expected to use their prior knowledge in "breaking down parts of ERs into components" and then to "critically examine and judge" the accuracy of the information represented. In this regard, students were expected to assess new information in relation to prior knowledge, by assessing the compatibility of the two.

To test for students' ability to integrate prior knowledge and new information, students were asked to explain if an ER is a good representation of a eukaryotic cell (Probe 06). Observations by the researcher indicated little evidence of students' deep engagement with this probe. As a result, an interview question was set up to investigate this trend. Below is a response from two students who were asked if the ER is a good representation of a eukaryotic cell:

Student P012:

> *"[it is a eukaryotic cell because] there is a visible number of features presents. A nucleus, nucleolus, mitochondria, lysosomes, rough and smooth endoplasmic reticulum as well as visible cytoplasm and cell wall. Golgi bodies are also present"*

Student P022:

> *"No, it is not a good model because one cannot distinguish [between] some of the things…but can see things like endoplasmic reticulum [and] nucleus but not all of its features…like antibodies so it's not a good model"*.

From student P022's response, it can be deduced that some students fail to understand that models are limited representation of reality. Furthermore, the two students (P012 and P022) responded to the same question very differently, yet prior to posing the current question, both students gave a scientifically correct version of their understanding of a eukaryotic cell which included detail most cellular organelles. For instance, the first student used her knowledge of cell structure and related it to the current model (in Probe 6). However, the second student failed to present her prior knowledge (verbally in her response) to evaluate the ER. Furthermore, student P012 was able to identify the similarities between what she knew and what she saw. In this instance, student P022 only identified two cell components represented by the ER. The student further suggests that due to the absence of antibodies (brings in new component, which would not be visible at the magnification of the ER), the cell is not a good model. In this instance, the student lacks proper knowledge and hence has a difficulty integrating prior knowledge with current information presented in the ER.

6.3.2.4 Expression

Another important stage of visualization is expression, where one applies knowledge in new situations, or translates mental models into visual models (e.g. Mayer, 2003). This can be done in various formats depending on the need; for example, students may be required to respond to a question by producing their own ER (section 2.3.1.6). Data in the current research showed "expression-related" difficulties that students had when responding to the probes. In this regard, data suggested that once students have acquired knowledge about different phenomena, they struggled to apply such knowledge to new situations. In particular, it was found that students had difficulties with applying skills learned in one situation to a new situation. This is termed poor transfer ability (Mayer, 2002). Some examples of this scenario are discussed below.

a) Find, Locate – VS T09, Identify shapes/identify – VS T16

With regards to "discovering by searching and ascertaining through observation" (Find/locate), as well as "to perceive multiple items with different orientation and shapes" (Identify shapes), students were found to have a difficulty. Here some students showed a difficulty in relating their prior knowledge (such as mental models) to an ER or parts thereof.

An example of this is similar to that reported in 6.3.2.3 *b*) above (concerning integration of knowledge using VSs such as, "Evaluate/Assess", "Critique" and "Judge"). In this instance, the student (2P22) could not explicitly define the various components of an ER (see students' response in 6.3.2.3 *b)* above). In the same scenario, the converse was also found when observations were made where the student only responded to a question using prior knowledge and not the ER as expected. Furthermore, the student did not perceive the differences between shapes of ER features as significant in providing scientific information about represented concepts. In this case, students may lack the proper image scanning skills and symbolic language skills that are necessary to locate and make sense of various parts of the ER.

b) Complete – VS T04; Outline – VS T17; Propose/Develop/formulate/etc. – VS T22

It was observed that students had limited ability when it came to, "making whole, with all necessary or normal elements or parts". As explained by the Gestalt principles (e.g. proximity, similarity, closure and simplicity, Figure 2.5), the present study revealed that, when students were provided with an incomplete diagrammatic phenomenon (e.g. Probe 05) and asked to use their understanding to complete the represented phenomenon (the incomplete ER), 52% of the students (who wrote the VLT) tended to struggle (either scored *incorrectly* or *partially correct* for the VS) to do so, regardless of the level of their conceptual knowledge. This, however, may be linked to other skills such as drawing skills or multitasking, where students are known to have difficulties.

Furthermore, when expected to perceive separate elements as a whole (e.g. Figure 6.4), some students had a tendency to perceive them as individual elements. In this regard, students (e.g. 2P22) referred to diagrams as *"complex and not easy to understand*". It can be deduced from such a response that when ERs have different components (e.g. differently coloured alpha helices in Figure 6.4), students view them as "complex", due to the overwhelming nature of such ERs. In this regard, two students suggested that the diagram showed a variety of individual alpha helices indicated in different colours. Another student suggested that the diagram showed different proteins consisting of different amino acids and hence, different types of helices. From this information, it is clear that students had difficulty putting the elements of the ER together (i.e. synthesizing them), and preferred to view them as separate elements.

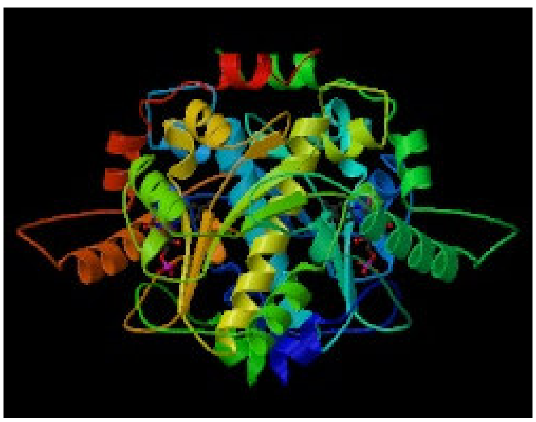


Figure 6.4: An example of an ER representing *Aspergilloglutamic peptidase* enzyme perceived by students as complex.

c) Infer/predict – VS T14, Imagine – VS T13

"Inferring" or "predicting" refers to "concluding by reasoning" and is associated with the availability of sound knowledge in a given context (Allen, 1990). Similar to "completing" (see 6.3.2.4 *b)* above), students were expected to study a phenomenon represented in an ER and then predict the final outcome of such a process (Probe 5). Observations in this regard showed that students were able to extract information from an ER and interpret such information (Figure 6.5). However, when expected to make deductions from such information, students showed limited ability.

