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A DESCRIPTION OF VISUAL LITERACY AMONG THIRD YEAR BIOCHEMISTRY STUDENTS

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Abstract. *The use of visual models in teaching, learning and research has increased. Consequently, students have to develop various new competencies including visual literacy in order to learn efficiently. However, visual literacy among biochemistry students is not well documented. Using quantitative research methodology, the current research was aimed at determining visual literacy among biochemistry students. The participants were 74 purposefully selected third year undergraduate biochemistry students from the University of KwaZulu-Natal. The data were collected using a Senior Aptitude test and BioVisual Literacy test. The results show that students performed well in the sub-sections of the Senior Aptitude test including patterns test and spatial perception 2D test. They had difficulties with non-verbal reasoning with figures and spatial visualization 3D tests, as well as with the BioVisual Literacy tests. The results suggest that students generally have poor visual literacy, which could affect their ability to comprehend content knowledge in biochemistry.*

Keywords: *biochemistry, bio-visual literacy, senior aptitude, visual literacy, visuo-spatial abilities.*

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Introduction

The last fifty years have seen an unprecedented knowledge explosion, which has led to an education dominated by visual models which are used for teaching, learning and research. As a result, students have to develop various new competencies such as academic communication literacy (Spektor-Levy, Eylon & Scherz, 2008), science literacy (Van Eijck & Roth, 2010), and visual literacy (Bottomley, Chandler, Morgan & Helmerhorst, 2006) in order to effectively learn and communicate. As part of the continuing knowledge explosion, biology has become one of the most diverse fields. Similarly, biology knowledge exists at various levels of complexity including macroscopic, microscopic and molecular levels, which increases the cognitive demand on students. Biology literacy therefore means that students must be able to comprehend and communicate across the various levels of complexity at which biological phenomena exist. To facilitate this process, instructional designers make use of visual models (also known as external representations) such as pictures, diagrams and animations. Nitz, Ainsworth, Nerdel and Prechtl (2014) argue that interpreting, constructing, transforming, and evaluating different scientific representations are crucial skills for students to build and communicate a conceptual understanding of science. They argue that being scientifically literate includes being visually literate which means having the ability to construct and interpret visual scientific information. There is however a dearth of knowledge regarding students' visual literacy, particularly their ability to effectively use visual models in their respective subfields of biology. In fact, the use and significance of visual models in various subfields of biology is yet to be quantified. The current research therefore sought to explore the significance of visual literacy amongst biochemistry students. The researcher hopes that discoveries within the biology context could facilitate similar research in other fields.

Problem of Research

Biochemistry is generally regarded as a difficult subject. This is because students may lack necessary skills to learn related concepts. For example, scholars highlight the importance of visual communication, which involves the ability to communicate through drawings and words that represent biochemical phenomena that exist at the macroscopic, microscopic, molecular and symbolic levels (Rundgren, Chang Rundgren & Schönborn, 2010). Mnguni (2014, p. 6) argues that, "in the macroscopic level students attempt to produce a visual model of the phenomenon as they directly experienced it through any of their senses. In the microscopic level, students attempt to produce visual models of biological phenomena as they exist in nature, even though such phenomena cannot be observed directly with the naked eye, meaning that students may not have any previous direct experience with the phenomena. In the symbolic level, the visual model produced by students is a qualitative abstraction such as a mathematical model, which is used to represent phenomena. Examples include a chemical equation of glucose metabolism which attempts to explain a metabolic process which cannot be directly observed". Given the complex nature of visualization, one wonders whether students have sufficient visualization skills in order to effectively learn in biochemistry. Recent research suggests that students may not have these skills (Mnguni, Schönborn & Anderson, 2016) and hence the current research explores the matter further.

