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The Development of an Instrument to Assess Visuo-Semiotic Reasoning in Biology

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ABSTRACT

Purpose: The significance of visuo-semiotic models in biology education has increased. Students have to develop visuo-semiotic skills, which could enable them to learn biology effectively. However, a lack of a universal theory of visual literacy has made it challenging to develop and assess visualization skills, including visuo-semiotic skills. The aim of the present research, therefore, was to develop an instrument for assessing visuo-semiotic reasoning in biology (VSR-b) in the context of amino acid structures. The research question guiding the research was "how could an instrument for assessing visuo-semiotic reasoning in biology be developed?"

Methods: Guided by a theoretical framework, the VSR-b Test was developed using a mixed-methods approach, by first identifying VSR-b Skills through a panel of nine experts after which items were designed and validated through the same panel of experts and pilot participants (n=18). The VSR-b Test was then tested on a group of molecular biology students (n=30).

Findings: Results showed satisfactory reliability and inter-item correlation. However, further research is required to corroborate findings of the present research in other contexts, with particular emphasis on assessment and development of visuo-semiotic reasoning among students.

Implications for research & practice: The current research has shown that VSR-b can be understood and assessed within the context of the theoretical cognitive process of visualization. It provides teachers and researchers a starting point in understanding how learning occurs through visuo-semiotic models. Instructional and curriculum designers, therefore, can use findings of this research as a guide to support student development in biology.

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Introduction

Researchers around the world acknowledge the significance of visuo-semiotic models (VSM) in teaching and learning biology. VSMs are defined as visual models that use discipline-specific semiotics to represent scientific phenomena for research, teaching, and learning. These include written language, static multidimensional images, animations, simulation, and symbols. VSMs are used in biology because some biological content knowledge and phenomena exist at multiple microscopic levels, which cannot be visualized with a naked eye.

Consequently, VSMs are then used to visually illustrate and represent these otherwise unobservable phenomena and related scientific theories (Arnerson & Offerdahl, 2018). Scholars argue that in the 21st century, the concept of scientific literacy must include the ability to interpret, construct, transform, and evaluate different scientific representations which include VSMs (Nitz, Ainsworth, Nerdel & Prechtl, 2014). For instance, students are now expected to develop 21st-century skills, content literacy, academic communication literacy, science literacy, and visual literacy (Arsad, Osman & Soh, 2011; Mnguni, 2014). This is because the ability to construct and interpret visual scientific information has become a significant skill in modern science.

While scientists agree on the significance of VSMs and related competencies, there remain debates related to the definition of visual literacy (Avgerinou & Pettersson, 2011). For example, Arnerson and Offerdahl (2018) suggest that a description for visual literacy should include disciplinary discourses such as decoding and interpreting visual representations, encoding and creating visual representations, as well as generating mental models. Offerdahl, Arneson and Byrne (2017), however, suggest that visual literacy means the ability to read and write visual representations by using a complex system of semiotics used to represent disciplinary ways of knowing. Such a complex system of semiotics includes written language, images, and symbols which represent discipline-specific knowledge. Avgerinou and Pettersson (2011), however, suggest that visual literacy is an interdisciplinary visual language, grammar, syntax, and vocabulary which make up a visual language. Linenberger and Holme (2015, p. 24) also suggest that "visual literacy is the ability to understand (read) and use (write) images and to think and learn in terms of images."

Similar to the varying perspectives on what visual literacy means, there is also a lack of a cohesive theory of visual literacy (Avgerinou & Pettersson, 2011). As a result, there is no general agreement regarding the pedagogical applications of visual literacy, including methods for developing, measuring, and assessing it. Therefore, it is not surprising that a wide range of techniques has been used to measure and assess visual literacy. For example, Arnerson and Offerdahl (2018) proposed a visualization blooming tool, Offerdahl et al. (2017, p. 6) proposed a "taxonomy for characterizing abstraction in instructional representations," while Linenberger and Holme (2015) proposed a Biomolecular Visualization Framework. The complexity and variation between these tools are indicative of the differences in the understanding of visual literacy amongst scholars. It further justifies the present researcher's argument that visual literacy cannot be understood outside specific disciplines.

