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## The impact of scientific visualization quality on visual literacy and conceptual understanding in biology

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### ABSTRACT

This study investigates how high-quality scientific visualizations enhance students' academic performance and visual literacy in biology, focusing on abstract concepts in the digestive system. A quasi-experimental design involved 39 high school science students using a pre-test post-test non-equivalent group format. Data were gathered through questionnaires, visual quality rubrics, and a visual literacy instrument adapted from Avgerinou's framework. Visual media were assessed by both media experts and students across six quality criteria. While lecturers rated the visuals as high quality, students perceived them as moderate, highlighting a mismatch between expert design and learner experience. This discrepancy underlines the need to align visual content more closely with students' cognitive and perceptual needs. Visual literacy was evaluated through students' ability to identify, interpret, evaluate, and transform visual information. Results showed that most students demonstrated only basic skills, with none achieving advanced proficiency. A moderate positive correlation ( $r = 0.45$ ,  $p < 0.05$ ) was found between perceived visual media quality and students' visual literacy, with media quality accounting for 20% of the variance in scores. These findings suggest that well-designed, pedagogically grounded visual materials, coupled with direct visual literacy instruction, are critical for supporting conceptual understanding and improving academic outcomes in science education.



## INTRODUCTION

Biology, defined as the scientific study of life, serves as a method of understanding the natural world through inquiry (Simon et al., 2018). Among the various subjects in science education, the human body and its components, including the digestive system, are of significant interest. The digestive system (DS) is a crucial subject in biological science teaching (Mattos Feijo et al., 2020), as it consists of essential organs that help maintain vital bodily functions. Comprehension of the DS fosters a more comprehensive understanding of the systemic and homeostatic mechanisms of the human body and its interactions with the surrounding environment (Hall, 2016; Urry et al., 2021). This foundational knowledge enables learners to connect biological theory with real-life physiological phenomena.

Research has underscored the prevalence of misunderstandings regarding the DS among students at different educational stages. A study indicated that pupils at these stages faced conceptual challenges and a lack of understanding of the digestion process. Furthermore, high school students displayed an inadequate understanding of the physiological roles of the primary and accessory organs of the DS, such as the liver, pancreas, and small intestine (Aydin, 2016). These misconceptions are not only persistent but also resistant to traditional teaching methods. Such misunderstandings can obstruct the development of more complex biological reasoning and hinder progress in related subjects.

Relying exclusively on abstract-based instruction can make it difficult for younger learners to engage with and grasp the material. The technique of dissecting animal organs acts as a teaching method that offers students a direct and tangible perspective on morphological structures. As an interactive, hands-on experience, it promotes both methodological learning and a deeper grasp of the scientific inquiry process. Research indicates that a majority of students feel dissection improves understanding (91.8%) and provides a three-dimensional view of anatomical structures (92.4%) (Kalthur et al., 2022). Nevertheless, the dissection process is frequently associated with certain negative emotions that may hinder effective learning. Studies have demonstrated that students who participated in dissection experienced greater levels of perceived disgust compared to those who interacted with a video or a model (Kaiser, 2023). To mitigate this, educators must consider complementary methods or provide emotional support to ensure students remain engaged and comfortable during the activity.

Because many biological processes are not directly observable, science educators and researchers frequently rely on visual representations such as diagrams, models, illustrations, animations, and simulations to communicate complex ideas. In biology education, these visual tools are fundamental components of textbooks and instructional materials. Scientific visualizations are particularly valuable for explaining phenomena at the sub-microscopic level or involving abstract concepts that are otherwise difficult to grasp (Jenkinson, 2018). By translating intricate and often invisible processes into accessible visual forms, they help make abstract biological ideas more concrete for students. These visualizations aim to promote deeper engagement and a clearer understanding of complex biological systems (Parthasarathy & Premaltha, 2022). When integrated with abstract concepts, they improve students' attention, enhance cognitive processing, and foster more meaningful learning experiences. Visual learning not only aids in comprehension but also supports the mental construction and internalization of scientific knowledge (Quillin & Thomas, 2015; Schmidgall et al., 2019).