Theoretical Background

The cognitive theory of multimedia learning, dual coding theory and limited capacity theory have been used to describe how students learn from visual models in science. In his cognitive theory of multimedia learning, Mayer (2014) argues that principles of multimedia learning can enhance visual learning through proper design and use of models as well as training of faculty and students. It is on this premise that the current paper explores visual literacy in biochemistry. Visual literacy can be defined as the ability to select and effectively use a set of cognitive skills for perceiving, processing and producing visual models (Mnguni, 2014). This view is supported by other scholars such as Hortin (1983) and Schönborn and Anderson (2010). Schönborn and Anderson (2010) identified eight cognitive skills that they argue are central to expert visual literacy in biochemistry. These skills are:

- Decoding the symbolic language composing a representation
- Evaluating the power, limitations, and quality of a representation
- Interpreting and using a representation to solve a problem
- Spatially manipulating a representation to interpret and explain a concept
- Constructing a representation to explain a concept or solve a problem
- Translating horizontally across multiple representations of a concept
- Translating vertically between representations that depict various levels of organization and complexity
- Visualizing orders of magnitude, relative size, and scale

Linenberger and Holme (2014) explored these skills by asking biochemistry experts to identify what they perceived as the most and least important skills for biochemistry students. Their findings showed that there was generally no consensus on which skills are most or least important. They argue that this may be due to varying interpretations of what Schönborn and Anderson's (2010) skills actually mean. For example, the most favoured skills in Linenberger and Holme's (2014) research were 1) "Constructing a representation to explain a concept or solve a problem" and 2) "Interpret and use a representation to solve a problem". In light of Bloom's taxonomy however, one may argue that "constructing a representation to explain a concept or solve a problem" entails several individual cognitive abilities that can be individually developed and assessed. It is in light of this that Mnguni et al.'s (2016) list of skills were explored in the current research. In their research, Mnguni et al. (2016) identified 24 visualizations skills, which they suggest, comprise visual literacy and are critical for learning biochemistry. Using the Rasch model these scholars were able to rank the 24 skills in order of difficulty and also assess students' ability to perform these skills.

Based on Mayer's (2014) cognitive theory of multimedia learning Mnguni (2014) argues that visualization as a cognitive process, is understood to consist of three interrelated and overlapping stages, namely, Internalization of Visual Models (IVM), Conceptualization of Visual Models (CVM) and Externalization of Visual Models (EVM) (Mnguni, 2014). Within each of these stages are individual interrelated and overlapping visualization skills which can be developed, measured and ranked (Mnguni et al., 2016). IVM is the stage where sense organs, such as the eyes, are used to "absorb" visual information from visual models in the external world, such as pictures, diagrams and animations. CVM is the meaning making stage where visual information is interpreted cognitively using available prior knowledge, which could both be correct conceptions and misconceptions. EVM is a cognitive stage where knowledge existing in cognitive structures is externalized by way of visual communication using diagrams and words. As stated earlier, these stages are interdependent and nonlinear.

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Mnguni (2014) suggests that learning skills in biology that are associated with IVM include the "ability to comprehend the scientific meaning of the part of a visual model that lies behind objects that are in the foreground" such as the cytoplasm in a cell depicting organelles. What makes IVM a potential source of learning difficulties however is the fact that it is divided into three interdependent and nonlinear phases, namely, low-level, middle level and high-level IVM (Healey, 2007). According to Healey (2007) the main tasks in the low-level IVM include feature extraction without any cognitively demanding interpretation of such features. Relevant low-level IVM tasks can be performed in less than 250 milliseconds of viewing a visual model (Mnguni, 2014). High level IVM on the other hand involves a cognitively demanding process of concept formulation (Healey, 2007). This entails utilization of higher amounts of cognitive effort and is linked to IVM (Mnguni, 2014).

According to the constructivists, meaning-making depends on available prior knowledge (Thompson, 1995). As such, the CVM stage is characterized by the interpretation of incoming visual information using prior knowledge and skills (Mayer, 2003; Thompson, 1995). In the context of biochemistry, such prior knowledge would have to be context-specific. Various researchers have contended that effective conceptualization of information presented through visual models occurs when such models are properly designed and used (Mayer, 2003; Moreno & Mayer, 1999). An example of a biology related skill that is involved in CVM is the the ability to recognize and interpret visual models of a concept that is represented in different orientations and formats (Mnguni, 2014). For example, molecules presented in 2D versus those presented in 3D. Another example is the ability to recognize protein molecules represented using for example, a ball and stick model versus beta sheets models.