A case for visuo-semiotic reasoning in biology

In line with the above argument, Avgerinou and Ericson (1997) suggest that visual literacy abilities include visual thinking, visualization, and other related cognitive abilities. This includes cognitive abilities for understanding, using, and thinking through VSMs (Avgerinou & Quinn Knight, 2005). However, these VSMs are generally context-specific. For this reason, the present researcher cautions that definitions that draw parallels to general verbal literacy by referencing the ability to read (make sense of) and write (draw or create) visual representations (e.g., Offerdahl et al., 2017) may be misplaced. This is because visual literacy is context-specific rather than generic.

For this reason, visual literacy is directly intertwined with subject-specific knowledge and semiotics, which may differ significantly within and between disciplines. For example, a student may be visually literate in mathematics, but be visually illiterate in biology. Therefore, the present researcher proposes that visual literacy should be defined within the context of related disciplines. This could include, bio-visual literacy, and mathematical-visual literacy, wherein the visual literacy is directly defined within the context of disciplinary discourse and related semiotic resources, which provide access to a discipline-specific epistemology and ontology. This view is in line with Airey and Linder (2009, p. 33) who suggest that "visual literacy can be defined in terms of discursive fluency, that is, when a student understands the various ways in which the discipline generally uses that mode to represent a particular way of knowing." Similarly, Avgerinou and Knight (2005) argue that mathematics teachers who are visually literate in the mathematics context could teach mathematics better than those who are not. This is to say; mathematical visual literacy could be useful for teaching mathematics, and not for other disciplines.

Weliweriya, Sayre and Zollman (2018) suggest that semiotic resources include symbolic tools such as language, diagrams, sketches, graphs, and signs which are used to construct mental models and knowledge. According to Van Leeuwen (2005), semiotic resources offer the capability to students and researchers to construct the meaning of content knowledge depending on how they are used. Consequently, semiotics provide access to disciplinary knowledge, which student would otherwise not have (Weliweriya et al., 2018). In line with this reasoning, therefore, the present researcher believes that there is a specific set of semiotic resources which could afford biology students access to relevant biology-specific content knowledge, which however varies with the various sub-disciplines of biology. It is for this reason that content knowledge and related semiotic resources are arranged and taught hierarchically (Khodor, Halme & Walker, 2004). Therefore, the present research explores visuo-semiotic reasoning in biology (VSR-b) concerning content knowledge and semiotics of amino acid structures.

Based on the above discourse, VSR-b is defined in the present research as the ability to internalize, conceptualize, and externalize biology content knowledge through the use of VSMs and discipline-specific semiotics representing biology content. A small letter 'b' is used in the above abbreviation because 'biology' knowledge explored in the present research does not reflect all existing Biology knowledge.

Aims of the research

In light of the above discourse, the present research aimed to develop an instrument for assessing VSR-b by asking the question "how could an instrument for assessing visuo-semiotic reasoning in biology be developed?". While biology as a broad field was chosen, the research focused primarily on amino acid structures as a context for studying visuo-semiotic reasoning.

Theoretical Framework framing the VSR-b test

The following theoretical perspectives informed the development of a VSR-b Test reported in this article:

a) The theoretical cognitive process of visualization (Mnguni, 2014);
b) The taxonomy for teaching, learning and assessing content knowledge (Anderson, Krathwohl, Airasian, Cruikshank, Mayer, Pintrich, ... &, Wittrock 2001);
c) The model of factors determining students' ability to interpret external representations in Biochemistry (Schönborn & Anderson, 2009); and,
d) The taxonomy for characterizing abstraction in instructional representations (Offerdahl et al., 2017).

In the theoretical cognitive process of visualization, Mnguni (2014) relies on cognitivism, constructivism and the cognitive theory of multimedia learning to suggest that learning from VSMs involves i) inputting of information from the external world into the cognitive structures (Internalization of VSMs, IVM), ii) the cognitive development and processing of visual information (Conceptualization of VSMs, CVM), and iii) the externalization of (visual) information (as VSMs) (Externalization of VSMs, EVM). Consequently, in the present research, VSR-b included skills related to IVM, CVM, and EVM (Figure 1).