A theoretical rationale for the beneficial effects of visuals is provided by Mayer's cognitive theory of multimedia learning from text and pictures (Lewalter, 2003). When learners create referential links between their independently formed mental representations of verbal and visual content and their existing knowledge, learning improves. Studies have revealed that learners occasionally struggle to make connections between visual and textual information. They also find it challenging to identify the pertinent information presented in an illustration (Lewalter, 2003). Students' ability to interpret and organize these visuals is closely tied to their conceptual

understanding of biology and their overall visual literacy. However, Biology students often lack the visual literacy skills required to interpret the visualizations they encounter (Jenkinson, 2018).

Proficiency in visual literacy is a critical competency across diverse disciplines such as marketing, design, journalism and education (Zhu & Lim, 2024). Visual literacy refers to the ability to fluently engage in the disciplinary discourse used by scientists, particularly in activities such as decoding and interpreting visual representations, encoding and creating them, and constructing mental models (Arneson & Offerdahl, 2018; Ausburn & Ausburn, 1978; Brumberger, 2019). It plays a critical role in fostering deep conceptual understanding, making it essential to develop visual skills alongside meaningful learning outcomes in biochemistry and related curricula (Schönborn & Anderson, 2010). Defined as the ability to effectively recognize, interpret, evaluate, utilize, and create images and visual media, visual literacy is a key component of broader science literacy (Arneson & Offerdahl, 2018; Newman et al., 2023). As an integral aspect of scientific literacy, visual literacy goes beyond mere content knowledge to encompass the foundational skills needed to interpret science, specifically, the ability to understand and critically evaluate information conveyed through both textual and visual formats (Newman et al., 2023). Building on this, visual literacy is a critical component of global education goals (SDG 4.4), as it equips individuals with essential ICT skills needed to navigate an image-driven digital world, combat misinformation, and effectively interpret and create visual content in multimodal communication (Levratto et al., 2024).

Schönborn & Anderson (2006) emphasized that, "Students do not necessarily automatically acquire visual literacy during general instruction". This suggests that students need ample opportunities to develop and refine their visual literacy skills. Research has identified at least six key factors that influence students' ability to visualize and interpret visuals in Biology. These factors include students' general reasoning skills used to interpret visuals, their ability to read and understand the features of the visuals, and their skill in selecting and applying relevant conceptual knowledge. Additionally, students' overall understanding of the concepts depicted, the clarity, format, and quality of the visuals themselves, and the scope and representation of the conceptual knowledge such as symbols, annotations, and aesthetic elements also play significant roles (Schönborn & Anderson, 2006).

Nevertheless, research on visual literacy, particularly in the context of science education, remains limited and underexplored (Mnguni, 2014). Visual literacy has been investigated in topics such as DNA and biochemistry, which are considered highly abstract due to their sub-microscopic nature and complex conceptual structures (Newman et al., 2023; Schönborn & Anderson, 2006; Uminski et al., 2025a) and visual literacy is considered essential for effectively communicating climate change and other scientific topics through visual media (Bombara & Duan, 2024). In contrast, topics related to bioprocesses, such as the digestive system, have not yet been the focus of visual literacy research. To address this gap, the present study focuses on developing students' visual literacy skills through the topic of the digestive system, recognizing that these skills are learnable, teachable, and capable of ongoing improvement (Avgerinou & Pettersson, 2011). For visual literacy instruction to be effective, it must be supported by high-quality visual media. Therefore, it is crucial to first evaluate whether the quality of visual media correlates with students' visual literacy. Integrating well-designed visual materials is anticipated to strengthen students' abilities to interpret, analyse, and apply visual information, skills essential for understanding complex biological processes.

