VISUAL LITERACY SKILLS AMONGST MOLECULAR BIOLOGY STUDENTS

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ABSTRACT - The use of visual models in biology is increasing due to learning difficulties associated with various concepts and processes especially those that exist at a microscopic level. Sources of these learning difficulties, including a lack of visual literacy, have been explored extensively. However the nature of students' visual literacy in biology, which could cause learning difficulties, has not been explored adequately. Consequently, the aim of this mixed-method study was to explore third year university biology students' visual literacy and its relevance to biology knowledge using psychometric and content knowledge tests. This would hopefully help researchers and teachers decide on intervention strategies to improve students' visual literacy. Results showed low levels of content knowledge and inadequate ability to work on generic tasks that required non-verbal reasoning with figures and 3D spatial visualization amongst participating students. Students however performed above average on tasks related to patterns test and 2D spatial perception. Content knowledge levels correlated with 3D spatial visualization and the visual literacy abilities. Learning difficulties related to visual literacy were also identified. In particular, results indicate that students have difficulty interpreting visual cues and symbolism, integrating knowledge as well as expressing knowledge visually. Recommendation to teaching, learning and research are made.

Key words: Learning difficulties; Molecular Biology; Visual Literacy; Visuo-spatial abilities

1. INTRODUCTION

The use of visual models in science education continues to increase. This is fuelled by the increased use of technology both in research and in teaching and learning. This however requires that students develop a new set of skills for the comprehension, communication and construction of knowledge. Researchers have identified various contemporary skills and competencies that students have to develop. These include various 21st century skills (Arsad, Osman & Soh, 2011) such as academic communication literacy (Spektor-Levy, Eylon & Scherz, 2008), science literacy (Van Eijck & Roth, 2010) and visual literacy (Bottomley, Chandler, Morgan & Helmerhorst, 2006). Visual literacy is one of the most critical competencies in molecular biology due to the complex microscopic and molecular levels at which concepts exist. To improve teaching, learning and research therefore, visual models such as diagrams and animations are then used to represent these biological phenomena at a larger (Dori & Barak, 2001). While theoretically this is the case, the significance of visual literacy, as a competence, in molecular biology is yet to be defined. In line with this, the learning difficulties associated with visualization amongst molecular biology students requires exploration.

1.1 Theoretical background

Mnguni (2014) defines visualization as the ability to select and effectively use a set of cognitive skills for perceiving, processing and produce visual models. Based on the constructivist epistemology of learning and Mayer's (2003) cognitive theory of multimedia learning, Mnguni (2014) postulates that visual models are processed cognitively in three overlapping and interrelated stages, namely, Internalization of Visual Models (IVM), Conceptualization of Visual Models (CVM) and Externalization of Visual Models (EVM). He defines IVM as the process where sense organs, such as the eyes, work with the brain to "absorb" information from world, whereas CVM is the process where images are interpreted cognitively in order to give meaning to their depictions. This stage is dependent on available prior knowledge, which could both be correct conceptions and misconceptions. EVM is cognitive stage where knowledge existing in cognitive structures is externalized through various forms of communication including diagrams and words.

Researchers suggest that there are at least three levels of IVM, namely, low-level, middle level and high-level IVM (Healey, 2005; van Schoren, 2005). In the low-level IVM the main tasks include feature extraction whereas high level IVM involves a cognitively demanding process of concept formulation (Healey, 2005). In this regard, Stevenson and Roorda (2005) have shown that low-level IVM tasks require a relatively less degree of attention. For example, these tasks can be performed in less than 250 milliseconds of viewing a visual model" (Mnguni, 2014). High-level IVM on the other hand requires higher amounts of cognitive effort and is linked to internalizing visual information (Van Schoren, 2005). Mnguni (2007) 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

During the CVM stage, the mind relies on short and long term memories to conceptualize visual information by way of interpreting incoming visual information against prior knowledge as explained by constructivist theory (Mayer, 2003; Thompson, 1995). Various theories related to cognitivism have been used to explain this stage. These include dual coding theory, constructivist theories as well as the limited capacity theory. Various researchers have contended that effective conceptualization of information presented through visual models occurs when such models are properly designed and used. 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.

Another significance skill in biology is the ability to communicate visually through drawings for instance. In this instance, such modules could include macroscopic, microscopic and symbolic models (Rundgren, Chang Rundgren and Schönborn, 2010). According to Mnguni (2014: 6) "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 a visual model 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, and the increased use of visual models in biology, the aim of this study was to explore third year university biology students' visual literacy and how it relates to their biology knowledge which is taught using visual models. The research questions framing this study are, *i)* what is the significance of visual literacy in biology, and *ii)* what are the learning difficulties associated with visualization amongst biology students?