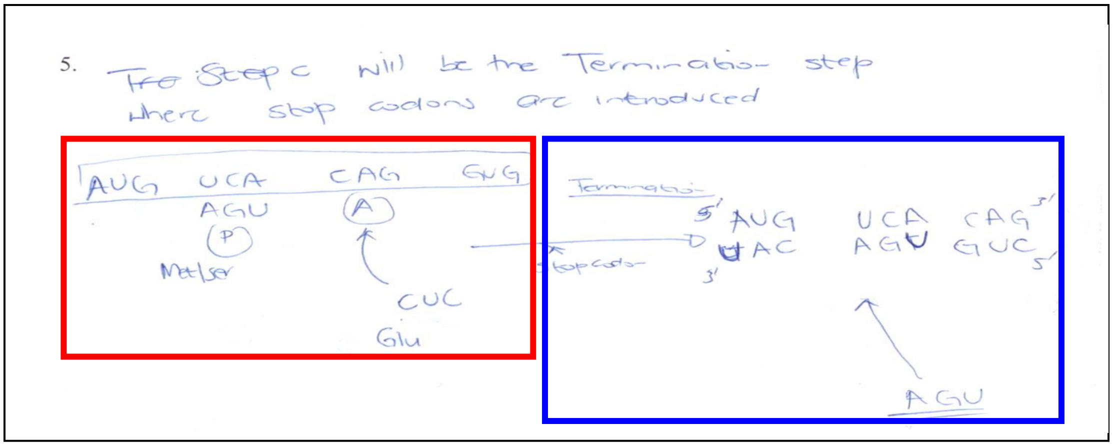


Figure 6.5: An example of a student generated diagram where the student has difficulties inferring or predicting.

In figure 6.5, the student (2P32) is evidently able to perceive and interpret the information presented. For example, the student showed that she understands that the figure is representing protein synthesis by including the term “termination and stop codon in her response. As shown in the red box, the student was able to perceive and “re-draw” the information represented. However, looking at the blue box, the student fails to use the extracted information to predict the outcome and hence, provides an incorrect outcome.

d) Mental Rotation/Orientation/Recognition – VS T16

Another important part of expression is when students are expected to be able to work with ERs of the same phenomenon but represented in a different orientation. This VS deals with one’s ability to “move, arrange, operate, or control cognitively in a skilful manner for examination purposes and then to perceive multiple items with different orientation and/or shape to be the same if orientation and/or shape is rearranged”. Different probes were set to test this VS e.g. Probes 1, 3, 6, 8, 11 and 12.

Data revealed that some students were not able to cognitively manipulate the depth cues of ERs to determine their position in space. In this regard, these students (e.g. 2P17 and 2P31 from the interviewees) struggled to recognise ERs when placed at different views. These students also had difficulties recognising ERs and relating prior knowledge to the knowledge represented in an ER (Todorova & Mills, 2004). This difficulty increased when different orientations, symbols or colours were used in the ERs

In one example where students were required to relate the orientation of two different ERs representing the same concept, 27% of the students who wrote the VLT could see that one is in a different orientation but the two are the same (Figure 6.6). In this instance, students thought the two ERs represented different concepts.

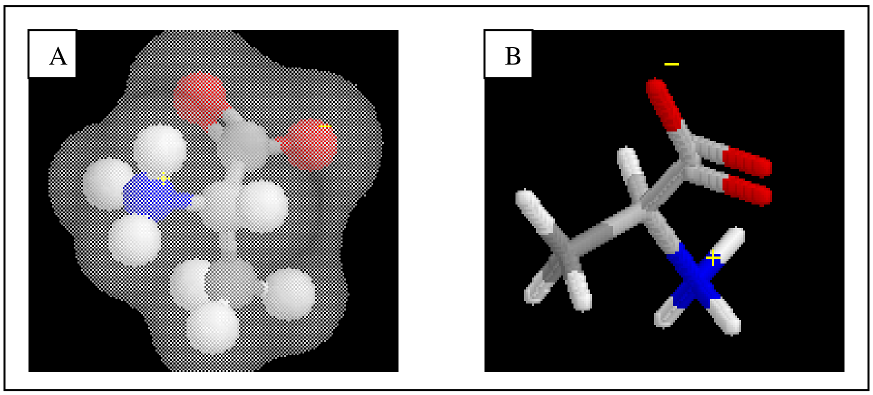


Figure 6.6: Two ERs where students were required to observe the differences in orientation of the amino acids.