## METHODS

This research employs a quantitative method with a quasi-experimental approach since it includes groups that have naturally occurred, like classes, without a random selection of participants (Wiersma & Jurs, 2009). Because it lacks a control group, this research design is designated as a pre-test post-test non-equivalent multiple-group design (Wiersma & Jurs, 2009). The subjects of this study were students of class XI Science in high school, which amounted to 39 people. The

selection of this class was based on the assumption that the students in it have relatively homogeneous characters. The instruments used in this study include questionnaires, visual quality assessment rubrics, and visual literacy instruments. The objective of this study is to analyse the relationship between visual media quality and visual literacy, so two types of data are needed: namely, visual media quality data and visual literacy data.

The data on visual media quality was obtained through assessments made by students and lecturers of learning media courses (Smaldino et al., 2005). Prior to the utilization of images in the research, the media lecturer conducted an "off class" assessment by assigning a score of 1-3 on the assessment rubric. Meanwhile, students assessed the quality of the visual media after interpreting the images by filling out a closed questionnaire. Following the collection and analysis of the data, the results were categorized into three quality levels: high, medium, and low.

In order to assess visual literacy, researchers have referred to the competencies proposed by Avgerinou (2007). These competencies include knowledge of image vocabulary, knowledge of image rules, visual differences, visual associations, meaning reconstruction, meaning construction, critical views, visual thinking, visualization, visual thinking, and visual reconstruction. From the eleven competencies proposed by Avgerinou (2007), the researcher simplified them into four indicators, namely: The first is the ability to identify visual elements (shape, colour, size, etc.). The second is the ability to understand and interpret the visual elements seen. The third is the ability to evaluate images or visual elements. The fourth is the ability to process, transform, and present information in different forms. The four indicators are categorized into decoding ability (visual reading). These competences have similarities with 4 visual competences are constructing, interpreting, transforming and critiquing (Cheung & Winterbottom, 2021).

Technically, researchers distributed each student with a well-chosen image of the digestive system process and a visual literacy instrument containing three guiding questions. Students were asked to extract information from the picture according to the directions in the questions. The results of the interpretation were written as a form of decoding, namely understanding the visual message conveyed. Each student's work was collected and checked by matching it with the answer key. During the checking process, the assessment was also guided by a rubric developed by the researcher to evaluate each indicator that appeared. After obtaining two groups of quantitative data in the form of an interval scale for each variable, the analysis was carried out using the correlation test with the help of SPSS. The resulting data were then interpreted to obtain research conclusions.

## RESULTS AND DISCUSSION

### Assessment of Visual Media Quality

In order to evaluate the quality and effectiveness of the visual learning media, both experts and students assessed the material based on twelve specific indicators. Each indicator was evaluated on a scale ranging from 1 to 3, with higher scores denoting superior performance. Table 1 presents a comparison of experts and students' scores for each indicator, highlighting discrepancies in perception between professional evaluators and actual users.

The evaluation data reveal a notable discrepancy between expert and student perceptions of the visual learning media. Experts awarded a high total score of 32 out of 36, equivalent to approximately 89 out of 100, indicating that the media is regarded as high quality in terms of instructional design and technical aspects. Conversely, students allocated a substantially diminished total score of 23 out of 36, or approximately 63 out of 100, indicating that the media did not entirely align with their expectations or learning requirements. The majority of the indicators received relatively high scores from the experts, particularly in categories such as suitability to learning objectives, accuracy of information, ease of use, technical quality, and

communication clarity. However, students consistently assigned lower ratings to several aspects, particularly simplicity, colour use, and visual appeal. While both groups concurred on the impartiality and overall clarity of the content, students perceived the design to be less engaging, less visually appealing, and somewhat challenging to interpret.

