A Qualitative Analysis of Biochemistry Students' Visuospatial Reasoning Difficulties Associated with Amino Acid Models

Lindelani Mnguni[a]

Corresponding author: Lindelani Mnguni (lindelani.mnguni@wits.ac.za)
[a]Centre for Health Sciences Education, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa.

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Abstract

The adoption of multimedia learning tools, including visual models in biochemistry, has increased considerably over the last few decades. Adopting these tools necessitates the development of visual literacy competencies, such as visuospatial reasoning, for students to learn effectively. The extent to which biochemistry students have the necessary visuospatial reasoning skills to learn from visual models effectively is a subject of continuing research. The current qualitative research sought to describe biochemistry students' visuospatial reasoning difficulties associated with amino acids. Seven purposively selected students were interviewed using a semi-structured protocol to solicit their learning difficulties when asked to perform specific tasks related to visuospatial reasoning. The research question explored in this study is: "*What are biochemistry students' visuospatial reasoning difficulties associated with amino acids models?*" Learning difficulties related to perceiving spatial orientation, mental rotation, interpreting colour codes, and generating a visual model depicting spatial depth were identified. Identifying and describing these learning difficulties could help teachers adopt remediation strategies to enhance content understanding. The researcher concludes that students may not always have the visuospatial reasoning skills required for successful learning in biochemistry. Given the complex nature of visual literacy, the researcher recommends explicit remediation strategies to address learning difficulties associated with visuospatial reasoning in biochemistry.

Introduction

Multimedia learning, including various computer-integrated learning modes, has increased over the last century (Mnguni, 2014). More recently, the COVID-19 pandemic accelerated online learning adoption, necessitating the increased use of multimedia for teaching (Turnbull, Chugh & Luck, 2021). As physical classrooms transitioned to virtual environments, multimedia resources became essential to engage students, replicate hands-on experiences, and maintain the efficacy of instruction in a new educational landscape. Multimedia learning uses visual models like interactive infographics and video animations to simplify complex concepts, offering an enhanced understanding over traditional methods. Virtual laboratories, simulations, and data visualisation tools encourage hands-on engagement, fostering deeper learning and development of critical analysis skills (Liu et al., 2022). However, given the nuanced complexities associated with learning through multimedia, in-depth research is required to explore students' learning experiences associated with these models.

Current research shows that multimedia learning facilitates the interactive visualisation of complex molecular processes and reactions (Mnguni, 2014). It enhances comprehension by integrating text, graphics, and animations, offering students a more engaging and intuitive grasp of intricate biochemical concepts, thereby potentially improving retention and fostering a deeper understanding (Schönborn & Anderson, 2006). However, to learn effectively from multimedia tools, students must become multi-literate, with competencies such as visual literacy becoming critical for successful learning (Brumberger, 2019). Visual literacy itself is not new (Brumberger, 2019; Kędra, 2018); however, it has become prominent in molecular biology due to a growing use of visual models to research, teach, and learn phenomena that exist at complex sub-microscopic levels. Nevertheless, the extent to which students have the necessary visual literacy skills to learn effectively using visual models requires further investigation. In fact, the increased reliance on online multimedia warrants research concerning students' visuospatial reasoning difficulties associated with molecular representations.

Visuospatial reasoning

Visuospatial reasoning is a component of visual literacy and is a cognitive process characterised by using the eyes to internalise scientific information represented as visual models to create mental models (Uchinokura & Koba, 2022). It may include deductive and inductive cognitive processing of mental models to solve scientific problems, generate new ideas, and communicate understandings through visual models. Visuospatial reasoning also includes creating mental models of how an object would look from a different perspective by mentally reorienting or rotating it (Harle & Towns, 2011). These skills are significant in molecular biology, where visual models represent concepts at multiple microscopic and molecular levels that cannot be visualised with the naked eye (Mnguni, 2014, 2018). Therefore, students must develop the visual literacy skills required to understand the scientific concepts presented.