Given the complex nature of visualization, coupled with the increased use of visual models in biology, the aim of this research was to describe third year biochemistry university students' visual literacy and how it relates to their content knowledge, which is taught using visual models. The research question framing this research asked, "what is the level of visual literacy among third-year biochemistry students?"

Methodology of Research

General Background

This research was a non-experimental quantitative research, with a relatively small sample of participants. In particular, the researcher used a descriptive design to describe the visual literacy of the participants. This design was specifically chosen as visual literacy level among biochemistry students is not well understood. This research therefore would provide a frame of reference from which future explanatory studies can be based.

Sample of Research

In this quantitative research, the researcher explored the significance of visual literacy by measuring biochemistry students' visual literacy in relation to their content knowledge of biochemistry phenomena. Participants were 74 third-year Bachelor of Science students majoring in Biochemistry at the University of KwaZulu-Natal. These students were selected purposefully, and they participated voluntarily following ethical clearance from the university (ethical clearance number HSS/0150/07). At the time of the research, the participants were all enrolled for a Protein Biochemistry module. They had all passed pre-requisite biochemistry modules in the first and second year, including other prerequisite subjects like Maths, Physics and Chemistry.

Content Knowledge Test

In light of their academic background, the researcher believes that the participants had relevant pre-requisite content knowledge and skills related to the current research. However, a short multiple-choice test consisting of twenty questions testing students' basic knowledge of amino acid and protein structures was administered to the students to determine their content knowledge related to the research. These questions were adapted from end-of-year university exam papers that the students had written in their second year Biochemistry modules over six months before the research. Students' answers were scored against a set of correct model answers found in the exam memoranda. Descriptive statistics of the results were then generated for the students' results using *SPSS 24*.

Visual Literacy Tests

Students' visual literacy was measured two days later, using a Senior Aptitude Test and a BioVisual Literacy test.

The Senior Aptitude Test, designed and validated by the Human Sciences Research Council (HSRC) of South Africa, was used to measure spatial and visual reasoning by testing students' ability to perform generic (context-free) spatial and visual reasoning tasks. As per HSRC regulations, the administration and scoring of this test was performed by a qualified educational psychologist according to the guidelines of the HSRC and the Health Professions Council of South Africa. This Senior Aptitude Test was divided into four subtests, namely, patterns test, spatial perception 2D, non-verbal reasoning with figures and spatial visualization 3D. The Patterns subtest required students to copy mirror images of specific geometric patterns. It allows for assessment of students' ability to read and interpret graphic visual models. The spatial perception 2D test required students to perceive and mentally rotate geometrical figures on a plane surface. Based on their rotations, students are required to distinguish similarities and differences between a range of options and pre-defined figures. The non-verbal reasoning with figures test required students to perceive the relationship between figures presented and manipulate these to form logically sequenced material. The spatial visualization 3D test measured students' three-dimensional visuo-perceptual and spatial visualisation. In this test students were presented with a series of geometric images which had to be rotated, folded or rolled mentally to form required shapes. These tests were selected because the tasks are similar to those used in undergraduate biochemistry such as different models of nucleotides, amino acids, monomers and polymers. As recommended by the HSRC developers of the tests, normed scores of the students in the tests were presented on a stanine (1-9) scale with 1 being *very poor* performance and 9 indicating a *very good* performance. Scores of 4 to 6 are in the average range.

The BioVisual Literacy Test probed students' visual literacy within the biochemistry context using 12 items. Mnguni et al. (2016) and Schönborn and Anderson (2009) suggest that students' ability to effectively respond to the questions that utilize visual models depends on at least three interdependent factors, namely: 1) students' visualization skills that they use to make sense of the visual model, 2) their prior conceptual knowledge that they 'bring' to the visual model and, 3) the mode (e.g. the graphical features and markings, diagram, animation etc.) in which they externalize their knowledge. These factors are regarded as indicative of BioVisual Literacy. In the current research therefore BioVisual Literacy was assessed using the 12 items developed and validated by Mnguni et al. (2016) with specific focus on a set of visualization skills (Table 1).

Table 1. List of visualization skills required for visual literacy.