**Table 1.** Personal information of respondents based on gender

No	Indicators	Score	
		Experts	Students
1	Suitability to the competency standards and learning objectives	3	2
2	Accuracy and novelty of information	3	2
3	Language suitability to age	2	2
4	Level of attention & engagement	3	2
5	Ease of use (User: teacher or student)	3	2
6	Technical quality	3	2
7	Impartiality	3	2
8	Readability (size and brightness)	3	2
9	Simplicity (clarity, design unity)	3	1
10	Suitability of color use	2	1
11	Clear and effective communication	3	2
12	Visually appealing	1	1
	Total	32	23

Source: Instructional Media and Technologies for Learning 8th edition (Smaldino et al., 2005).

These discrepancies underscore the necessity of aligning media designed by experts with the preferences and usability requirements of students. In order to enhance the effectiveness of the aforementioned revisions, it is imperative that the following areas be given priority: enhancing visual appeal, simplifying the layout, and increasing student engagement through the implementation of more intuitive and appealing design features. A well-crafted infographic is more than just an eye-catching visual. It requires careful and strategic integration of design elements such as colour, icons, and typography. For instance, colour in infographics serves a purpose beyond mere aesthetics. Thoughtful colour selection can help distinguish different sections of information, improving clarity and comprehension of the visual representation (He et al., 2024).

The discrepancy in perceptions between faculty members and students regarding the quality of visual media can be attributed to the theory proposed by Smaldino et al., (2005). This theory posits that the effectiveness of learning media is contingent upon their alignment with the needs and characteristics of learners. According to this theory, the selection of media that does not take into account students' preferences or levels of understanding can result in varied perceptions of its quality and effectiveness in facilitating learning. Furthermore, Mayer (2024) in *Multimedia Learning* underscores that the efficacy of visual media in learning is contingent on the harmonious integration of visual elements with the subject matter. In the event that the visual design does not align with students' cognitive processing principles, its effectiveness may be diminished, notwithstanding its technical sophistication.

The assessment of learning media should encompass not only technical aspects but also the level of engagement it fosters with learners (Cuenca et al., 2024; Smaldino et al., 2005). Media that is perceived as interesting and accessible by instructors may not necessarily exert a similar effect on students, particularly if it lacks interactivity or does not align with their learning style (Smaldino et al., 2005). Consequently, the outcomes of this disparity in evaluation suggest that, in the design of visual media, consideration must be given not only to technical aspects but also to the context of use, the needs of students, and the effectiveness of media in facilitating concept

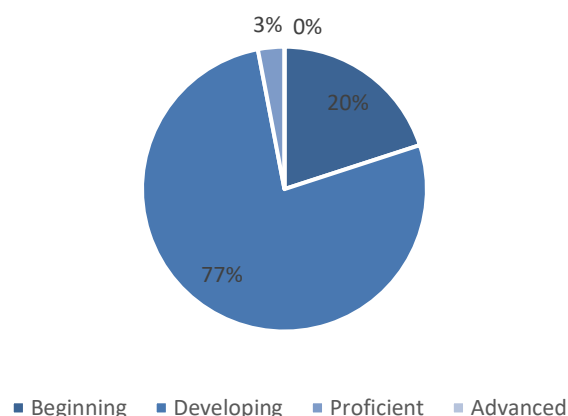
understanding. Well-designed data visualizations enable viewers to leverage their visual processing abilities to recognize patterns across various fields such as science, education, health, and public policy. However, when visualizations are poorly constructed, they can lead to confusion, misinterpretation, or even distrust—particularly among individuals with limited graphical literacy. Ineffective visual displays may also result in perceptual errors and visual illusions (Franconeri, 2021). Low graphical literacy and ineffective design lead many viewers to struggle to understand these otherwise powerful thinking tools.

### Assessment of Visual Literacy

Infographics, which convey data and information through a blend of text and visuals, are being increasingly adopted across various fields, including education. They are recognized as powerful and engaging tools for presenting complex ideas in a clear, concise, and easily digestible format (Zhu et al., 2020). Based on students' descriptions related to the indicators asked, the average visual literacy of students is 53. Figure 1-4 presents the achievements of all students on each indicator.