The significance of visual literacy and visuospatial education has been widely highlighted in research, which shows that visuospatial reasoning is associated with improved content understanding and performance (e.g., Uchinokura & Koba, 2022). However, teachers must define, identify, and remedy learning difficulties associated with visuospatial reasoning to support students. This is particularly important given the convergence of arguments suggesting that visuospatial education should form part of science education reform in the 21st century (Habraken, 2004). Several recommendations were made by scholars in the early 2000s concerning the use of visual models in teaching and learning in molecular biology (e.g., Schönborn & Anderson, 2006; Tibell & Rundgren, 2010). These include explicitly teaching disciplinary conventions as a component of discipline-specific knowledge (Schönborn & Anderson, 2006).

Disciplinary conventions of visual representations

Disciplinary conventions encompass textual language, stationary multi-faceted visuals, animated graphics, simulations, and symbolic representations (Mnguni, 2019). In biochemistry, disciplinary conventions such as ball-and-stick and stick models simplify complex molecular structures to better understand molecular geometry, functional groups, interactions, stereochemistry, and reactivity (Kondo & Nakamura, 2023; Turner, 1971). These conventions act as instrumental media for articulating discipline-specific knowledge, fostering comprehension, and enhancing problem-solving abilities (Dressen-Hammouda, 2008; Moreno, Ozogul & Reisslein, 2011). Given their wide usage, students must understand disciplinary conventions, which use specialised graphical and semiotic elements to convey scientific concepts for research, teaching, and learning.

Disciplinary conventions could influence the progression from novice to expert in a discipline (Dressen-Hammouda, 2008; Rau, 2017). Johnson-Glauch and Herman (2019) posit that there is a marked distinction in the interpretation of disciplinary conventions, including visual representations between experts and novices. Such distinction stems from novices' and experts' differential sensitivities towards disciplinary thinking and decoding information embedded in visual representations. Experts with a higher understanding of disciplinary conventions can discern nuanced discrepancies in visual representations that may alter the foundational science involved (Johnson-Glauch & Herman, 2019; Rau, 2017). Conversely, novices frequently encounter difficulties retrieving and prioritising the information encapsulated in visual representations (Johnson-Glauch & Herman, 2019). Novices are also inclined to concentrate on inherently perceptually prominent features of visual representations, irrespective of their task relevance (Johnson-Glauch & Herman, 2019).

Transitioning from a novice to an expert necessitates the acquisition of a disciplinary identity and mastering disciplinary conventions (Offerdahl, Arneson & Byrne, 2017). To effectively communicate and decipher information in their fields, novices must learn and apply these disciplinary conventions (Dressen-Hammouda, 2008). This development entails fostering a nuanced understanding of the disciplinary conventions pertinent to visual representations. It requires students to harmonise information from the representation features with their domain knowledge and objectives, facilitating the construction of an accurate mental model of the depicted concept (Johnson-Glauch & Herman, 2019).

Learning through visual models

Learning from disciplinary conventions is a complex cognitive process explained through theories like the cognitive theory of multimedia learning, emphasising the role of visuospatial reasoning in molecular biology and chemistry (Mayer, 2001, 2003, 2019; Mnguni, 2014). According to the cognitive theory of multimedia learning (Mayer, 2001, 2019), students learn from visual models per the dual coding and limited capacity theories. The dual coding theory suggests that information is encoded through verbal and visual channels, which can operate independently or synergistically (Kanellopoulou, Kermanidis & Giannakoulopoulos, 2019; Paivio, 2013). The limited capacity theory posits cognitive resource limitations, highlighting the need to manage these resources effectively to avoid cognitive overload (Bruya & Tang, 2018; Kahneman, 1973). Poor use of visual models and disciplinary conventions, coupled with a lack of visual literacy skills, could foster learning difficulties associated with visuospatial reasoning.

To minimise visuospatial reasoning difficulties, Mayer argues that optimised model design and training can enhance students' learning ability using visual models (Mayer, 2001, 2003). Mnguni (2014) extends this by identifying three cognitive processes: Internalization of Visual Models (IVM), Conceptualisation of Visual Models (CVM), and Externalization of Visual Models (EVM). These processes involve interconnected skills that can be learned, assessed, and graded (Mnguni, Schönborn & Anderson, 2016). In CVM, the meaning-making stage, cognitive interpretation integrates visual information influenced by correct and incorrect preconceptions (Mayer, 2003). IVM entails absorbing visual information from external models like diagrams or animations. It is divided into low-level, middle-level, and high-level processes. Low-level IVM involves rapid feature extraction without in-depth cognitive interpretation, while high-level IVM involves a more cognitively demanding concept creation (Healey & Enns, 2011; Mnguni, 2014). Constructivists stress the importance of past knowledge in meaning creation, particularly during the CVM stage (Thompson, 2012). Prior knowledge in specific domains like biochemistry is essential for evaluating incoming visual information (Mayer, 2003; Thompson, 2012). Effective design and usage of visual models facilitate better conceptualisation of information (Mayer, 2003; Schönborn & Anderson, 2010). For example, skills developed in the CVM stage include distinguishing different spatial orientations of a concept and recognising unique features of molecular models such as protein molecules (Mnguni, 2014). These cognitive processes are non-linear and interconnected, and their mastery is essential for effective learning.