In this example one student (W061) suggested that *"[the] orientation is the same, but different visualization technique*". Clearly the student could not see the differences in the orientation relative to the location of some atoms e.g., Nitrogen (blue) is on the left hand side in Figure 6.6 A, and on the right in B. This suggested that some students had difficulty identifying different orientations. In the above example, this problem may have been due to the different modes of representation (Figure 6.6). However, in contrast, one student who was able to identify the different orientation showed a different problem. Here, student (W101) suggested that *"The arrangement of the molecules is different… [which] causes a change in molecule [arrangement] resulting in an entirely new amino acid, [hence the two are not the same amino acid]"*. In this regard, the student assumed that "identical" amino acids can only be shown when they are presented in identical orientations. The source of this difficulty may be a lack of standardized models for representing concepts in MLS (Schönborn & Anderson, 2006).

e) Recall/Retrieve – VS T23, Illustrate/sketch – VS T12, Outline – VS T17, Imagine – VS T13

As part of the expression stage of visualization (Figure 2.4), students may be required to retrieve information from memory, either STM or LTM (Mayer 2001). Once information has been retrieved, students may be expected to illustrate, by means of examples, the main features or various aspects of a concept.

In probes requiring the use of such skills e.g., Probe 09 and 10, some students seemed to have difficulty, particularly with regards to illustrating by means of simple diagrams. In this regard one student (2P08) stated:

> *"No! Generally I don't [like drawing], I have never liked drawing…I don't have the patience"*.

In line with this mentality, a total of 15 students did not respond to any probe that required them to make drawing to express their mental models. Student 2P08 also suggested that he/she needs "assistance" for her to remember concepts. Here, the student suggested that:

> "*If I had a schematic diagram of something, I would remember that more than I remember text"*

Evidently, this student had difficulties recalling information unless she is assisted with ERs during the learning stage.

6.4 Summary and conclusions

Based on the difficulties described above, it is clear that visual literacy is multifaceted in nature, being composed of a wide range of different cognitive processes and skills with which students can have even more wide ranging difficulties. As shown, these include both non-visualization type- and visualization-type difficulties. In this regard, the data shows that there are different ways in which students struggle to work with ERs in relation to their VS. Also the frequencies of these varied from one VS to the other (see Chapter 5). At this stage, the research had generated qualitative data that may be viewed as independent from the quantitative data. This data highlights different stages of visualization at which the skills are performed, i.e. perception, visual imagery, integration and expression. In the next Chapter, the author will discuss how this data supports the quantitative data presented in Chapter 5 and to what extent it addresses the research questions, particularly research questions 2 and 3, i.e., “can specific levels of visual literacy be defined in the MLS?; and, “is a taxonomy a useful way of representing the levels of visual literacy for MLS?”

7. Chapter 7: Development of the Taxonomy for Visual Literacy

7.1 Introduction

The previous Chapters of this thesis have described evidence which can be used to respond to the research questions. In Chapter 2, it was shown that visual literacy is multifaceted, in Chapters 4 to 6, the facets of visual literacy were used to empirically define the nature of visual literacy. In this Chapter, the development of a taxonomy for visual literacy is described and presented. To achieve this, the author first gives the rationale behind opting for a taxonomy instead of other strategies. Following this the taxonomy is presented and described in detail.

7.2 Reasons for using a taxonomy to classify learners' visual literacy levels

Consideration of Bloom's taxonomy, as reviewed by Mayer (2002), it becomes clear that learning and teaching are done for specific reasons. Mayer (2002) suggests that meaningful learning occurs when learners have relevant knowledge and are able to transfer such knowledge. In this regard, various researchers (e.g. Mayer, 2002; Anderson *et al*., 2001) agree that meaningful learning requires a number of skills which emanate from the original Bloom's taxonomy. These skills include, to remember, understanding, applying, analyzing, evaluating and creating (Figure 2.6). These skills encompass a vast array of different cognitive processes (Anderson *et al*. 2001).

Successful learning, therefore, means a learner possesses relevant cognitive skills and is able to use them appropriately. In this regard, Chen and Yu (2000) suggest that accuracy and efficiency are important. Accuracy refers for instance to precision, high number of correct answers and on efficiency (efficiency is the average time to completion or performance time) (Chen & Yu, 2000).The question is then, how does the assessor use such standards for assessing the vast array of different, yet interdependent cognitive processes as listed by Mayer (2002) and Anderson *et al.*, (2001)?

To respond to the above question, one has to contrast between two common approaches namely, a matrix or list of cognitive processes or skills and taxonomies. If one uses a list of skills, then the most feasible approach is to use Boolean logic (Morse & Lewis, 2000). In this method conjunctions such as "*and*", "*or*", "+", "-", "*/*" as well as "*not*" could be used (e.g. Ghinea & Chen, 2006; Morse & Lewis, 2000). For instance, if one was looking at a list of VS e.g.:

Abstract, categorise, execute and discriminate;

Now to rate a student with regards to these the result would be something like:

"Student A can abstract and categorise but not execute or discriminate"; or,

"Student A: abstract + Categorise – Execute – discriminate" etc.

But obviously, it is difficult to quantifying such a rating, especially in comparison with other students. This is mainly because such a rating fails to show the effect of one skill on another. On the other hand, in a taxonomy each skill stands as an individual taxon. This means that upon rating the student, one would instead use conjunctions and give the student a score (quantitatively and qualitatively) by coding individual skills as individual taxa (Chen & Yu, 2000). Depending on the need, one can then average out the scores to get a mean score.

Given the above arguments, the current researcher decided to present visual literacy for the MLS as a taxonomy. The following sections indicate how data generated in the previous Chapters was used to generate such a taxonomy.

7.3 The nature of visual literacy and the taxonomy

In order to be able to determine whether visual literacy can be presented in a taxonomy, the nature of visual literacy had to be understood. This would form a basis on which a taxonomy can be based. Therefore, before one responds to the question of the taxonomy it is important to first provide information regarding the nature of visual literacy.