The initial indicator evaluated in this study is the capacity to discern visual elements, encompassing shapes, colours, leading lines, and arrows. These elements play a pivotal role in facilitating students' comprehension of the representation of various processes in the digestive system, including the digestion of carbohydrates, fats, proteins, and the process of digestive absorption. The comprehension of these visual elements is expected to enhance students' capacity to interpret information presented in visual form. In visual perception, what an individual chooses to focus on among numerous surrounding images is critically important. For example, students are generally more responsive to bright, vivid colours, while pastel tones tend to attract less attention. Cognitive processes play a key role in shaping visual perception, as a child's ability to interpret and make sense of images is strongly influenced by their prior knowledge and life experiences (Unal & Demirel, 2024).

In this study, students were tasked with explaining 37 symbols employed in visual representations of various digestive processes. The subsequent assessment of their achievement was conducted on a scale ranging from 1 to 4, with 1 representing a beginning and 4 signifying an advanced level. As illustrated in Figure 1, the results obtained demonstrate that only scores 1 (beginning), 2 (developing), and 3 (proficient) are present in the score distribution, with no student achieving a score of 4 (advanced).



**Figure 1.** Percentage of responses for ability to identify visual elements

The distribution of scores in Figure 1 indicated that the majority of students, 30 students (77%), fell into the Developing category, indicating a basic understanding of the visual elements but still exhibiting difficulty in providing a more in-depth explanation. A total of eight students

(20%) were categorized as Beginning, reflecting struggles to recognize even basic visual elements. A mere 3% of the students reached the Proficient level, suggesting that a negligible number of students possessed the necessary proficiency to accurately identify and articulate visual components.

The findings indicate that students' proficiency in identifying visual elements remains suboptimal. The majority of students were in the Developing category, indicating that, while they could recognize basic symbols, they still exhibited difficulty in comprehending and articulating the relationships between visual elements in greater depth. The absence of students in the Advanced category indicates that visual understanding requires further enhancement through the implementation of more effective learning approaches. These approaches may include the use of interactive methods, more intensive practice, or the integration of richer visual media in learning. The students' responses are presented as follows.

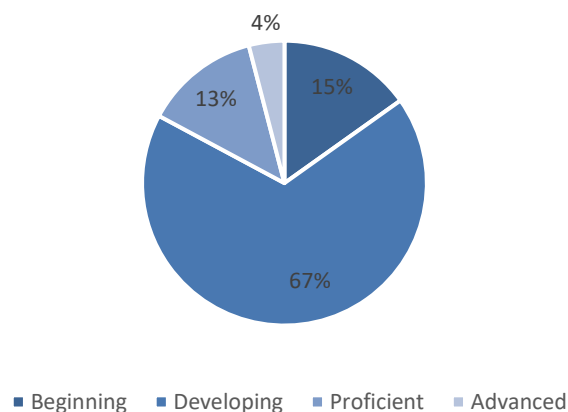
*"There are some parts in the picture, but I don't know what they are. Maybe the stomach is there, but I'm not sure." (Student respondent-score 1)*

*"I can see the stomach and intestines. The big red part must be the stomach. There are also lines, maybe veins?" (Student respondent-score 2)*

*"I can identify the esophagus, stomach, small and large intestines. The different colors help to separate each part." (Student respondent-score 3)*

A comparison of these results with the expected standard reveals the necessity for the refinement of learning strategies, particularly in enhancing students' capacity to read, comprehend, and interpret visual elements with greater depth. In the context of the study of the digestive system, the implementation of more specific interventions, such as the utilization of scaffolding techniques, has been posited as a potential alternative to enhance students' visual comprehension.

The second indicator measured in this study is the students' ability to find and identify concepts contained in the images. In this indicator, students are expected to identify as many concepts as possible contained in the visualization given. The maximum attainable score in this indicator is 80, with an assessment range of 1 (beginning) to 4 (advanced).