Effective learning through visual models necessitates developing particular visualisation skills encompassing visual literacy informed by cognitive processes and related theories. To this end, Schönborn and Anderson (2010) delineated several critical visualisation skills integral to fully grasping and engaging with visual representations. These skills include decoding the symbolic language embedded within a representation and evaluating its potency, limitations, and quality. Additionally, learners must be adept at utilising these representations to solve problems and interpret complex concepts through spatial manipulation of the representations. Moreover, constructing new representations to elucidate concepts or address problems is an essential skill, as is the ability to seamlessly transition horizontally across various representations of a single concept. Equally vital is the skill of vertically translating between representations that portray differing levels of organisation and complexity. Lastly, learners should be proficient in visualising different orders of magnitude, comprehending relative sizes, and grasping different scales to benefit fully from visual models in the learning process. Mnguni et al. (2016) further divided the above skills into 24 individual visualisation skills as informed by Bloom's taxonomy (Anderson & Krathwohl, 2001). Using the Rasch model (Linacre, 1999), these researchers ranked the 24 skills in terms of difficulty and evaluated students' proficiency in each (Mnguni et al., 2016).

Aim of the research

Given the intricacies of visual literacy and related processes, the current research sought to describe biochemistry students' visuospatial reasoning difficulties associated with amino acid structures. Specifically, the research sought to solicit students' experiences and challenges when asked to perform specific tasks related to visuospatial reasoning. The research question explored in this study is: "*what are biochemistry students' visuospatial reasoning difficulties associated with amino acids models?*"

Research Methods

The current research was a follow-up on previous research (i.e., Mnguni, 2018; Mnguni et al., 2016), which described third-year biochemistry university students' visual literacy and how it relates to their content knowledge taught using visual models. Using a quantitative research approach, (Mnguni, 2018; Mnguni et al., 2016) reported the level of visual literacy among third-year biochemistry students. However, they did not provide a qualitative description of the related learning difficulties that affect students learning through visual models. To address this gap, the current study adopted a qualitative research approach through which students' learning difficulties were explored. Given its qualitative nature, the current research adopted a constructivist paradigm. The constructivist paradigm posits that reality is socially constructed and subjective (Creswell, 2021). It focuses on understanding human experiences from the perspective of those experiencing them, where qualitative methods like interviews are often employed to capture complex social phenomena. This paradigm values context and human interpretation over generalizability. Therefore, in the current research, individual semi-structured interviews were used to determine learning difficulties associated with visual models of protein and amino acid structure representations among biochemistry students.

BioVisual Literacy Test

Before the interviews, as reported by (Mnguni, 2018; Mnguni et al., 2016), participants took a BioVisual Literacy Test, which used 12 items to assess students' visual literacy in the context of biochemistry. According to Mnguni et al. (2016) and Schönborn and Anderson (2010), student's ability to respond correctly to questions involving visual models is influenced by at least three interrelated factors: 1) their ability to visualise the visual model; 2) prior conceptual knowledge they "bring" to the visual model; and 3) the model (including its features and form). These factors are recognised as biovisual literacy indicators. Therefore, biovisual literacy was evaluated by Mnguni (2018) and Mnguni et al. (2016) using the 12 items created, emphasising a particular set of visualisation skills.