These skills were identified using the taxonomy for teaching, learning, and assessing, also known as Bloom's taxonomy (Anderson et al., 2001). This taxonomy classifies a list of learning objectives in the cognitive domain, which involve knowledge and the development of intellectual skills, including the recognition of specific facts, procedural patterns, and concepts that serve in the construction of knowledge as well as the development of mental abilities and skills (Bloom, Krathwohl & Masia 1956). Bloom's taxonomy was used in the present research because it includes skills that would be used in the process of visualizations (i.e., IVM, CVM, and EVM) as suggested by Mnguni (2014) (Figure 1). Mnguni (2014), however, indicates that IVM skills are pre-attentive and require a significantly low degree of cognitive effort and almost no content knowledge. In line with this view, Kawahara and Yokosawa (2001) also indicate that these pre-attentive skills include target detection, region tracking, and counting.

Schönborn and Anderson's (2009) model of factors determining students' ability to interpret external representations in molecular biology was used in the present research to identify additional factors that could affect VSR-b. Schönborn and Anderson (2009) suggest that students' ability to interpret VSMs is affected by i) their

existing conceptual understanding and prior conceptual knowledge (of relevance to the VSM in question), ii) their ability to reason with the VSM and with their conceptual knowledge of relevance to the VSM, and iii) the actual external nature of the VSM. As a result, the development of the VSR-b Test in the present research would include investigating these three factors (Figure 1). In particular, students' existing content knowledge and their ability to process visual information (i.e., CVM) cognitively were investigated. The external nature of the VSM was understood in the present research within Offerdahl et al.'s (2017) taxonomy for characterizing abstraction in instructional representations. Offerdahl et al. (2017) argue that abstract VSMs can be classified as a symbolic, schematic, graphic, cartoon, or realistic, and students require a specific set of skills to be able to learn from them.

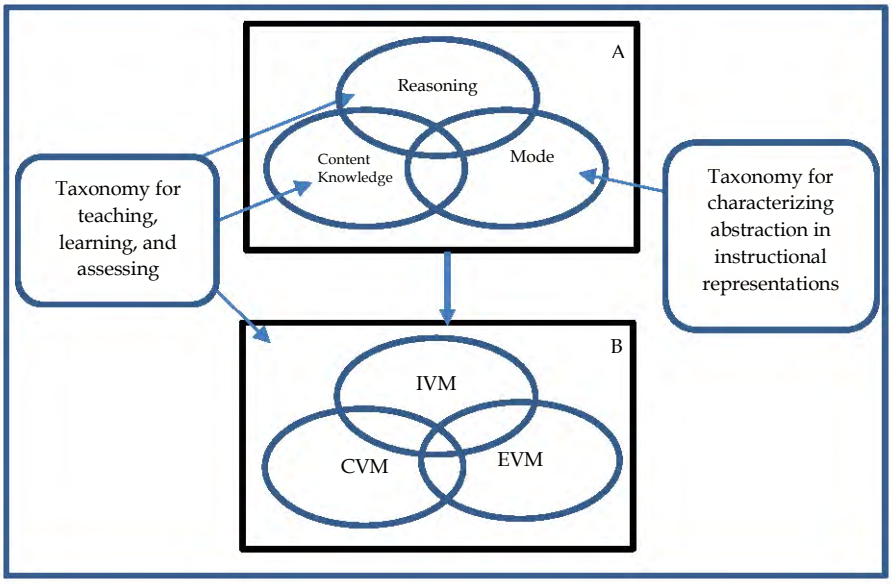

Figure 1. A theoretical framework used in the development of the VSR-b Test. In the framework, 'A' is Schönborn and Anderson's (2009) model of factors determining students' ability to interpret external representations while B is Mnguni's (2014) theoretical cognitive process of visualization.

Methods

As indicated earlier, the present research aimed to develop an instrument for assessing VSR-b using the theoretical framework discussed in Figure 1. To do this, a multiplistic realism research paradigm was adopted, which, according to Krauss (2005), allows for flexible integration of both qualitative and quantitative research methods. This enhances the validity and credibility of the findings. Consequently, the present research followed the explorative mixed-method research method approach for data collection and analysis.

Content knowledge and semiotics of amino acid structures were used as the context of the research. In particular, the researcher investigated knowledge and reasoning ability of students concerning the structures of α-amino carboxylic acid which contain an α-carbon, to which an amino, a carboxyl group, a hydrogen atom, and the R group are attached.