2. METHODOLOGY

In this study, the researcher intended to determine the significance of visual literacy by measuring students' visual literacy in relation to their content knowledge of biology using a mixed-method approach. To this end, generic visual skills of final year BSc Molecular Biology students (n = 30) from a university in South Africa were measured. This entailed students' ability to perform spatial and visual reasoning using a previously validated Senior Aptitude Test designed by the Human Sciences Research Council (HSRC) for South African students. As per regulations, the administration and scoring of the test was performed by a qualified educational psychologist according to the guidelines of the HSRC and the Health Professions Council of South Africa. The aptitude test was divided into four sections 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, they 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 biology. Normed scores of the students in the tests are 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.

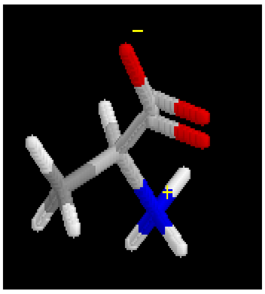
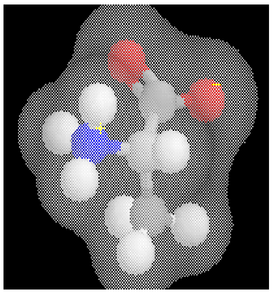
The researcher also collected students' final score for two Molecular Biology modules which tested their content knowledge and not visual literacy. In the first module (BIOCM 1) students were taught biochemical methods while in the other (BIOCM 2) they were taught about Nucleic Acids and Protein Informatics. Only the final results (percentage scores) in these modules were used in the study.

Finally students were given a BioVisual Literacy Test which probed students' visual literacy within the biology context. This test was made up of 12 probes testing 24 previously identified visualization abilities (Mnguni, 2007) in the context of amino acid and protein structure. These probes were previously validated to ensure that all participating students had sufficient content knowledge required to respond to the probes. An example of the probes and the relevant visualization abilities is given in Figure 1.

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.

In this probe, the following were some visualization abilities that were tested:

1. *Analyse* (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)
2. *Compare* (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)
3. *Depth perception* (perceive spatial relationships and distances between objects, in multi-dimensions)

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

All probes were made up of text and still diagrams. Students' responses were scored against a set of correct model answers by the researcher to determine the students' ability to respond to items that require visual literacy and content knowledge simultaneously. The responses were also analysed inductively to determine existence of predetermined visualization difficulties that the students had in responding to the probes. In this regard the researcher sought to determine whether learning difficulties listed in literature would be identified in students' responses. For credibility, interviews were also conducted with ten participants who were randomly selected from the total group. This was to ensure that the researcher's narration of the learning difficulties is actually credible. In the interview each student was asked to discuss his/her learning difficulties in relation to the probes that were administered initially. All participating students consented voluntarily to participate in the study and ethical clearance was given by the university in which the study was conducted.

3. RESULTS

3.1 Visual literacy amongst students

Data show that generally students were able to perform visuo-spatial tasks related to patterns test, spatial perception 2D. As shown in Table 1, the stenine scores for these two tests were above the norm average of between 4 and 6. However results for non-verbal reasoning with figures and spatial visualization 3D proved to be more challenging for students. Notably, 63% of the students scored 8 or 9 in the patterns test, while 60% scored 9 in the spatial perception 2D. On the other hand, 57% and 60% the students scored between 1 and 4 in the non-verbal reasoning with figures spatial visualization 3D tests respectively. Clearly, the students seem to have had difficulties reasoning with visual models as well as working with models that attempt to illustrate phenomena in 3D.

Table 1 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	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Patterns	30	3.00	9.00	7.1667	.37165	2.03560
SP2D	30	1.00	9.00	7.1000	.53466	2.92846
NVRF	30	1.00	9.00	4.0333	.33385	1.82857
SV3D	30	1.00	9.00	4.1333	.41725	2.28539
Valid N (listwise)	30					

Results also showed that students' visual literacy is not dependent on availability of content knowledge. The average score for the students were 55% (S.D. = 26%) and 49% (S.D. = 23%) for BIOCM 1 and BIOCM 2 respectively. In the BioVisual Literacy Test the average score was 52% (S.D. = 9%). Results also indicate that all visual literacy tests correlate significantly with each other (Table 2). The two content tests also has a significant correlation with each other. BIOCM 1 was the only content test that had a significant correlation with two visual literacy tests. This could be due to the nature of the module and its content. Of importance however is that this observation suggests that visual literacy could be linked to Molecular Biology students' content knowledge.