In the 12 items, students were required to use content knowledge to interpret visual models to arrive at the correct answer. As a result, each question included at least one visualisation skill and content relating to an amino acid or protein structure. Depending on the requirements of the questions, some visualisation skills were evaluated more than once. The participating students' instructors used blended-learning resources to create all the visual models used in the questions. The current study addressed four visuospatial reasoning skills associated with representing amino acids as ball-and-stick, and stick models. Three of the 12 items probed the same skill, so each skill was tested thrice. The visuospatial reasoning skills are:

- **Perceiving spatial orientation**: the ability to identify the position or direction of objects or points in space. This includes the ability to perceive and give scientific meaning to the nature and role of spatial relationships and distances between objects in multi-dimensions and their meaning concerning the object.
- **Mental rotation**: Mental rotation is the ability to rotate mental representations of two-dimensional and three-dimensional objects related to the visual representation of such rotation within the human mind.
- **Interpret colour codes**: To detect or perceive a visual attribute of things resulting from the light they emit, transmit, or reflect.
- **Generating a visual model depicting spatial depth**: produce a visual model that depicts a scientific concept, reflecting the spatial relationship between its parts.

Research participants

In the current study, participants were seven third-year Bachelor of Science students majoring in Biochemistry at a South African university. While this sample size is relatively small, it is consistent with standard practices in qualitative research methodology, where sample size recommendations vary widely, ranging from as little as five to up to 60 participants (Hennink & Kaiser, 2022). The participants in the current research participated voluntarily following ethical clearance from the university (ethical clearance number HSS/0150/07). The participants were all enrolled in a Protein Biochemistry module during the research. They all had completed prerequisite biochemistry modules in the first and second year, including other prerequisite subjects like Maths, Physics, and Chemistry. These participants, who also participated in Mnguni (2018) and Mnguni et al. (2016), were purposively selected based on their performance in the previous study. In particular, the participants were identified as possessing high, medium, and low biovisual literacy. Regarding their performance in Mnguni (2018) and Mnguni et al. (2016), the Rasch model was used to rank students' biovisual literacy, where it had been "*observed that students generally performed poorly in the BioVisual Literacy test. Results show that 85% of the students have over a 50% chance of failing to correctly respond to probes requiring them to utilise the average difficult visualisation skills. This suggests that most of the participating students have poor visualisation skills.*"

Participants in the current study were classified as shown below, following their performance in Mnguni (2018). Pseudonyms are used for ethical reasons.

- High visual literacy: Thabo demonstrated over a 50% chance of correctly responding to probes, requiring utilising all but two visualisation skills.

- Average visual literacy: Ntombi, Shaun, Gayle, and Samira demonstrated a 50% chance of correctly responding to probes, requiring them to utilise the average difficult visualisation skills.
- Low visual literacy: Nathan and Keke demonstrated over 75% chance of incorrectly responding to probes, requiring them to utilise all the visualisation skills tested in this research.

Data were analysed qualitatively to determine students' difficulties in the different skills.

Results

The following section presents these skills and the nature of related difficulties.

Spatial orientation and Mental rotation

Concerning spatial orientation and mental rotation, students were asked to consider two visual models of amino acids and determine if these represented the same amino acid (Figure 1). They were also asked to give reasons for their answers.

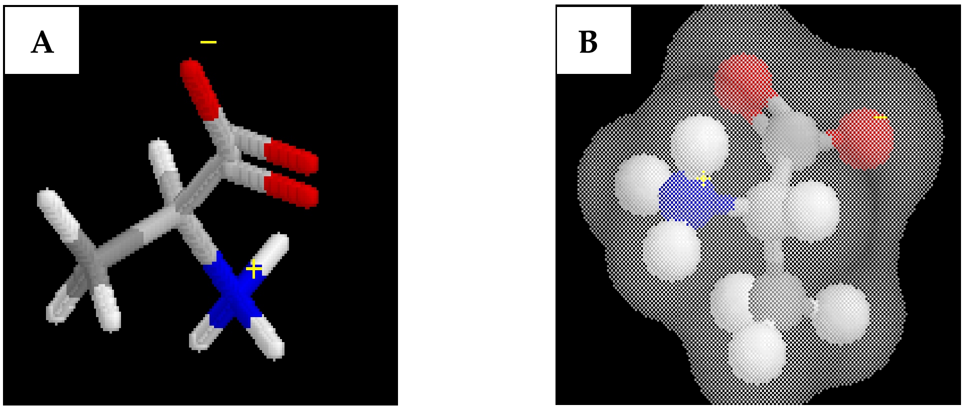

Figure 1. Visual representation of Alanine using a stick model (A) and a ball-and-stick with an electron cloud model (B).