To understand the nature of visual literacy, current literature was reviewed (Chapter 2). Here, it became clear to the author that most researchers (e.g. Velez *et al.*, 2005; Aanstoos, 2003; Bamford, 2003; Mayer & Moreno, 2002; Bloomer, 1976) used the process of visualization to define the nature of visual literacy. Most authors (e.g. Bamford, 2003) suggest that visual literacy includes perception, visual imagery 1, visual imagery 2, integration and expression. Furthermore, it emerged that some authors (e.g. Mayer, 2001) suggest that the process of visualization includes transfer of knowledge between WM or STM and LTM where a number of sub-functions, e.g. chunking, selecting and rearranging, are carried out to fulfil the above stated stages of visualization (Figures 2.1 and 2.2).

Other researchers also used the ER's mode of presentation when defining visual literacy (e.g. Aanstoos, 2003; Bloomer, 1976). Such authors placed great emphasis on "visual elements" (NoER, see section 2.3) as contributors to the meaning of the represented phenomena, thereby allowing or denying a learner the ability to visualize what is represented. In this regard, visual literacy can not only be defined by one's ability to perceive, process and/or express knowledge through ERs, but the mode of representation also contributes to such visual literacy. In support of this suggestion, Schönborn and Anderson (2005) highlighted for instance that the lack of standardized symbolism in Biochemistry may limit students' ability to access information presented in ERs.

In addition to the above, other authors (e.g. Swenson *et al.*, 2005) suggest that visual literacy involves VSs (emanating from the facets of visual literacy, Table 2.2). In this regard, given the definitions of visual literacy that mention stages of visualization and those that highlight the mode of presentation, it became apparent to the current author that, to be able to "reason" with the ER, one requires specific VSs in order to be visual literate.

Based on the abovementioned understanding of visual literacy, in the present project, the "cognitive processes" that are involved in the creation of knowledge were explored (Mayer, 2003; Anderson *et al.*, 2001; Bloomer, 1976). In this regard, the results reported in this thesis established that:

- Depending on propositional knowledge required, the NoVL cannot be defined out of context. For instance, visual literacy in Biochemistry differs from visual literacy in Mathematics.
- Similarly to Bloom's taxonomy, visual literacy is multifaceted, i.e. composed of a set of underlying cognitive skills (see Table 2.2 and 4.1) that are applied in order to create meaning through ERs.

Since very few authors (e.g. Swenson *et al.*, 2005) have focussed on VSs in their definition of visual literacy, the present research was expanded to establish the existence and nature of such skills as components of visual literacy (Chapter 4). To achieve this, Bloom's taxonomy (Mayer 2003; Anderson *et al.*, 2001) was used as a guiding framework to help derive a set of skills (Table 4.1). These were then incorporated into probes that were in the Biochemistry context. The authenticity of these contextualized skills was then tested through a panel of experts (Chapter 4). Data indicated that:

- There are at least 24 VSs with distinct definitions (Table 4.1). These skills can be incorporated into different probes that were designed in the study.
- The skills are interrelated and thus, testing for any one skill may require the use of another related skill (see Section 4.3.1.1).

From the above knowledge, it was concluded that, visual literacy in the MLS can defined (by the current author) as, the *ability to select and effectively use a set of cognitive skills for perceiving, processing and expressing external representations in response to scientific knowledge in the MLS*. In this regard, a visually literate individual is one who has a well-defined set of VSs, performed as probes, as well as various relevant intelligences such as visuo-spatial intelligence. Given these, one needs to be able to identify the correct skills in relation to a given problem. Once such skills have been identified, one needs to be able to use them appropriately in response to the VS at hand. Overall, such skills may be performed at the stages of visualization, viz. perceiving, processing mentally (visual imagery 1 and 2), integrating and expressing visual knowledge in the form of ERs.

The above knowledge shows a multifaceted NoVL. However, given the different skills, in order to formulate a taxonomy, it was important to determine whether these skills vary with regards to difficulty. This would provide understanding as to whether the taxonomy would have progressive levels of skills or not. If the levels are generated, what would be the order in terms of difficulty? The next section focuses on the levels of visual literacy.

7.4 Levels of visual literacy for the MLS

Based on relevant literature (e.g. De Santis & Housen, 2007; 2000; Housen, 1992), the current author suggested that perception, visual imagery 1 and 2, integration and expression all be identified as distinct levels of visual literacy each with a distinct set of cognitive skills. The current researcher further suggested that these five levels are defined by distinct components of visual literacy (Anderson *et al.*, 2001). These are the objectives and the skills (Anderson *et al.*, 2001). In this regard, clear skills were defined.

Following the development and validation of the probes, an item difficulty map of visual literacy for the MLS was constructed by utilizing Rasch model (Figure 5.4). In this item map ranking, it was observed that the SoD varied from one VS to the other. Therefore, this provided a new understanding of the levels of visual literacy. Using the Rasch analysis, the difficulty trends in the form of item difficulty indices were calculated (Figure 5.4 and Bond & Fox, 2001). Qualitative data also validated this by providing visualization difficulties.

In addition to the above, during testing, it was noted that even though some difficulty levels of the VSs were almost identical e.g. VSs “outline” and “propose” (Figure 5.4), these varied with a fraction of a logit in terms of difficulty. Therefore, such VSs can not merely be regarded as having the same degree of difficulty. Hence, in the item difficulty map the current researcher opted for an *infinite* number of levels, each with its own difficulty index.

Therefore, according to the item difficulty map, the visualization stage at which a VS is performed does not reflect the difficulty degree of that VS. Furthermore, the item difficulty map places VSs on a “level” based on that each VS’s degree of difficulty and not with respect to the associated visualization stage. This also means that for the item difficulty map, a “level” is not based on the “stage of visualization, objectives and related cognitive processes”, but rather on the norm difficulty degree of each VS. In this way, using performance, students can be assigned to different levels on the item difficulty map.