Table 2 Correlation between visual literacy and content knowledge

Correlations									
		Patterns	SP2D	NVRF	SV3D	VisLit	BIOCM 1	BIOCM 2
Patterns	Pearson Correlation	1	.761**	.693**	.529**	.404*	.200	.050
	Sig. (2-tailed)		.000	.000	.003	.027	.290	.792
	N	30	30	30	30	30	30	30
SP2D	Pearson Correlation	.761**	1	.656**	.616**	.535**	.219	-.026
	Sig. (2-tailed)	.000		.000	.000	.002	.246	.891
	N	30	30	30	30	30	30	30
NVRF	Pearson Correlation	.693**	.656**	1	.684**	.428*	.244	.083
	Sig. (2-tailed)	.000	.000		.000	.018	.194	.664
	N	30	30	30	30	30	30	30
SV3D	Pearson Correlation	.529**	.616**	.684**	1	.335	.435*	.104
	Sig. (2-tailed)	.003	.000	.000		.071	.016	.584
	N	30	30	30	30	30	30	30
VisLit	Pearson Correlation	.404*	.535**	.428*	.335	1	.393*	.038
	Sig. (2-tailed)	.027	.002	.018	.071		.032	.843
	N	30	30	30	30	30	30	30
BIOCM 1	Pearson Correlation	.200	.219	.244	.435*	.393*	1	.616**
	Sig. (2-tailed)	.290	.246	.194	.016	.032		.000
	N	30	30	30	30	30	30	30
BIOCM 2	Pearson Correlation	.050	-.026	.083	.104	.038	.616**	1
	Sig. (2-tailed)	.792	.891	.664	.584	.843	.000	
	N	30	30	30	30	30	30	30

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

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

3.2 Learning difficulties associated with visualization

While the students performed relatively well in all visual literacy tests, the results of this study revealed at least four learning difficulties associated with visualization in Molecular Biology. While these difficulties overlap between the stages of visualization (Mnguni, 2014), based on the characteristics of visualization the researcher believes that they may be occurring predominantly at particular stages of the visualization process as discussed below.

Visualization difficulties related to IVM

A typical difficulty associated with visual perception found in the study is “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. In the study it was found that all participating students (100% of 30) do not recognize the cytoplasm in a visual model as meaningful or even associated with the rest of the organelles in the image unless they are prompted to. An example of this was observed in a probe where students did not recognize the electron cloud as being part of the information presented in a model (Figure 2). Asked what is (and the significance of) the “grey area” in the model (Figure 2), one student (2P17) said, *“I don’t know, I am guessing…it’s a way of showing the amino acid…the background”.* This student seems to lack conceptual meaning associated with aspects of the visual model presented. As a result, extracting meaningful knowledge is limited and misconceptions develop.

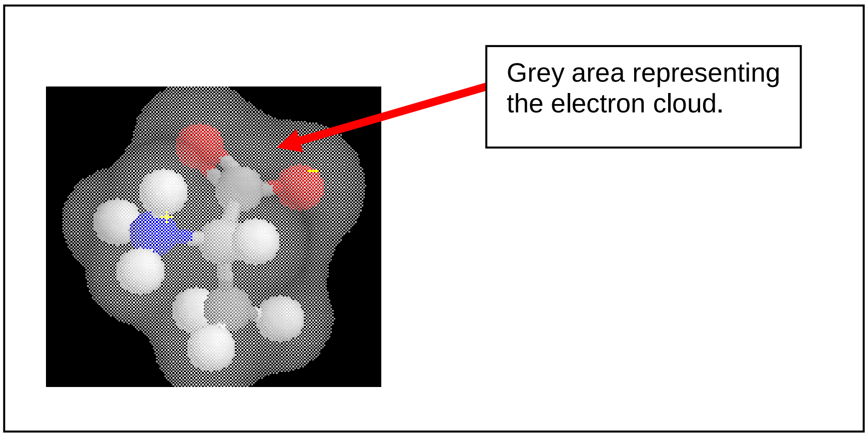


Figure 2 ER in which students perceived the electron cloud as a background.