In response to this question,

- Thabo suggested that "*it was the same amino acid. The diagrams show their stereochemistry rotated on a 2D plane.*"
- Gayle suggested that "*the two are of the same structure…the first is a stick model, the second is a ball and stick model…both have the same charge and spatial arrangement…same number of carbons and hydrogen atoms.*"
- Shaun suggested that it was the "*same amino acid, but the positions of molecules have moved. That is why they appear in different positions*".
- Keke argued, "*it's the same amino acid, just viewed differently.*"
- Nathan indicated that it was "*different amino acids because the NH_3 (pointing to the blue molecule) and CH_3 (pointing to the grey molecule) have swapped positions*".
- Samira 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]*".
- Ntombi 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 the above examples, Thabo could identify the molecules' stereochemistry. Gayle could identify the different models, ball and stick and stick models, of the same molecule. She calculated the number of the individual molecules, noted the charges, and deduced that it must be the same amino acid. Nathan and Samina were partly correct in that they could identify the molecules. However, both were incorrect in saying the positions of the amino acids had moved and, therefore, the models represented different amino acids. Ntombi's answer was incorrect in that she suggested that the positions of the molecules had been swapped and, therefore, these were different amino acids.

What is evident in this regard is that the students had the prerequisite knowledge through which they could recognise the structures as amino acids. However, some students could not correctly explain the stereochemistry concerning angular rotation, dimensionality, and depth. Some students also found it challenging to observe visual models on a 2D page and then cognitively rotate these and observe that the two models represented the same amino acid.

The ability to rotate visual models cognitively was further probed in another model where students were asked to study two models (Figure 2) and indicate if they were the same.

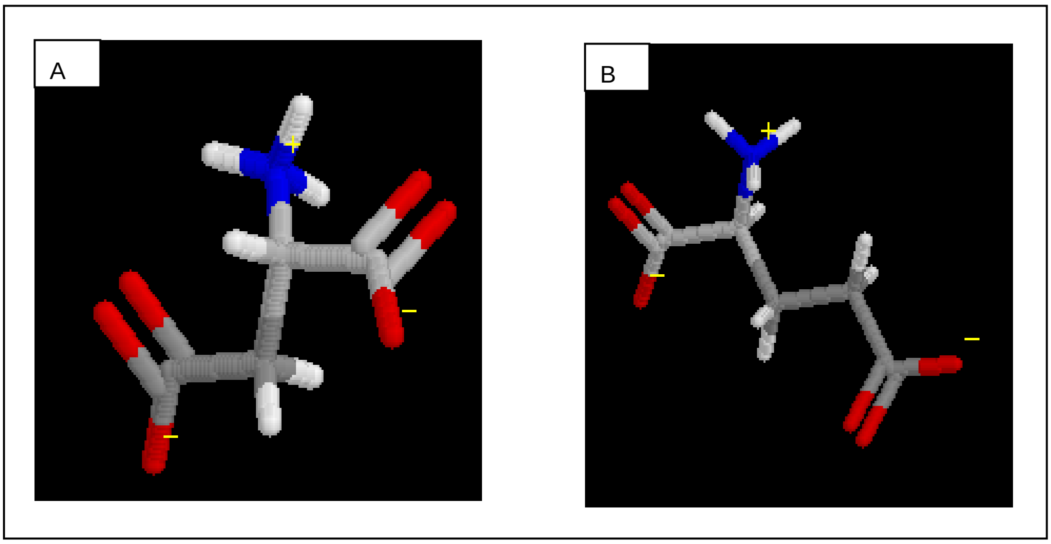

Figure 2. Visual representation of Aspartate (A) and Glutamate (B) using stick models.