From the data, it can be deduced that:

- Specific “levels” of visual literacy for the MLS can be defined. However, the definition of these requires much attention. Levels for visual literacy refer to specific VSs that are unique in nature.
- Each level requires specific generic visual skills and conceptual knowledge utilized simultaneously in response to a given probe.
- Each of these levels has a unique level of difficulty which emanates from non-visualization and/or visualization type difficulties.

At this stage, the current research has managed to provide enough information with which the taxonomy of visual literacy for MLS can be generated. In the next section we present such an empirical taxonomy, which is based on the above presented data.

7.5 A taxonomy of visual literacy for the MLS

The current study has been able to characterize the NoVL for the MLS and the levels thereof. The question is how can such knowledge be used to assist students improve their visual literacy. This question required a strategy of representing visual literacy for the MLS in a format that can be used to identify students' level of visual literacy and then define how such students can "move" from one level to the next.

Section 7.2, presented literature-based advantages of presenting visual literacy as a taxonomy instead of other formats such as the Boolean logic (Morse & Lewis, 2000). In this regard we suggested that through taxonomies, one is able to identify individual cognitive processes. Here Bloom's taxonomy is one example where specific cognitive processes are identifiable (Anderson *et al.*, 2001). Furthermore, in such a taxonomy, relevant skills associated with the cognitive processes can be identified (Mayer, 2003). In comparison to Bloom's taxonomy, our study has shown that visual literacy for the MLS also incorporates stages of visualization. In this regard, we have shown that each stage of visualization is characterized by a set of cognitive processes that take place, namely, perceiving, visual imagery 1 and 2, integration and expression.

Based on the data presented in the previous chapters, the current researcher proposes an empirical taxonomy of visual literacy for the MLS (Table 7.1). In this taxonomy six major components are presented. In column 1 (Table 7.1) the author provides the logit range, i.e. the difficulty sequence as obtained from the Rasch model (see also Figure 5.4). Each VS has a unique logit score which defines its level of difficulty. As shown in Table 7.1, some skills fall within the same logit range e.g. T18 and T06, this is because the difference between these skills is less than one logit.

Table 7.1 A taxonomy of visual literacy for the MLS.

Logit range	VS Code	VS name	VS definition	Examples of associated difficulty in MLS	Associated stage of visualization (Figure 2.4)
3					
2 to 3	T18	**Perceive Luminance/Identify colours**	To detect or perceive a visual attribute of things that result from the light they emit or transmit or reflect	Inability to understand the role of colours in ERs e.g. perceiving colours as a “real” one-to-one indication of how atoms are coloured, i.e. oxygen being red, carbon being grey and nitrogen being blue	Integration
2 to 3	T06	**Depth perception/ Recognition of depth cues**	To perceive spatial relationships and distances between objects, in multi-dimensions	Inability to differentiate between the cis and trans configurations of amino acids Inability to differentiate between 2-D angular rotation and 3-D depth	Perception
2					
1	T10	**Focus**	To concentrate attention energy on something	Not focusing on ER presented knowledge Not selecting and focusing on sections of complex ERs e.g. focusing on alpha helices and/or beta sheets of tertiary and quaternary proteins structures	Perception
0 to 1	T11	**Ground perception**	To detect or perceive the part of a scene (or picture) that lies behind objects in the foreground	Regarding the background not as part of the ER e.g. disregarding electron clouds in amino acid representations. Regarding background as part of the cellular matrix e.g. regarding background as an “empty space” in a cell.	Perception
0 to 1	T17	**Outline**	To give the main features or various aspects of; summarize	Inability to use available information to predict outcome of Biomolecular	Expression

				processes.	
0 to 1	T22	**Propose; Develop; formulate; devise; construct; create; produce; invent**	To cause to exist in a new or different form through artistic or imaginative effort	Inability to use available information or synthesise information from long term memory to propose outcome of Biomolecular processes.	Expression
0 to 1	T04	**Complete**	To make whole, with all necessary or normal elements or parts	Inability to use available information to predict outcome of Biomolecular processes.	Expression
0 to 1	T05	**Critique**	To critically examine and judge something	Inability to applying prior knowledge in analysing ERs' authenticity or reasoning with ERs, e.g. suggesting that absence of some cellular material means an ER is a bad representation of the concept	Integration
0 to 1	T20	**Perceive speed**	To recognize, discern, envision, or understand a rate of movement and meaning thereof	Inability to integrate rate of individual elements of a biomolecular process to the entire processes	Visual imagery
0	T08	**Discriminate**	To recognize or perceive the difference	Lack of a "holistic" perspective of ERs when analysing same amino acids presented differently	Visual imagery
-1 to 0	T12	**Illustrate; sketch**	To clarify, as by use of examples or comparisons and to use drawings to describe roughly or briefly or give the main points or summary of	Inability to illustrating using simple diagrams (associated with multitasking and lack of positive attitude towards ERs)	Expression
-1 to 0	T13	**Imagine**	To form a mental image of something that is not present or that is not given	Inability to synthesise information cognitively to predict outcome of Biomolecular processes.	Visual imagery
-1 to 0	T23	**Recall/retrieve**	To remember by retrieving information from memory	Inability to retrieve information from long term memory unless assisted	Expression
-1 to 0	T03	**Compare; relate**	To examine and note the similarities or differences of and bring into or link in logical or natural association and	Lack of a "holistic" perspective of ERs when analysing same amino acids presented differently	Visual imagery