Due to the nature of this research, specific research methods (i.e., sampling, instruments, validity, and reliability as well as data analysis) are discussed within the different stages of the research as explained below:

a) Identification of VSR-b Skills

As mentioned above, Mnguni's (2014) theoretical cognitive process of visualization for science education and Bloom's taxonomy of learning objectives were used to identify visualization skills required for effective learning in biology. According to Mnguni (2014, p. 3), visualization occurs in three non-linear overlapping stages; namely, IVM, CVM, and EVM. It was, therefore, essential to identify the cognitive skills that are required to process VSMs in each of these stages.

Similarly, Schönborn and Anderson (2009) suggest that students' reasoning ability, students' understanding of the concepts of relevance to the ER, and the nature of the mode in which the ER represents the desired phenomenon are necessary for effective learning with VSMs. Of these factors, reasoning ability was identified by the present researcher as a cognitive function which utilized VSR-b skills. These skills were identified through an independent panel of nine experts which comprised of two biochemists (with PhDs in Molecular Biology), four secondary school biology teachers who were enrolled for Ph.D. studies in science education, and three postgraduate molecular biology students. The panel of experts was asked to independently study learning objectives related to Bloom's taxonomy and indicate the VSR-b skills they believe were utilized during the IVM, CVM, and EVM concerning learning about amino acid structures. Their responses were collected using an open-ended questionnaire. After that, a semi-structured questionnaire was used to verify the classification of VSR-b skills that emerged from the open-ended questionnaire. Responses of this semi-structured questionnaire were then used to calculate the content validity index (CVI) (Hyrkäs, Appelqvist-Schmidlechner & Oksa 2003) to determine the extent of agreement between the panel members. As suggested by Hyrkäs et al. (2003), only those skills that obtained a CVI of .69 and above were included in the development of the VSR-b Test. Results of this exercise are presented under 'VSR-b skills identified through the panel of experts' in the Results section.

b) Design and validation of the items

The researcher then developed items through which the VSR-b skills (listed in Table 1) could be tested (see examples in Appendix 1). In line with the Theoretical Framework (Figure 1), these items probed:

i) *Students' conceptual knowledge of amino acid structures.* Therefore, the VSR-b Test, probed content knowledge of amino acid structures which did not incorporate the use of VSMs. This knowledge was identified as a

prerequisite for students to answer the subsequent sections of the Test. This knowledge was taken from textbooks (e.g., McKee & McKee, 2017; Walsh, 2014) used by students in undergraduate biology.

ii) *Content-free VSR-b skills for IVM.* Performing these skills did not require biology-related content. Relevant items similarly probed generic visualization skills as the Senior Aptitude Test (Mnguni, 2018). They tested students' ability to recognize orientation through mental rotation, perceive spatial orientation in 2D and 3D, perceive and track the motion of an object on a 2D and 3D planes, perceive luminance, speed, texture, shapes, and patterns related to amino acid structures.

iii) *Content-specific VSR-b skills for CVM.* Items in this regard probed students' ability to reason with models by utilizing prior biology content knowledge (Schönborn & Anderson, 2009). This included remembering, understanding, analyzing, and evaluating visuo-semiotic models used to represent amino acid structures. In this instance, all items incorporated visuo-semiotic models of amino acid structures. These models were taken from textbooks used by students in undergraduate biology (e.g., McKee & McKee 2017; Walsh, 2014).

iv) *Content-specific VSR-b skills for EVM.* Items in this regard probed students' ability to externalize content knowledge through the use of visuo-semiotic models when applying, creating, and synthesizing biology content knowledge.

The independent panel of experts (mentioned earlier) was then tasked with validating the items. They were given a semi-structured validation questionnaire through which they agreed or disagreed that the items probed, i) students' knowledge of amino acid structures, ii) VSR-b skills for IVM, iii) VSR-b skills for CVM, and iv) VSR-b skills for EVM. This exercise sought to determine face and content validity of the items by asking the panel of experts to indicate amongst other things if the items probed what they ought to be; and, were suitable for their intended purpose. Results of this exercise are presented under 'Design and validation of the items for the VSR-b Test' in the Results section.