On the contrary, another student identified the cytoplasm (depicted in black in Figure 2) not as part of the cell. This student (2P31) suggested that this area (Figure 2) represented an *“empty space in the cell*”.

Visualization difficulties related to CVM

One area where learning difficulties were observe related to comprehending the meaning of colours in a visual model, that is, to attribute a scientifically correct meaning to the colour coding used in the visual models. Results revealed that all participating students (100% of 30) believe that these colour shadings are the actual indication of how atoms exist in reality, e.g. oxygen being actually red and carbon being grey in reality. Changing colours was perceived by students as "wrong". For instance, student 2P17 suggested that:

"From what we 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 in the interview to recognise carbon when it was represented both in grey and light grey in an amino acid (Figure 3).

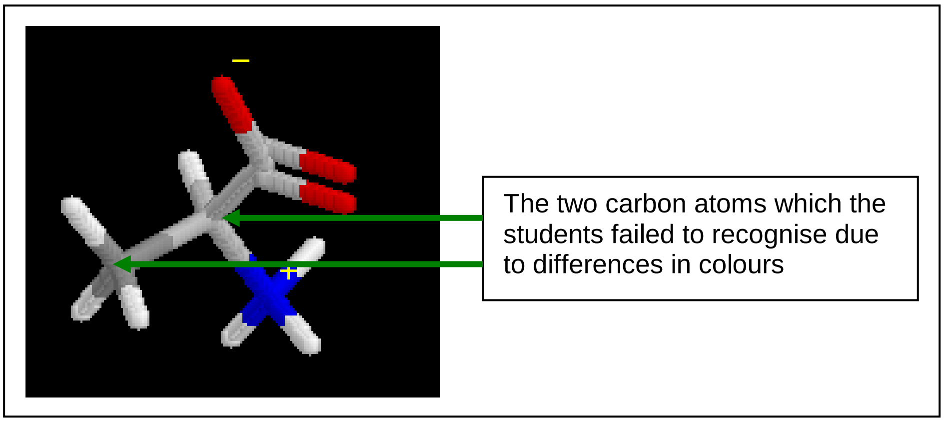


Figure 3 ER in which students failed to recognize atoms represented in different colours.

It was also found that mentally rotating visual models was challenging for participating students. In this regard students were expected to recognize and interpret visual models of the same concept even if these were represented in different orientations. Data revealed that some students (61%) were not able to cognitively manipulate the depth cues of visual models to determine their position in space. In this regard, these students (e.g. 2P17 and 2P31) had difficulties recognising amino acids when these were placed at different orientations (Figure 4). In this instance, students thought the two visual models represented different amino acids.

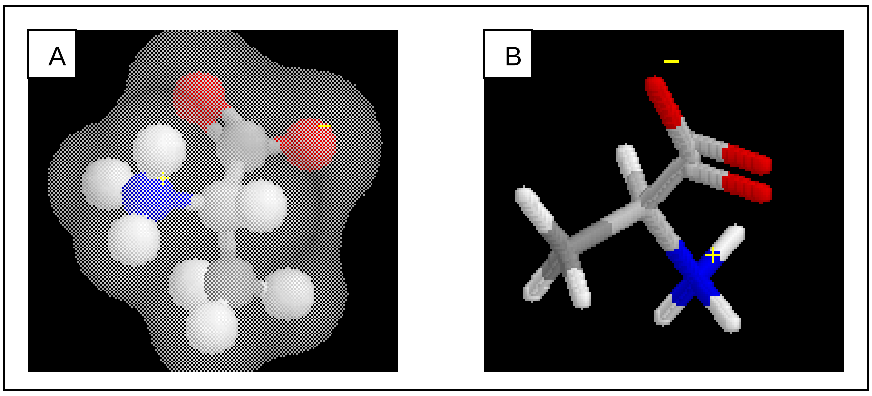


Figure 4 Two ERs where students were required to observe the differences in orientation of the amino acids.

In this example one 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, a possible misconception is that amino acids are identical only if they are represented in identical orientations.

Visualization difficulties related to EVM

Another learning difficulty associated with visual models in the study was in instances where students were expected make deductions based on what the model was representing. In this regard students were expected to study part of a biochemical process (with parts intentionally removed from the visual model) and then predict the missing parts of such a process. A visual model of protein synthesis from mRNA using codons was used in this regard. Results showed that some students (58%) were not able to use available information to make inferences about the subsequent steps of a biochemical process.