Responding to this, Shaun suggested that *"they first looked like same amino acid, but after looking at it for a while you see [that] there is an extra –CH_2 group [pointing at the amino acid on the right] hence they are not the same"*. Asked to explain his reasoning, Shaun suggested that "*you have to sort of hold them in your mental hand and rotate them around to see if they fit into one another. That way, you will see that they don't. You also see that there is an extra CH_2 on the one"*. Similarly, Samira indicated she "*held the amino acids* (in her) *mental hand and rotated them around to see if they fit into one another. That way (she could) see that they do not.* (She could) *also see that there is an extra CH_2 on the one"*. In this response, the student describes how she mentally rotates the models, which other students may struggle with. Related to this response, Keke, who could not differentiate between these two, suggested that "S*ometimes you get a diagram, and you cannot really see what's behind it or what it represents, you can't rotate it, you can't do anything to it…for me, that's not right, I don't like that. So, it's better for me just to read the notes"*. These two examples represent cases where students can cognitively rotate diagrams and cases where they cannot.

Probed further, participants were asked to identify molecules on the same plane (Figure 3). Participants were asked to describe the spatial position of the three carbon molecules and the nitrogen.

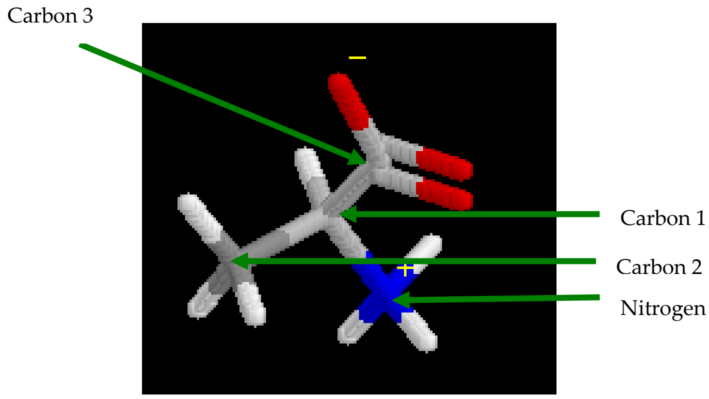

Figure 3. Visual representation of Alanine using stick models.

Responding to the question, Samira suggested that "*all the four molecules were on the same plane but pointing in different directions due to their relative charge*." Thabo indicated that "*carbon 1 is at the centre, while carbon 2 and 3 are coming out of the paper towards her, and nitrogen is going into the paper away from her*". Nathan indicated that "*the colour codes indicate the relative position of the molecules. Because they have different colours, they are in different spatial position*". However, he could not indicate which direction these point toward.

Interpret colour codes

According to Mnguni (2018), ground perception deals with one's ability to perceive and give scientific meaning to the nature and role of part of a scene (or picture) that lies behind objects in the foreground. In the current study, participants were asked to explain the meaning and role of the "grey area" (electron cloud) surrounding the molecules (see Figure 4).

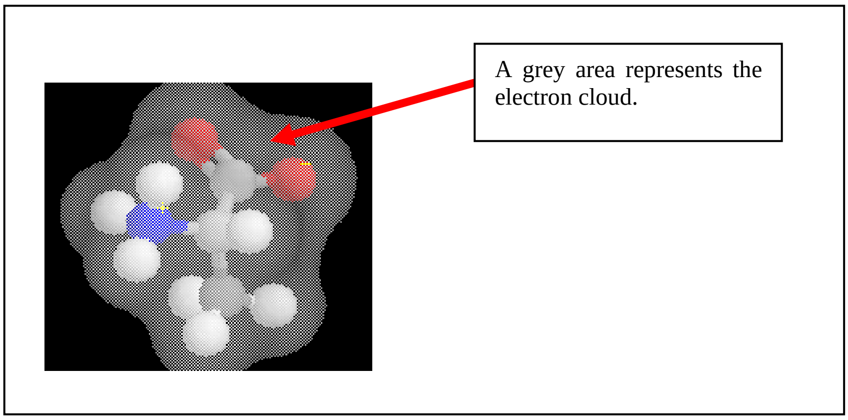

Figure 4. Visual representation of Alanine using ball and stick model with electron cloud represented.

In response:

- Gayle said, "*I don't know, I am guessing… it's a way of showing the amino acid…the background"*.
- Samira suggested this area "*represented an empty space in the cell. It contained nothing*".

While these students could perceive this "grey area", they did not know what it meant. In fact, by suggesting that it is the background, Gayle may be dissociating this area from the rest of the amino acid and views it as not part of the actual amino acid. Samira suggests that a cell has "empty space", implying a vacuum or empty room (i.e., with no molecules).
To further understand this phenomenon, students were asked to consider a visual model of an amino acid and describe the meaning of the colour coding used using prior knowledge.