The items were also piloted on a group of 18 second-year molecular biology university students who had completed a course in amino acids and protein structures and functions. The aim in this regard was to further determine the face and procedural validity and reliability of the Test (Aboraya, France, Young, Curci & LePage, 2005).

c) Testing of the VSR-b Test

The instrument was then used to probe VSR-b of a group of 30 third-year Bachelor of Science students majoring in Molecular Biology at a South African University. These students were selected purposefully as they had completed a course in amino acids and protein structures and functions. This group was, however, different from the pilot group even though they were studying at the same institution. At the time of the research, the participants were all enrolled in a Protein Biochemistry class. Lecture materials and other study materials provided to the students as part of their molecular

biology courses included static and animated VSMs. They had all passed pre-requisite molecular biology modules in the first and second year, including other prerequisite subjects in biology, mathematics, physics, and chemistry. Results of this exercise are presented under 'Results from the application of the VSR-b Test' in the Results section.

Results

VSR-b skills identified through the panel of experts.

Twenty-five visualization skills were identified (Table 1). The panel of experts classified each of these into the three visualization stage as well as into Bloom's taxonomy of cognitive skills. The number of visualizations skills varied in each of the visualization stages. The panel of experts also indicated that IVM could have the most amount of visualization skills which were also classified as 'pre-cognitive' in that they may not require extensive content knowledge to be carried out. The panel of experts also indicated that some of the skills could be performed in more than one visualization stages. For example, 'outline' was classified in both the CVM and EVM stages.

Table 1

The List of VSR-b Skills and Related Stages of Visualization by the Panel of Experts (n = 9).

Visualization Stage	Bloom's stage	Visualization skills	Definition	Code	CVI
IVM	Pre-cognition	Recognize orientation through mental rotation	To move, arrange, operate, or control cognitively in a skillful manner for examination purposes and then to perceive multiple items with different orientation and shape to be the same if orientation and shape is rearranged	IVM01	.70
		Spatial perception 2D	To perceive spatial relationships and distances between objects, in 2-dimensions	IVM02	.77
		Spatial perception 3D	To perceive spatial relationships and distances between objects, in 3-dimensions	IVM03	.74
		Track (including find, and 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	IVM04	.94
		Ground perception	To detect or perceive the part of a scene (or picture) that lies behind objects in the foreground	IVM05	.78
		Perceive luminance /Identify colors	To detect or perceive a visual attribute of things that result from the light they emit or transmit or reflect	IVM06	.74
		Perceive motion	To recognize, discern, envision, or understand a change of position in space and assign meaning to	IVM07	.87
		Perceive speed	To recognize, discern, envision, or understand a rate of movement and meaning thereof	IVM08	.91
		Perceive texture	To recognize, discern, envision, or understand the characteristic visual and tactile quality of the surface and meaning of such	IVM09	.91
		Perceive shapes	To recognize, discern, envision, or understand the external form, or outline of a geometric figure.	IVM10	.87
		Perceive patterns	To recognize, discern, envision, or understand the arrangement or design found in objects	IVM11	.87

Table 1 Continue

CVM	Evaluating	Critique (including to judge)	To critically examine and judge something	CVM01	.76
	Analyzing	Outline	To give the main features or various aspects of; summarize	CVM02	.95
	Understanding	Interpret (including to analyze; Assess; Evaluate; Examine; Investigate)	To break down into components or essential features by making sense of or assigning meaning to or give an explanation and to examine and or assess carefully and observe or inquire into in detail by examining systematically to observe carefully or critically	CVM03	.89
	Remembering/ comprehension	Compare (including discriminate)	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	CVM04	.70
		Classify (including to arrange, order, and organize)	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	CVM05	.91
		Describe (including to discuss, and explain)	To make understandable 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	CVM06	.89
		Recall/retrieve	To remember by retrieving information from memory	CVM07	.74
EVM	Creating/ synthesis	Complete	To make whole, with all necessary or standard elements or parts	EVM01	.71
		Imagine	To form a mental image of something that is not present or that is not given	EVM02	.77
	Applying	Illustrate (including to 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	EVM03	.82
		Outline	To give the main features or various aspects of; summarize	EVM04	.79
		Complete	To make whole, with all necessary or standard elements or parts	EVM05	.79
	Creating/ synthesis	Develop (including to formulate, devise, construct, create, produce, invent)	To cause to exist in a new or different form through artistic or imaginative effort	EVM06	.73
		Infer meaning	To conclude by reasoning; in logic or reason or establish by deduction or state, tell about, or make known in advance, based on specialized knowledge	EVM07	.76