Possible Visualization stage	Visualization skills	Visualization skills definition	Visualization skill code
Internalization	Classifying	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	VS02
	Perceiving depth	To perceive spatial relationships and distances between objects, in multi-dimensions	VS06
	Locating	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	VS09
	Focusing	To concentrate attention energy on something	VS10
	Perceiving the background	To detect or perceive the part of a scene (or picture) that lies behind objects in the foreground	VS11
	Interpreting colour codes	To detect or perceive a visual attribute of things that result from the light they emit or transmit or reflect	VS18
	Interpreting motion cues	To recognize, discern, envision, or understand change of position in space and assign meaning to	VS19
	Interpreting speed of objects	To recognize, discern, envision, or understand a rate of movement and meaning thereof	VS20
	Interpreting texture	To recognize, discern, envision, or understand the characteristic visual and tactile quality of the surface and meaning of such	VS21

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Possible Visualization stage	Visualization skills	Visualization skills definition	Visualization skill code
Conceptualization	Analysing	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	VS01
	Comparing	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	VS03
	Critiquing	To critically examine and judge something	VS05
	Imagining	To form a mental image of something that is not present or that is not given	VS13
	Describing	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	VS07
	Discriminating	To recognize or perceive the difference	VS08
	Determining	To determine or declare after consideration or deliberation; to form an opinion or evaluation	VS15
	Rotating mentally	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	VS16
	Recalling	To remember by retrieving information from memory	VS23
Externalization	Completing	To make whole, with all necessary or normal elements or parts	VS04
	Illustrating	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	VS12
	Inferring	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	VS14
	Outlining	To give the main features or various aspects of; summarize	VS17
	Constructing	To cause to exist in a new or different form through artistic or imaginative effort	VS22
	Using	To put into service or apply for a purpose	VS24

According to Mnguni et al. (2016), the 12 items are content knowledge questions that require students to cognitively process visual models in order to derive the correct answer. As such, each question, was made up of at least one visualization skill and a related amino acid and protein structure concept. Some visualization skills were tested more than once depending on the question requirements. All visual models used in the questions were taken from textbooks and other web-based resources that were used by lecturers teaching the participating students. The test was presented to students using *MS PowerPoint*.

Figure 1 is an example of a question used in the BioVisual Literacy test. In this question, the following were some visualization skills that were tested:

- *Analysing* (breaking down into components or essential features by making sense of or assigning a meaning to or give explanation and examine and or assess carefully and observe or inquire into in detail by examining systematically to observe carefully or critically);
- *Comparing* (examining and noting the similarities or differences of and bring into or link in logical or natural association and establish or demonstrate a connection between);
- *Perceiving depth* (perceiving spatial relationships and distances between objects, in multi-dimensions).

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PROBE 1

- **Time allocated: 3 minutes**

a) Study the following diagrams with respect to the amino acid features represented and then indicate whether the diagrams represent the same amino acid or different amino acids? Explain your reasoning.

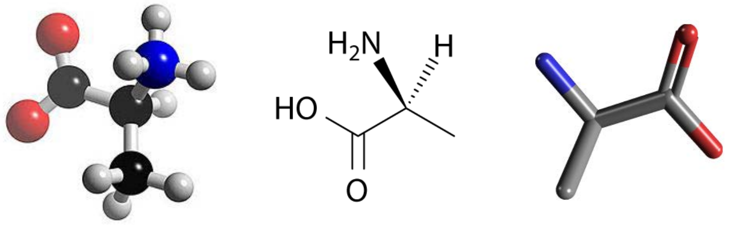

Figure 1: An example of the probes used to test students' visualization abilities.