**Figure 2.** Ability to understand and interpret the meaning of the visual

According to the findings of the study shown in Figure 2, the score ranges from Beginning to Advanced manifests in the full distribution of students' performance. The majority of students, specifically 26 students (67%), fell into the Developing category, indicating a basic interpretation of visual elements but with limited insight or only partial understanding. This was followed by six students (15%) in the Beginning category, who demonstrated difficulty explaining the meaning or function of visual elements. Additionally, five students (13%) reached the Proficient level, showing

that they were able to interpret visual elements correctly and explain their purpose in context. Conversely, only two students (4%) achieved the Advanced category, signifying a deep, insightful interpretation that connects visual elements to broader meaning or context. The following examples illustrate the students' responses.

*"I think food goes into the stomach and stays there. I don't know what happens after."* **(Student respondent-score 1)**

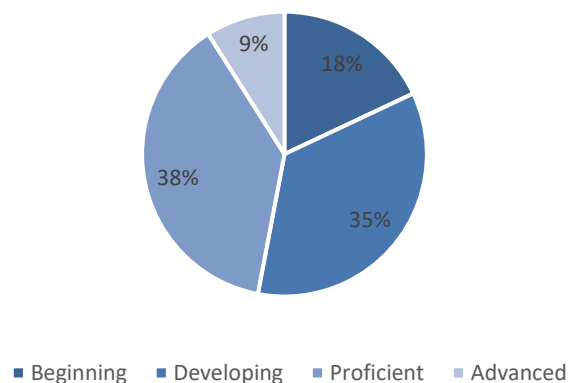
*"Food goes from the mouth to the stomach, then to the intestines. It probably just gets digested there."* **(Student respondent-score 2)**

*"The food travels from the mouth, through the esophagus into the stomach, where digestion begins, then continues into the intestines where nutrients are absorbed."* **(Student respondent-score 3).**

*"The image shows the entire process: ingestion in the mouth, propulsion through the esophagus, chemical breakdown in the stomach, absorption in the small intestine, water reabsorption in the large intestine, and waste elimination. Each stage is represented with visual cues like directional arrows and organ-specific textures."* **(Student respondent-score 4)**

A thorough examination of the distribution of these scores reveals that the achievement on this indicator has surpassed that of the previous indicator. This phenomenon is evidenced by the persistent ability of a select number of students to attain the Advanced category, despite the overall rarity of such achievements. The presence of students who reached the Proficient and Advanced levels suggests that a subset of students has demonstrated an adequate comprehension of the concepts presented in the images. However, it is noteworthy that the majority of students remain in the Developing category, indicating a need for further growth in this domain. Consequently, a more effective learning strategy is required to enable students to identify and comprehend concepts more profoundly through visual aids.

The next indicator assessed was students' ability to evaluate images or visual elements. In this task, students were asked to express their interpretations and pose questions based on the visual materials provided. Scores ranged from Beginning to Advanced (1 to 4).



**Figure 3.** Percentage of Responses for the Ability to Evaluate an Image or Visual Element

Based on Figure 3, the results revealed that 38% of students were in the Proficient category, and 35% were in the Developing category, indicating that most students demonstrated a moderate ability to critically assess visual content. However, only 9% achieved the Advanced level, reflecting strong critical thinking supported by clear reasoning and evidence. Meanwhile, 18% were classified as Beginning, highlighting ongoing difficulties in interpreting visual information. Compared to previous indicators, this one showed a relatively balanced distribution, suggesting that while many

students have a fair level of visual evaluation skills, there remains a need for improvement. Therefore, instructional strategies that emphasize visual analysis and interpretation should be further integrated into the curriculum to support students' development in this area. An overview of the students' responses is provided below.