			establish or demonstrate a connection between		
-1 to 0	T16	**Manipulate/Mental rotation; recognise orientation; Recognition; Identify; identify shapes**	To move, arrange, operate, or control cognitively in a skilful manner for examination purposes and then to perceive multiple items with different orientation and/or shape to be the same if orientation and/or shape is rearranged	Inability to explicitly define the various cellular organelles based on morphological differences Inability to relate the orientation of two different ERs representing the same amino acid	Expression
-1 to 0	T21	**Perceive texture**	To recognize, discern, envision, or understand the characteristic visual and tactile quality of the surface and meaning of such	Inability to understand by way of discerning, the meaning of surfaces such as the background in an ER e.g. disregarding electron clouds in amino acid representations. Inability to understand the role of colours in ERs e.g. perceiving colours as a “real” one-to-one indication of how atoms are coloured, i.e. oxygen being red, carbon being grey and nitrogen being blue	Perception Integration
-1 to 0	T09	**Find; locate**	To come upon or discover by searching or making an effort; to discover or ascertain through observation, to determine or specify the position or limits of by searching, examining.	Inability to explicitly define the various cellular organelles based on morphological differences	Expression
-1 to 0	T14	**Infer; Predict**	To conclude by reasoning; in logic or reason or establish by deduction or state, tell about, or make known in advance, on the basis of special knowledge	Inability to use available information to predict outcome of Biomolecular processes.	Expression
-1 to 0	T01	**Analyse; Interpret; Assess; Evaluate; Examine; Investigate**	To break down into components or essential features by making sense of or assigning a meaning to or give explanation and to examine and or assess carefully and observe or inquire	Lack of a “holistic” perspective of ERs when analysing same amino acids presented differently	Visual imagery

			into in detail by examining systematically to observe carefully or critically.	Inability to applying prior knowledge in analysing ERs' authenticity or reasoning with ERs, e.g. suggesting that absence of some cellular material means an ER is a bad representation of the concept	Integration
-1 to 0	T15	**Judge**	To determine or declare after consideration or deliberation; to form an opinion or evaluation	Inability to applying prior knowledge in analysing ERs' authenticity or reasoning with ERs, e.g. suggesting that absence of some cellular material means an ER is a bad representation of the concept	Integration
-1 to 0	T19	**Perceive motion**	To recognize, discern, envision, or understand change of position in space and assign meaning to	Inability to view rolling molecules in biomolecular phenomenon as in motion	Visual imagery
-2 to -1	T07	**Describe/discuss/explain**	To make plain or comprehensible by adding details or to justify or offer reasons for or a cause and give a description of, by conveying an idea or impression in speech or writing; characterize	Inability to explain by way of reasoning in analysing ERs' authenticity or reasoning with ERs, e.g. suggesting that absence of some cellular material means an ER is a bad representation of the concept	Integration/Expression
-2 to -1	T24	**Use**	To put into service or apply for a purpose	Applying conceptual information given only on the ER	Perception
-2 to -1	T02	**Arrange/order/organise/classify**	To put into a specific order or relation through a methodical or systematic arrangement or to arrange in a coherent form or pattern based on specific features	Inability to use diagnostic features based on conceptual knowledge to "arrange, order, organise, classify" ERs e.g. inability to classify proteins based on their complexity	Perception

The second column (Table 7.1) presents the skill codes. These are the codes that were used in the current study instead of using the full name of each skill; such a full name is given in column 3. In column 4, a definition of each VS is given (see also Table 4.1). Following the definition in column 5 (Table 7.1) are visualization difficulties (section 6.3) associated with each VS. These difficulties were identified within the scope of the VLT, which is context based (see Section 4.3.1.1), thus making the taxonomy to be context based. As shown in Chapter 6, these difficulties were found to be the underlying factor for the SoD (presented as logit range in column 1). Table 7.1 also presents the stage of visualization at which each VS is performed (see column 6) in column.

According to the findings of this research, visual literacy is multifaceted (Table 2.2). The taxonomy presented here (Table 7.1) suggests that, each VS, can be regarded as a facet of visual literacy, based on which individuals can be regarded as visually literate, within the area of MLS. This means for one to be visually literate they should show a certain degree of ability to perform the VS, associated with ERs used in the MLS, with minimal visualization difficulties as presented in Table 7.1. Should one have a visualization problem, it is possible to specifically identify the problem by defining the nature of the difficulty (using the skills' definitions, the nature of visualization difficulty and/or the stage at which the VS is performed).

In this section, it has been shown that the NoVL for the MLS can be defined. Further more, the levels of visual literacy have been identified with which a taxonomy of visual literacy was generated. In the next section the author discusses the significance of the taxonomy in terms of its uses.

7.6 Using the taxonomy of visual literacy

There a number of ways that educators, researchers and model designers in the MLS can use the taxonomy of visual literacy for MLS. These include ER development, assessment and classification of students' visual literacy levels, identification and remediation of students' visualization difficulties.

Concerning the development of ERs, Schönborn and Anderson (2006) note a lack of consistency of symbols used in ERs. These authors suggest that this lack of consistency may negatively impact learning. This is coupled by other authors' observations that poorly designed models may hinder effective learning (e.g. Mayer, 2001). Given this, the current taxonomy of visual literacy (Table 7.1) will provide researchers and model designers with a "reference" point when designing and using models. For instance, when designing a model, the researcher can now assess his/her model to determine whether the visualization difficulties listed in the taxonomy will not be enhanced by his/her model. For instance, as shown in Table 7.1, students may have difficulty "differentiating between the *cis* and *trans* configurations of amino acids" i.e. VS "Depth perception/ Recognition of depth cues". Such a difficulty is associated with still diagrams and animations that do not show 3-D. Therefore, computer based model designers for instance should consider the dimensional aspect of their ERs. At the same time, perhaps more physical models should be used to counter this visualization difficulty. Furthermore, it appears that Schönborn and Anderson's (2006) concern over inconsistent symbols may in fact include inconsistent models as well. In this regard, the vast diversity of models that show concepts in different dimensions may be difficult for students to process, and hence students' "inability to relate the orientation of two different ERs representing the same amino acid" (see *T16* Table 7.1).