Students' responses were manually scored against a set of previously validated model answers leading to each student having an aggregate score for each visualization skill, which enabled the calculation of an overall average score for the entire student sample. From this an output of non-linear raw scores was generated which were then further processed using the *WINSTEPS* Rasch model to convert this non-linear raw data into linear logit scores (Mnguni et al., 2016; O'Neill, 2005). The logit scores are generated according to the Item Response Theory which converts non-linear raw student scores to linear logit values that can be used to control for the difficulty level of scale items and the non-additive feature of ordinal data (Anshel, Weatherby, Kang & Watson 2009; Bond & Fox, 2015). Unlike raw scores, logits are interpreted directly such that an item with 10 logits is twice as difficult an item with 5 logits; and a student with 10 logits has twice the ability of a person with 5 logits. The logit scores were therefore used in this research to rank students' relative level of visual literacy against Mnguni et al.'s (2016) visualization skills. In their research, Mnguni et al. (2016) ranked the 24 visualization skills in order of difficulty using the Rasch model. They then used this order of difficulty to rank students in order to determine students' visual literacy in relation to visualization skills. In the current research participating students were also ranked against Mnguni et al.'s (2016) visualization skills' order of difficulty.

Results of Research

Biochemistry Content Knowledge

Results from the content knowledge test showed that the participating students had an average score 67% with a median and mode of 66%. The standard deviation was 15.5%. Students generally knew the definitions and characteristics of amino acids and how amino acids form proteins. Majority of the students (72%) however could not answer questions related to protein structures and how these structures form. However, the average score obtained demonstrated that the participating students have a sufficient content knowledge of amino acids and protein structures.

Spatial and Visual Reasoning amongst Students

Data showed that generally students were able to perform visuo-spatial tasks related to patterns test, spatial perception 2D. As shown in Table 2, the stanine scores for these two tests were above the norm average of between 4 and 6. Notably, 62% of the students scored 8 or 9 in the patterns test, while 60% scored 9 in the spatial perception 2D. However, the non-verbal reasoning with figures and spatial visualization 3D subtests proved to be more challenging for students. Here 67% and 60% the students scored between 1 and 4 in the non-verbal reasoning with figures spatial visualization 3D tests respectively. This suggests that the students had difficulties reasoning with visual models as well as working with models that attempt to illustrate phenomena in 3D.

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Table 2. Showing results from the aptitude test testing patterns test (patterns), spatial perception 2D (SP2D), non-verbal reasoning with figures (NVRF) and spatial visualization 3D (SV3Dabilities), N = 74.

	Minimum	Maximum	Mean	SE	SD
Patterns	3.00	9.00	6.1667	.37165	2.03560
SP2D	1.00	9.00	7.1000	.53466	2.92846
NVRF	1.00	9.00	3.0333	.33385	1.82857
SV3D	1.00	9.00	2.1533	.41725	1.28539

BioVisual Literacy

A reliability co-efficient of 0.801 was obtained for the BioVisual Literacy test using the raw scores data. The Rasch model was also employed to determine 'dimensionality', which is an important measurement when employing the Rasch model (Mnguni et al., 2016; Linacre, 1994). The dimensionality of ranged from 0.58 to 1.5 for infit statistics and 0.56 to 1.67 for outfit statistics, falling within the acceptable range for unidimensionality as suggested by Velozo, Kielhofner, Gern, Lin, Azhar, Lai and Fisher (1999).

It was observed that students generally performed poorly in the BioVisual Literacy test (Figure 2). Results show that 85% of the students have over 50% chance of failing to correctly respond to probes requiring them to utilize the average difficult visualization skills (VS08, VS12, VS13 and VS23, see Table 1 and Figure 2). This suggests that a significant majority of the participating students have poor visualization skills. In fact, seven students (S008, S030, S035, S037; S053, S065 and S070) have over 75% chance of incorrectly responding to probes requiring them to utilize all the visualization skills tested in this research. Results also show that only students S006, S009, S018, S025, S054 and S069 have a 50% chance of correctly responding to probes requiring the use of visualization tasks VS08, VS12, VS13 and VS23. These students have a 25% chance of correctly responding to probes that require the utilization of VS10 and VS11. Similarly, student S062 has an over 50% chance of correctly responding to probes requiring the utilization of all but two visualizations skills VS18 and VS06.