Design and validation of the items for the VSR-b Test

During the validation of the VSR-b Test, expert validation of the instrument showed a significant inter-rater agreement measured through the inter-rater reliability (Table 2). The experts generally agreed with the design of all the items and their classification into the four sections, namely, Students' conceptual knowledge, Content-free VSR-b skills for IVM, Content-specific VSR-b skills for CVM, and Content-specific VSR-b skills for EVM. Results from the pilot research also showed that students in the pilot research were able to respond to all 45 items within 45 minutes where the reliability co-efficient (i.e., Cronbach Alpha) was .78. One point was allocated to each item, such that the total obtainable score was 45 points.

Table 2

Inter-Rater Reliability Within the Different Components of the VSR-b Test Items Computed from the Panel of Experts Responses.

Construct	Number of items	Inter-rater reliability
Content knowledge	20	.831
IVM	11	.793
CVM	7	.801
EVM	7	.768

The panel of experts also provided qualitative comments on how the instrument could be improved further. For example, experts commented that:

- *"The content of the test is taught at undergrad biology. Students should be able to answer all the questions without problems" (P6, a postgraduate student)*
- *I had seen the pictures [in books] before, even if they were not the same…so interpretation of the test pictures was easy". (P3, a postgraduate student)*
- *"The IVM section is interesting and assessing critical generic skills. Maybe students should take this test before enrolling for molecular biology modules" (P5, a qualified biochemist)*
- *interpretation of the test pictures was easy". (P2, a postgraduate student)*
- *"[The symbols] are large enough and spaced comfortably. I can work through the diagrams and notice differences" (e.g., P1, a postgraduate student)*
- *"Some questions are too complicated and need careful observation and consideration before answers can be developed" (P4, a Ph.D. student).*
- *"Students may not [necessarily] know what is meant in scientific terms" (P8, a Ph.D. Student).*
- *"The test is appropriate for 3rd-year molecular biology students, but not for lower levels as it was quite a challenging test". (P5, a qualified biochemist)*

These comments were then used by the researcher to refine the VSR-b Test further.

Results from the application of the VSR-b Test

Having satisfied the instrument design and validation by experts and pilot group, the instrument was then tested on Molecular Biology students for whom it was designed. Results in this instance showed that the majority of participating students scored above 50% in the content knowledge (M = 63.27. $S.D.$ = 12.39), CVM (M = 55.90 $S.D.$ = 10.59) and EVM (M = 56.90, $S.D.$ = 13.74) components of the test. IVM was however lower (M = 47.00, $S.D.$ = 9.12). The IVM score was significantly lower than the other scores ($p < .001$) while the content knowledge score was significantly higher than the IVM, CVM and EVM ($p < .001$). An analysis of students' performance in individual skills showed that the pass rates in individual skills were low (Figure 2).

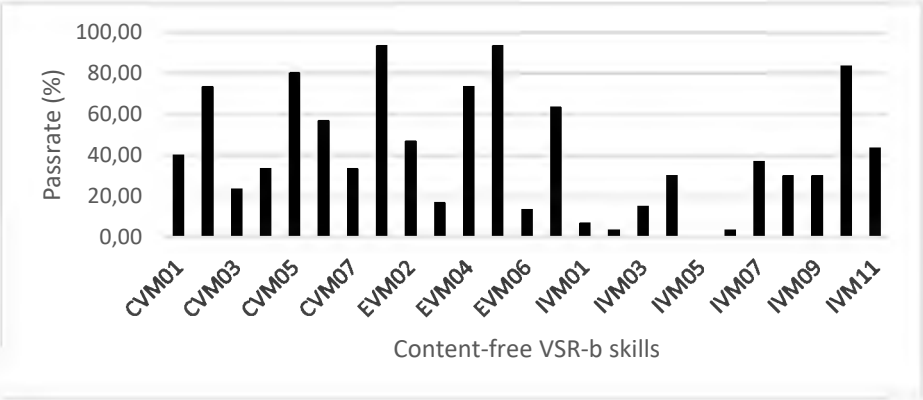

Figure 2. Students' performance in the IVM, CVM, and EVM

Results showed in this regard that in only eight of the 25 skills were half of the participants able to successfully perform the skills. Participants were not able to successfully perform most skills in the IVM. In this regard, the performance was worse in skills 1, 2, 5, and 6, where only very few students were able to perform the skills respectively successfully.