*"I don't know if the picture is good. It looks confusing to me."* **(Student respondent-score 1)**

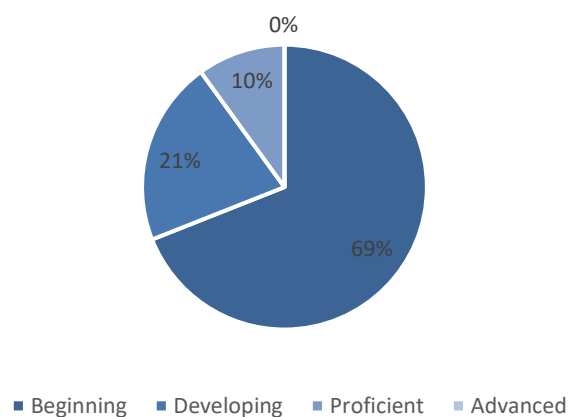
*"The picture is okay, but some parts are hard to understand, like the small intestine—it's too squiggly."* **(Student respondent-score 2)**

*"The image clearly shows each part of the digestive system, but labeling could be clearer and the arrows could be more visible."* **(Student respondent-score 3)**

*"The visualization is well-structured, with accurate proportions and color coding that enhances understanding. However, it could be improved with simplified annotations for younger students or animation to show movement through the tract."* **(Student respondent-score 4)**

The fourth indicator measured in this study is students' ability to process, transform, and present visual information into text. In this indicator, students are tasked with elucidating the meaning or information contained in the picture, either in paragraph or table form. The explanation provided must be systematic, accessible, and congruent with the intended meaning to be communicated through the visualization. This skill is closely linked to representational competence, which involves expressing the same concept in various formats, such as verbal, graphical, numerical, or through different formulas (Ainsworth, 2018; Fatmawati, 2022). Individuals with strong representational skills are characterized by their ability to convey information in a clear, efficient, and accessible manner (Ainsworth, 2018; Schnotz, 2014).

The use of multiple modalities benefits learners who actively engage with information, focusing not just on pictures and text, but on both depictive (iconic) and descriptive (symbolic) forms of representation. Research indicates that when teachers guide students in negotiating different representational forms, it can lead to deeper learning by fostering (a) a more robust conceptual understanding and (b) greater insight for teachers into students' thought processes (Prain et al., 2009). Despite these benefits, studies reveal that many students have yet to fully develop these skills. Often, they compile representations of complex scientific concepts passively, and their ability to translate these ideas into more comprehensible forms remains limited (Hwang et al., 2007).



**Figure 4.** Percentage of responses for ability to process, transform, and present information in various forms

The results of the study shown in Figure 4 indicated that the range of scores on this indicator was from Beginning to Proficient, with no student achieving the Advanced level. The majority of

students, 69%, were in the Beginning category, suggesting they were unable to reformat or present information from visuals effectively, and their output lacked clarity. Concurrently, 21% of students fell into the Developing category, indicating some attempt to reprocess or represent visual data, although the output was basic or only partially accurate. A mere 10% of the students reached the Proficient level, demonstrating the ability to accurately reformat and present visual information in a verbal form. These findings highlight the need to improve students' skills in transforming visual content into other forms of expression. The students responded as outlined below.

*The students' responses illustrated this approach.*

*"Writes only: "Food goes in mouth and comes out." (Student respondent-score 1)*

*"Creates a short list: "1. Mouth, 2. Stomach, 3. Intestines" with no explanation"*

**(Student respondent-score 2)**

*"Draws a simple labeled flowchart with arrows: "Mouth → Esophagus → Stomach → Small Intestine → Large Intestine → Anus" with short explanations". (Student respondent-score 3)*

A causal inference can be made based on these results, indicating that the achievement of this indicator is lower than that of the previous two indicators. This finding suggests that students continue to encounter difficulties in interpreting information from pictures and representing it in a more systematic and comprehensible form. Consequently, there is a compelling need to enhance the pedagogical methodologies employed, including the incorporation of visual aids such as pictures, structured group discussions, and the utilization of mind mapping techniques to facilitate more effective information organization among students. The implementation of more suitable learning strategies is expected to enhance students' capacity to transform visual information into written text.