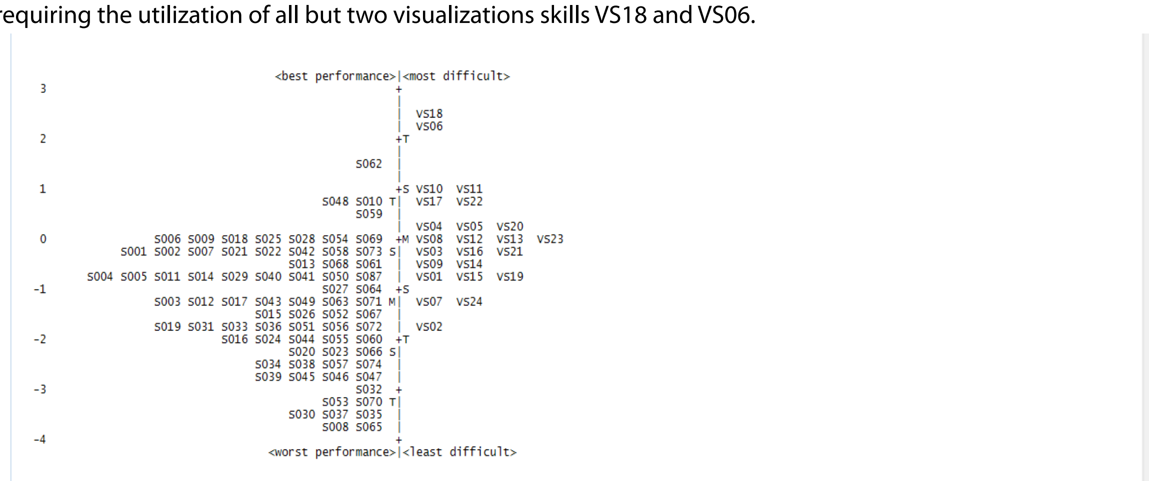

Figure 2. The distribution of students against the various visualizations ranked in order of difficulty.

Visual Literacy and Content Knowledge

Using the linear regression model with biochemistry content knowledge as a dependent variable, data showed a significant correlation ($r = .801$). The proportion of variance in the dependent variable which can be explained by the independent variables was 0.642. Data also showed that the regression model statistically significantly predicts the outcome variable (i.e. $p < .0005$). Furthermore, the data showed that Spatial Perception 2D, Spatial Visualization 3D and BioVisual Literacy were found to be likely useful predictors of students' content knowledge ($p < .05$).

To further understand the emerging patterns from the data, raw scores were used to determine correlations between the different tests individually. Results (Table 3) showed that the two visual literacy tests have a significant correlation between them. In particular, the subtests of the Senior Aptitude Test had a very high correlation coefficient with one another. This is in spite of the fact that students performed better in two of these subtests and poorer in the other two. Perhaps most important for the research was that the two subtests of the Senior Aptitude Test, which were found most challenging for the participating students, had a significant correlation with both the content knowledge test and the BioVisual Literacy test. The BioVisual Literacy test also had a significant correlation with the content knowledge test. This correlation may suggest that an improvement in students' aspects of visual literacy may lead to an improvement in their content knowledge.

Table 3. Correlation between visual literacy and content knowledge.

		Biochemistry Content knowledge	Patterns test	Spatial perception 2D	Non-verbal reasoning with figures	Spatial visualization 3D
Biochemistry Content knowledge	Pearson Correlation					
	Sig. (2-tailed)					
	N	74				
Patterns test	Pearson Correlation	.357**				
	Sig. (2-tailed)	.002				
	N	74				
Spatial perception 2D	Pearson Correlation	.222	.642**			
	Sig. (2-tailed)	.058	.001			
	N	74	74			
Non-verbal reasoning with figures	Pearson Correlation	.543**	.631**	.495**		
	Sig. (2-tailed)	.001	.001	.001		
	N	74	74	74		
Spatial visualization 3D	Pearson Correlation	.510**	.667**	.623**	.809**	
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	74	74	74	74	
BioVisual Literacy	Pearson Correlation	.657**	.338**	.437**	.378**	.303**
	Sig. (2-tailed)	.001	.003	.001	.001	.009
	N	74	74	74	74	74

***. Correlation is significant at the .01 level (2-tailed).*

Discussion

Students entering tertiary education are subjected to a number of competency tests, of which visual literacy is generally not one of. This is in line with Schönborn and Anderson (2009) who argue that science educators seem to assume that students will develop visual literacy by 'osmosis' on their own without being explicitly taught. This is in spite of a large volume of evidence which demonstrates the significance of visual models both for teaching and learning (Mnguni et al., 2016). Students' ability to perform visuo-spatial tasks related patterns, spatial perception 2D, non-verbal reasoning with figures and spatial visualization 3D are rarely explored, let alone in the context of biochemistry.