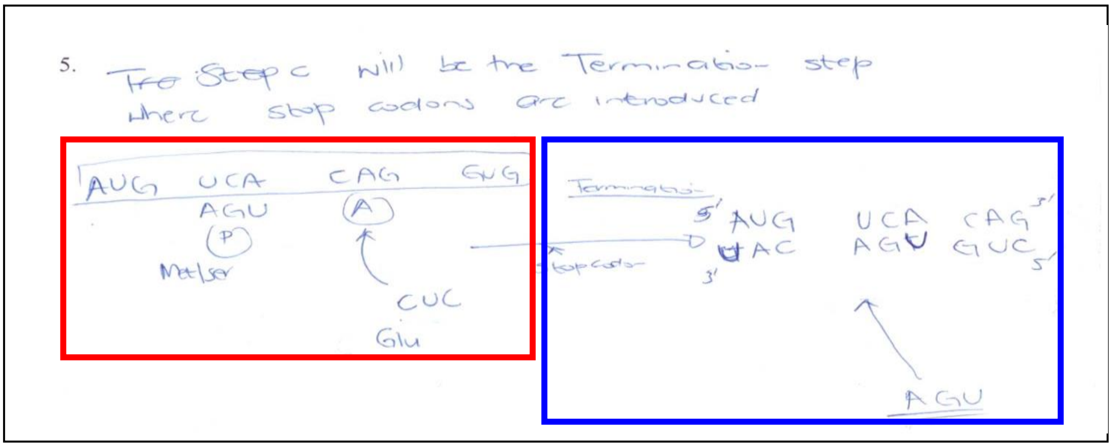


Figure 5 An example of a student generated diagram where the student has difficulties inferring or predicting.

In Figure 5, for example, student 2P32 was able to recognise the process and use correct terminology in describing it (i.e. the use of terms “termination” and “stop codon” in the response). As shown in the red box (Figure 5), the student was also able to re-present the information already depicted in the visual model. However, looking at the blue box, the same student fails to use the extracted information (red box) to predict the subsequent stages (which were missing in the blue box) and hence, provides an incorrect outcome of the process.

4. DISCUSSION

Students entering tertiary education are subjected to a number of competency tests, of which visual literacy is 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 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. 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 molecular biology.

The current has however demonstrated that the assumption that the apparent assumption that students will 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 this study has shown that a significant number of students have challenges related to these tasks, challenges that have the potential to hinder effective learning in molecular biology. This especially given the observed relationship between performance in a molecular course and visual literacy tests.

The study has also demonstrated that there are various learning difficulties associated with both content knowledge and visualization skills. As shown in Mnguni (2014), these difficulties range across the various theoretical cognitive stages of visualization. As such, it is apparent that the integration of new knowledge with existing knowledge can be affected by the lack of appropriate visualization skills. To this end, the results also show that there are widespread misconceptions and learning difficulties that occur when students learn using visual models. Literature documents various strategies that can be used to remedy some of these misconceptions and learning difficulties. Of significance to the author is the complexity of visualization and the associated consequences.

The author believes therefore that there is an urgent need to consider formalizing visual literacy education in a similar way to other competencies such as content literacy (McKenna & Robinson, 1990), academic communication literacy (Spektor-Levy, Eylon & Scherz, 2008) and science literacy (Van Eijck & Roth, 2010). Furthermore, the author argues that teachers need to be alerted to the complexity of visualization and its significance, in order to assist them develop tools with which learning difficulties could be minimized. The learning difficulties and misconceptions identified in the study indicate that if not addressed, poor visual literacy could prove detrimental to student learning.

The intricate nature of the process of visualization suggests that the availability of visualization skills and the fluency of students in operating within the various stages of visualization may influence students' visual literacy, which in turn affects their understanding of content knowledge. The author argues therefore that there is a need to:
Explore the visualization skills that are utilized by students in each of the visualization stages and which are pivotal to academic success in biology,
Understand factors that affect biology students' ability to operate efficiently in each visualization stage, and
Investigate strategies within various stages of the curriculum that could be used to facilitate development of visual literacy in biology.
Mnguni, Schönborn and Anderson (2009) identified some visualization skills associated with visual literacy within the framework discussed in this paper. Their study showed that visualization skills can be identified, measured and their levels of difficulty determined. According to the findings of the current study, there is a significant correlation between content knowledge and visual literacy. As a result the author argues that biology students' visual literacy ought to be explored further in order to determine strategies to improve students' visual literacy and minimize learning difficulties.

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