While model designing requires attention, assessment of visualization is also another important component that the current taxonomy (Table 7.1) addresses. The current study has used VSs to test for visual literacy. As shown in Chapter 4, these were incorporated into the Biochemistry context. Therefore, the current taxonomy does not only rank VSs, but also provides important skills that can be incorporated into assessment tasks with which to test for visual literacy in different contexts. For example, the current VLT was designed for 3rd year Biochemistry students. Given this, it is possible to use the same skills to design tests for other academic levels, e.g. entrant university students, to determine their visual literacy. This is especially important as the taxonomy indicates potential visualization difficulties that students may have. For instance, if a module requires students to work with ERs where students are expected to "Perceive motion" (*T19*; Table 7.1), instructors may have to test whether students understand what is meant by "motion", a difficulty shown by the taxonomy (Table 7.1). Once the test has been used, the instructor will have an idea of challenges that students might have when working with ERs.

Concerning assessment of students' visual literacy, another important component of the current taxonomy (Table 7.1) is that it can be used to rank students according to their visual literacy. For instance, using the logit range, it is possible to determine potential problem areas for the students. Here, students performing an assessment tasks can be placed at specific levels based on their score in the test (e.g. VLT). For example, a student obtaining an average mark would be placed at level "0" of the taxonomy. Such scoring can be obtained by analysing student scores using the Rasch model. From this, it is possible to determine which areas will be difficult for students. For instance, at "Discriminate" level (*T08*) students have a 50% chance of getting *T08* correctly, over 50% chance of doing well in VSs below this level and over 50% chance of doing badly for those above (Kim & Hong, 2004). Therefore, instructors can use this taxonomy to determine whether students will be able to work with any given tasks that use these skills. Furthermore, by ranking students, it is possible to determine which students are able to work better with ERs.

The current researcher also suggests that this taxonomy is used as a means of helping students improve their visual literacy rather than only judging them. For example, if a student is at level "0" as given in the above example, such a student's potential problem areas can be predicted. As stated in section 5.3.1, this student has a chance of over 50% of failing to perform tasks above level "0" (Kim & Hong, 2004). Therefore, for this student to improve his/her visual literacy, more practice is required. Such practice should primarily focus on skills just above level "0". This could be repeated until the student's visual literacy has improved.

Given these uses of the taxonomy, the current researcher believes that this instrument should certainly be used to address visualization problems in the MLS. Furthermore, the current study has shown that while not much work is being done to understand visual literacy for the MLS, it is important that this area is explored as it plays a critical role both in research and education. In the next Chapter, some of the major findings are listed and discussed in the light of the original research questions

(Chapter 1), while potential areas of research are presented that can be explored in pursuit of more knowledge regarding visual literacy for the MLS.

8. Chapter 8: Conclusions and Future Research

The aim of this study was to address the following research questions:

1. What is the nature of visual literacy in the MLS?
2. Can specific levels of visual literacy be defined in the MLS?
3. Is a taxonomy a useful way of classifying the different levels of visual literacy for the MLS?

Previous studies indicate that pictures and text, instead of text alone are more effective transmitters of information (Dori & Barak, 2001; Russell *et al.*, 1997). Due to learning difficulties that are, however, associated with ERs, it is important that educators have a clear understanding of what might pose problems in a learning environment, particularly due to learners lack of skills (e.g. Schönborn & Anderson, 2006). The current study may assist educators with identifying VSs related to MLS as the study addresses some important questions including those stated above.

In response to research question 1, i.e. "What is the nature of visual literacy for the MLS?"; the current study showed that:

- Visual literacy is multifaceted in nature;
- Visual literacy requires specific propositional knowledge, which renders it context based;
- Visualization is a process through which visual literacy can be expressed;
- There are several visualization skills that compose, and are essential prerequisites for optimal visual literacy in the context of the Molecular Life Sciences; and
- Such visualization skills can be assessed through the development of probes in the context of Biochemistry.

In response to research question 2 i.e. "Can specific levels of visual literacy be defined in the MLS?"; the study showed that:

- Visualization skills incorporated into Biochemistry probes can be used to determine the degree of difficulty of each skill;

- The Rasch model is a good way of quantifying the degree of difficulty of the visualization skills in MLS;
- The degree of difficulty of each skill forms a level of visual literacy;
- Levels of visual literacy in MLS should be defined in terms of their norm difficulties and not stages of visualization;
- Visual literacy in MLS has infinite levels occurring on a continuum from low to high visual literacy; and,
- There are non-visualization and visualization type difficulties which contribute to the differences in visual literacy levels between Biochemistry students.

In response to research question 3, i.e. "Is a taxonomy a useful way of classifying the different levels of visual literacy for the MLS?"; the study showed that:

- It is possible to generate a taxonomy of visual literacy for the MLS using the visualization skills;
- The taxonomy of visual literacy for the MLS can be used to determine the level of each VS, its name and definition, typical difficulties found in the MLS as well as the visualization stage at which each skill is performed; and,
- The taxonomy of visual literacy for the MLS can be used to design models, assess students visual literacy, identify and inform the remediation of students' visualization difficulties.