### **An analysis of the relationship between visual media quality and visual literacy**

This established relevance connects the quality of visual media with students' visual literacy, providing a foundation for empirical analysis. To examine the strength and nature of this relationship, statistical tests were conducted using SPSS software. The analysis focused on three key metrics: the correlation coefficient, the coefficient of determination, and the regression equation. Table 2 presents the results of this analysis.

**Table 2.** SPSS calculation results for correlation coefficient, coefficient of determination, and regression equation

<b>Independent variable</b>	Quality of Visual Media
<b>Dependent variable</b>	Visual Literacy
<b>Sig</b>	0,004
<b>Correlation Coefficient</b>	0,45
<b>Determination Coefficient</b>	20%
<b>Regression Equation</b>	$Y = 0,1 + 0,78 x$

The subsequent discussion will be structured around five primary aspects of the findings. Initially, the value of 0.004, which is less than 0.05, signifies a substantial correlation between students' visual media quality and their visual literacy. Secondly, the correlation coefficient of 0.45 indicates that the relationship between the two variables is in the medium category. Thirdly, the coefficient of determination of 20% indicates that the quality of visual media contributes 20% to students' visual literacy, while the remainder is influenced by other factors not examined in this study. Fourthly, the regression equation suggests a prediction of an increase in students' visual literacy of 0.78 for each unit increase in visual media quality. The positive sign (+) on the Pearson correlation coefficient indicates that the relationship between the two variables is unidirectional,

meaning that an increase in the quality of visual media corresponds to an increase in students' visual literacy.

This finding underscores the significant impact of visual media quality on students' ability to interpret and understand visual information. It lends strong empirical support to the notion that incorporating high-quality visual media in educational contexts is crucial for fostering visual literacy. As visual literacy is increasingly recognized as a vital component of 21st-century learning, its improvement is closely linked to enhanced academic outcomes across disciplines (Faridha et al., 2023; Schoonover, 2021). For instance, Uminski et al. (2025b) found that 97% of participants (34 out of 35) demonstrated misconceptions about chromosome structure and function, misconceptions that only became evident through students' drawings or explanatory visuals.

This highlights the importance of visual literacy not only in science education but also in diagnostic assessment and conceptual understanding. Therefore, integrating visual literacy instruction into the curriculum, using diverse and well-designed visual models, and explicitly teaching students how to decode and apply abstract visual conventions is essential. Educators must also place greater emphasis on the pedagogical quality of visual media, as teaching strategies that incorporate visual analysis have proven effective in strengthening visual literacy skills across various educational levels.

## CONCLUSION

This study affirms that the quality of scientific visualizations significantly influences students' visual literacy and conceptual understanding in biology, particularly regarding abstract topics like the digestive system. The findings reveal a moderate positive correlation ( $r = 0.45$ ) between students' perceived quality of visual media and their visual literacy levels, with media quality accounting for 20% of the variance. Despite expert evaluations rating the visuals as high quality, students perceived them as only moderate, highlighting the gap between technical design standards and learners' cognitive and perceptual needs.

Moreover, students predominantly demonstrated only basic proficiency in visual literacy, with few reaching advanced levels across the four core indicators: identification, interpretation, evaluation, and transformation of visual information. These results underscore the necessity of integrating well-designed, pedagogically informed visual materials into instruction, while also providing direct visual literacy training to enhance students' ability to decode and apply visual representations effectively.

To foster meaningful learning, educators must not only ensure the visual quality of educational media but also explicitly teach the skills required to interpret and construct visual information. By doing so, biology education can move beyond rote content delivery to cultivate deeper understanding and critical engagement with visual scientific information, skills essential for success in today's visually driven and information-rich world.

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