- Nathan reiterated that colours indicate the molecules' spatial position. He argued that "*the molecules that are in the same spatial position are given the same colour. But if they are different, then different colours are given*".
- Keke indicated that the colours are the true real-life colours of the different molecules. He was adamant, *"From what we have learned, it would be wrong to say carbon is red because it is grey in real life*." He suggested that molecules identified as Carbon 1, Carbon 2, and Carbon 3 in Figure 4 were not all carbon because the "*colours differ*."

Generating a visual model depicting spatial depth
As part of the expression stage of visualisation, students were asked to generate an amino acid drawing that depicts spatial depth. Students had the option to use any model of their choice, including the "ball and stick," "stick," and "3D" models. Most students preferred to draw the stick model (see example in Figure 5A). One student, Ntombi, attempted to draw an amino acid in "3D" format (Figure 5B). Asked in the interview, this student suggested that this format was due to her experience in fine arts. When asked about their models, other students reported that they disliked generating visual models. For example, one student (Keke) responded, "*Generally, I don't like drawing, I have never liked drawing… I don't have the patience".*

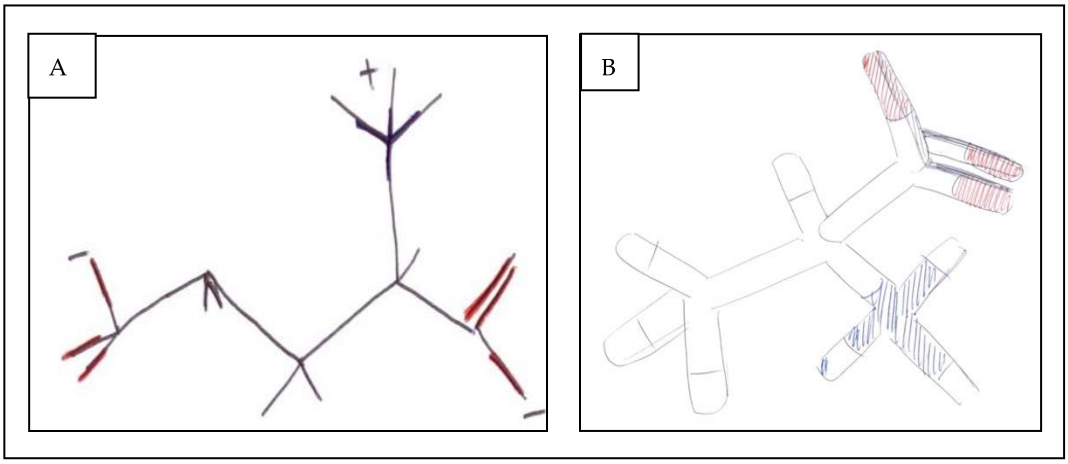

Figure 5: Different representations of amino acids generated by students.

Discussion

The significance of visuospatial reasoning in molecular biology is well documented in the literature. Some researchers have shown that enrolment in science courses improves students' spatial reasoning abilities within specific contexts (Hegarty, 2014). However, the need for deliberate training and development of visuospatial reasoning and visual literacy remains a critical component of student development in science. Hegarty (2014) argues that the development of visuospatial reasoning may have to be done in the context of specific content and be focused on fundamental spatial processes. In the current research, visuospatial reasoning was investigated within the context of amino acid structures, focusing on specific fundamental spatial processes necessary to study amino acid structures in molecular biology. These processes are perceiving spatial orientation, mental rotation, interpreting colour codes, and generating a visual model depicting spatial depth. This context specificity would help us understand students' difficulties and, therefore, develop remediation intervention training that could help students develop the necessary visuospatial reasoning skills for effective learning about amino acids.

The current research has found that students may experience spatial orientation and mental rotation difficulties when presented with 2D models of amino acids. While spatial orientation and mental rotation difficulties have been reported widely (Linn & Petersen, 1985; Rodán, Gimeno, Elosúa, Montoro & Contreras, 2019), there is little evidence exploring this phenomenon in the context of amino acid structures. This is despite the wide use of 2D and 3D models of amino acids, which require students to be able to manipulate these structures for effective cognitive learning. Paukstelis (2018) suggests that most students rely on 2D visual models, such as those used in the current research. As such, appreciating the 3D configuration of these models "is a vital step in understanding core concepts, including molecular symmetry in inorganic complexes, stereochemistry and chirality in organic compounds" (Rodán et al., 2019, p. 169).