As discussed above, this study has in the author's opinion, within the scope of this research, successfully addressed the critical research questions concerning visual literacy in the MLS, a field where visual literacy is central to its understanding but poorly understood. While this study constitutes a small step in the right direction, substantial more work is required in order to improve our current understanding of visual literacy, especially in fields such as Biochemistry where it is essential.

Acknowledging the extent of the research, the currently presented visualization skills, probes and the taxonomy are a preliminary work. For this work to be well established, more intellectual work including the revision and testing would be required so as to render the taxonomy valid across contexts. Furthermore, such work would need to be done with larger samples of experts and students from different cultures and institutions. This would improve the validity of the data and the reliability of the instruments. In line with this, due to limited resources, the current study used postgraduate students as experts. This mainly because the current study was a preliminary study focusing on establishing a foundation to the formulation of the taxonomy for visual literacy. However, in the future, there should be a very clear distinction, in terms of intellectual capability, between the experts and the actual subjects.

Looking at the propositional knowledge of the probes, the author acknowledges the need to refine the focus so as to probe specific and in-depth nature of visual literacy. In this regard, the current study broadly looked at different areas of Biochemistry. However, in the future, the study will select a specific theme and provide a relevant taxonomy. Related to this is the "wide" nature of ERs used. For instance, the study used one animation out of 12 still diagram-based probes. In this instance, the one animation used does not necessarily reflect broadly the nature of visual literacy relative to animations. Furthermore, one cannot assume that visualizing still diagrams is the same as visualizing animations. As a result, future studies will address this issue so as to generate clear and rigorous data.

In including a wider range of ERs, more modern ERs should be considered. Such could involve other animations, interactive images and maybe virtual reality which could significantly improve our ability to probe understanding and visualization of symbolic knowledge. The influence of a student's conceptual understanding on the ability to perform the VSs also requires deeper understanding, particularly in different environments, age groups, experiences and so on as the current study showed that visual literacy is influenced by a number of factors, particularly the context in which the test is based. New studies are also required to test the current taxonomy's ability to measure and improve students' level of visual literacy in other contexts (e.g. different universities). This could also be done in wider contexts, i.e. other fields of study and perhaps general community

While there is clearly an enormous amount of research waiting to be done, the current study has successfully provided researchers, particularly in the Biochemistry field, with a tool, in the form of the taxonomy, with which they can base any further studies into visual literacy in the context of Biochemistry. In this regard, researchers, textbook writers and animation designers can use the current definition of the NoVL and related taxonomy to inform the design of teaching tools. For instance, one of the questions that ER designers will be able to ask themselves before producing an ER is, besides conceptual knowledge, what visual literacy level should students have in order to effectively use the ER being designed. Also, what VSs is the ER addressing and how? In this way learning Biochemistry, and MLS in general, with ERs would be more effective as designers would be taking cognisance of students' visualization skills and competencies, when developing ERs. Furthermore, ERs can now be based not only on what the researcher or instructor perceives as relevant, but also on what learners are able to work with.

Thus in conclusion, the author feels strongly that the current research has laid a strong foundation for visual literacy research in the MLS, which has stimulated the urgent need for more extensive research towards a better understanding of the nature and measurement of the visual literacy of our students studying in the MLS.

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10. Appendices

10.1 Appendix 1: Consent form

A. Researcher's details

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Supervisor(s):	Prof Trevor R. Anderson Dr. Konrad J. Schönborn
Institution:	University of KwaZulu-Natal (Pietermaritzburg)

B. Nature of the Research and Purposes

Visual literacy and visualization are key components of learning in the cellular and biomolecular sciences. Many biomolecular phenomena are impossible to visualize with the naked eye due to their submicroscopic sizes and associated levels of complexity. To visualize such phenomena a range of visual models, such as diagrams, animations and pictures, are used to represent the phenomena, which assists students with constructing knowledge of how these phenomena occur in reality. However, the success of such models in communicating scientific concepts is not guaranteed, amongst other reasons, due to the lack of visual literacy amongst students as well as the use of inadequate models.

The current research intends providing a platform for improving visual literacy amongst students and improving the effectiveness of the use of visual models. In this regard, visual literacy skills necessary for the interpretation of visual models in the Biomolecular and Cellular Sciences will be defined. The nature of such skills and how they can be improved will also be characterized. This will be done by formulating a series of probes testing specific skills and using such skills to formulate a taxonomy of visual literacy in the Biomolecular and Cellular Sciences. Such a taxonomy can be used to measure and improve the visual literacy.

C. Participant's involvement

In the research a visual literacy and psychometric tests will be administered. Participant's scores in such tests will be analyzed to fulfill the above mentioned aims of the research. If a need arise, test participants may be requested to participate in an interview aimed at getting more data in relation to the tests. The information from this study will be used to write a report which will be published in research publications as well as a thesis.

D. Participation terms

The following conditions will be followed throughout the research:

1. Real names will not be used in any report(s); instead, pseudonyms (unreal names and codes) will be used in all verbal and written records and reports.

2. The reports will be treated in a confidential manner and will only be accessed by the participant, the researcher and the supervisors.

3. Participation in this research is voluntary; participants have the right to withdraw at any point of the study, for any reason, and without any prejudice, and the information collected and records and reports written will be discarded.

4. Should the participant be interviewed, cash payments will be done.

5. Findings of the research will be used to improve the Biochemistry 304 course work.

E. Agreement to Participation Terms

Do you want to participate in the research tests?
Yes ______ No ______
Do you want to be selected for an interview?
Yes ______ No ______

Full Names
____
Age
____

Student Number
____
Signature Date
____
Researcher's signature
____
Date
____