The average inter-item correlation was then calculated for the items that measured within each of the four components of the test. To this end, internal consistency reliability was generated within and between each of the four component of the test (i.e., content knowledge, IVM, CVM, and EVM) (Table 3 and 4). Results showed high internal consistency reliability in each of the four components of the test, except for CVM where Cronbach's Alpha was .597.

Table 3

Internal consistency reliability coefficients within the different components of the VSR-b Test.

Construct	Cronbach's Alpha	Cronbach's Alpha Based on standardized items
Content knowledge	.880	.883
IVM	.816	.857
CVM	.597	.660
EVM	.828	.840

The overall reliability of the test was relatively high (Cronbach Alpha = .843). Results also showed that there was a significant correlation between the different components of the test (Table 4). However, the correlation was not very strong between IVM and EVM as well as IVM and content knowledge.

Table 4

Correlation between content, IVM, CVM and EVM (n = 30)

		IVM	CVM	EVM
CVM	Correlation	.590**		
	Sig. (2-tailed)	0.001		
EVM	Correlation	.467**	.790**	
	Sig. (2-tailed)	0.009	0.001	
Content	Correlation	.443*	.600**	.596**
	Sig. (2-tailed)	0.014	0.001	0.001

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Discussion, Conclusion, and Recommendations

The significance of VSMs in science education cannot be ignored, as suggested in the literature (e.g., Mnguni, 2014). However, the challenge that has stood for decades has been the lack of clear and universal theory and definition of what visual literacy is, and how it could be developed and assessed (Avgerinou & Pettersson, 2011). The present research has attempted to demonstrate that visual literacy does not exist independent of content knowledge. Therefore, the present research was informed by Schönborn and Anderson (2009), who argue that content knowledge affects students' ability to reason with VSMs. This is supported in the present research in that content knowledge correlated significantly with the different skills utilized during visualization. As expected, however, the correlation between content knowledge and

skills related to IVM was low. This is because IVM in the present research was defined as those pre-attentive skills that did not require content knowledge related to the present research. Similarly, the present research has demonstrated that visualization skills tested in CVM and EVM are also crucial for the development of content knowledge. While causality was not tested in the present research, the strong association between content knowledge and IVM, CVM and EVM suggest that a lack of visualization skills may impact on students' understanding of related content knowledge.

Related to the difficulty of developing a universal theory and definition for visual literacy, the present researcher argues that visual literacy can be better understood within specific contexts. In line with this reasoning, the researcher is of the view that the instrument presented in this research could be used to design context-specific tests for visual literacy. For example, the present instrument can only be reliable in the context of amino acid structures. However, it cannot be applicable in other contexts. For this reason, the researcher suggests that the instrument be adapted accordingly, for example, by modifying the content knowledge and semiotics. This is because visual literacy is affected by subject-specific knowledge and semiotics (Offerdahl et al., 2017; Schönborn & Anderson, 2009).

Conclusion

The present research has shown that VSR-b can be assessed using the VSR-b Test. In particular, this research has shown that VSR-b can be understood within the context of the theoretical cognitive process of visualization (Mnguni, 2014), the taxonomy for teaching, learning and assessing (Anderson et al., 2001), the model of factors determining students' ability to interpret external representations in Biochemistry (Schönborn & Anderson, 2009), and the taxonomy for characterizing abstraction in instructional representations (Offerdahl et al., 2017) as a theoretical framework. The research has also shown that VSR-b includes students' conceptual knowledge, content-free VSR-b skills for IVM, content-specific VSR-b skills for CVM as well as content-specific VSR-b skills for EVM. The present researcher, therefore, argues that researcher, teachers, curriculum, and instructional designers should consider all these factors as significant in the development and assessment of visualization skills amongst students. The researcher also proposes further researcher to improve the understanding of teaching and learning that utilizes visuo-semiotic models. This could include testing and further developing the present instrument in different contexts.

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