In line with Clements-Stephens, Rimrodt, Gaur and Cutting (2008), this study reaffirms that while students might hold considerable content knowledge, they can struggle with processing visuospatial models due to inadequate visual literacy competencies. Notably, possessing content knowledge does not guarantee an adeptness at interpreting visual representations. Schönborn and Anderson (2010) elucidate this notion, emphasising that "decoding a ball-and-stick representation transcends mere perceptual processing, encompassing the engagement of conceptual knowledge symbolised within." Comprehending a visual model hinges on the complete decoding of its symbolic language. Consequently, ensuring that students grasp the content and are equipped with the essential visual literacy skills is pivotal for effective learning from such models.

Empirical studies reveal that students frequently perceive visual models as precise duplicates of real-world phenomena instead of abstract representations, potentially fostering misconceptions (Treagust, Chittleborough & Mamiala, 2004). This issue is exemplified in the current research by instances where colours in models are misinterpreted as literal portrayals of scientific elements. Unfortunately, this literal interpretation, supported by earlier studies, has students construing models as "real-life metaphors" rather than nuanced abstractions of reality (Tibell & Rundgren, 2010). Such a fundamental misunderstanding, where visual elements in models are mistaken for real-life equivalents, may lead to misconceptions, which are further compounded by preconceived notions, non-scientific beliefs, conceptual misunderstandings, or vernacular understandings (Atchia, 2022; Mierdel & Bogner, 2019). These barriers can obstruct students' comprehension of accurate scientific narratives, hindering their assimilation of scientific principles (Yates & Marek, 2014). Consequently, pinpointing and rectifying these misconceptions is vital in fostering students' learning and conceptual development.

The results also suggest that students may be able to internalise visual models in some instances but have difficulties externalising them. This is in line with Mnguni (2014), who showed that the internalisation and externalisation of visual models are related but different processes. For example, students may find it challenging to draw visual models, even if they have created acceptable mental models. Our finding highlights the need to adapt teaching and learning to students' learning style preferences. In the current research, the participant most comfortable generating drawings had a history of fine arts. This may suggest that the student has an inherent passion for drawing, which others do not share. As a result, how students externalise knowledge may be associated with their preferred learning styles and interests.

Limitations of the study

While the sample size of the current research is consistent with practice in qualitative research, a small sample size has several limitations. For example, small sample sizes in qualitative research can limit the generalizability and robustness of study findings as they might not adequately represent the broader population. Additionally, smaller sample sizes may not allow for detecting subtle yet significant trends or phenomena, making it difficult to establish complex patterns and relationships within the data. Consequently, the depth of insight and ability to make informed recommendations or interventions based on the research findings might be compromised. Therefore, the author acknowledges these limitations and posits that the current findings are significant as a preliminary effort to understand students' experiences and challenges related to visuospatial reasoning in biochemistry. Future research could explore this phenomenon on a larger sample and in biochemistry contexts other than amino acids.

Conclusion and recommendations

While the current research findings are not entirely novel in the broader field of visual literacy, they highlight significant issues related to using visual models to teach molecular concepts in biochemistry. Based on these findings, it is concluded that students may experience visual models differently depending on their visuospatial reasoning skills. We identify critical difficulties associated with perceiving spatial orientation, mental rotation, interpreting colour codes, and generating visual models depicting spatial depth when using amino acid models.

The researcher concludes that students do not always have the visuospatial reasoning skills required for successful learning in biochemistry. Teachers should integrate explicit training on interpreting molecular structures within science curriculums to foster enhanced visual literacy skills. Incorporating activities that focus on fundamental spatial processes, such as spatial orientation and mental rotation, can be pivotal. Moreover, introducing students to 3D representations alongside 2D models can facilitate a deeper understanding of amino acid structures. Pedagogical approaches should also encompass activities that encourage students to decipher the symbolic language of visual representations, fostering their ability to differentiate between abstract representations and real-world entities, thus mitigating potential misconceptions. Furthermore, individual learning preferences should be considered to encourage effective knowledge externalisation.

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