The current research has demonstrated that the apparent assumption that students will always be able to perform adequately on tasks related to patterns, spatial perception 2D, non-verbal reasoning with figures and spatial visualization 3D is not justifiable. In fact, the results have shown that even though their scientific knowledge is relatively high, a significant number of students have challenges related to these tasks, challenges that have the potential to hinder effective learning in biochemistry. This is especially true, given the observed relationship between performance in the content knowledge test and visual literacy tests. Lohman (2005) argues that non-verbal ability tests, such as those used in the current research, cannot necessarily be used to determine giftedness of students.

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However, it was concerning that students performed poorly in the non-verbal reasoning with figures test and the spatial visualization 3D test. This is because these results suggest that the students have a poor ability to understand and analyse visual information and solve problems using visual reasoning. These skills are significant in biochemistry where students are expected to analyse and solve complex problems without relying on verbal languages such as English. In the South African context, non-verbal reasoning and spatial visualization are most significant, given that linguistic diversity has been identified as a barrier to learning (e.g. Botes & Mji, 2010). Consequently, students' ability to reason non-verbally could improve content understanding irrespective of students' verbal abilities.

Anderson and Schönborn (2008) argue that while there is no absolute boundary between expert knowledge and novice knowledge, the aim of biochemistry education should be to develop students from being novices into experts. Stevens, Johnson and Soller (2005) however suggest that novices tend to 'hunt for the solution' using fragmented knowledge without qualitatively analysing problems in search for solutions. Perhaps this is why students participating in the current research demonstrated a relatively high level of content knowledge but failed to perform visualization tasks which did not necessarily require them to 'recall' a biochemistry answer but required them to demonstrate the ability to use cognitive skills to algorithmically synthesize solutions to a problem they had probably not encountered before. As argued by Anderson and Schönborn (2010), this level of competence requires one to be able visualize abstract structures and processes across different levels of organization, a skill only available to expert biochemists. It is for this reason that Novak and Canas (2006) as well as Marbach-Ad, Briken, Frauwirth, Gao, Hutcheson, Joseph, Mosser, Parent, Shields, Song, Stein, Swanson, Thompson, Yuan and Smith (2007) have suggested a deliberate effort to help novices develop visualization skills necessary for effective learning in biochemistry. The results of the current research also suggest that there may be a need to explore this in order to help students improve their visual literacy. Improving students' visual literacy through training is also supported by Mayer's (2014) cognitive theory of multimedia learning which suggests that deeper learning occurs when students have been trained to use visual models, thereby improving their visual literacy. The observed significant correlation between visual literacy results and content knowledge also suggests that improved visual literacy could lead to an improved content understanding among students.

Conclusions

In this research, the researcher aimed to describe the visual literacy level of the participating biochemistry students. In this regard, the research has shown that students do not always have the visual literacy skills that may be required for successful learning in biochemistry. In particular, students may lack non-verbal reasoning with figures, spatial visualization 3D, Spatial Perception 2D and BioVisual Literacy skills. Given the microscopic nature of concepts learnt in biochemistry, the researcher believes that it is necessary to consider formalizing visual literacy education in a similar way to other competencies such as content literacy. The researcher also recommends that teachers need to be alerted to the complex nature of visualization required in biochemistry teaching and learning as demonstrated by the multiplicity of visualization skills and their significance in biochemistry, in order to inform a better development and use of tools with which learning difficulties could be minimized. The researcher concedes however that the problems identified in this research may be localized. As such, further research is required to establish the nature of visual literacy amongst bio-molecular sciences, including biochemistry. Research is also required to determine the possible causal relationship between visual literacy and content understanding in biochemistry.

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