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The effect of hots-based question stimulus types and learning styles on students' cognitive response, thoroughness, and conceptual understanding in biology learning

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ABSTRACT

This study aimed to analyze the effects of higher-order thinking skills (HOTS) question stimulus types and students' learning styles on cognitive response, thoroughness, and conceptual understanding. The research involved 340 eleventh-grade high school students from three schools in West Nusa Tenggara Province, Indonesia. The stimulus types included narration, table, picture, and chart while learning styles were categorized as visual, auditory, and kinesthetic using a 4x3 factorial experimental design. Data on learning styles, cognitive response and thoroughness were collected through questionnaires while conceptual understanding was assessed through tests. Data analysis was performed using MANOVA in SPSS 26.0. Results revealed that stimulus types significantly influenced conceptual understanding ($\eta^2 = 0.289$) with narration stimuli yielding the highest scores but had no significant effect on cognitive response or thoroughness. Learning styles significantly affected thoroughness ($\eta^2 = 0.031$) and conceptual understanding ($\eta^2 = 0.036$) with kinesthetic learners demonstrating the highest thoroughness followed by auditory learners. Additionally, the interaction between stimulus types and learning styles significantly affected cognitive response ($\eta^2 = 0.048$) but not thoroughness or conceptual understanding. These findings suggest that teachers should integrate diverse HOTS question stimuli and consider learning styles to enhance thoroughness and higher-order thinking skills. Future research should replicate this study with larger, diverse samples and explore similar interactions in other subjects to broaden the applicability of the findings.

Contribution/Originality: This study uniquely explores the interaction between HOTS-based questions stimuli and learning styles in biology education. Findings reveal that narration stimuli enhance conceptual understanding, kinesthetic learners exhibit greater thoroughness, and stimulus-learning style alignment influences cognitive response, offering empirical insights for personalized instructional strategies to optimize student learning outcomes.

1. INTRODUCTION

1.1. Research Background

Science education, particularly biology subject is one of those effective tools to prepare the youth to fit into the key positions that would need resilience in problem-solving in globalized societies with their fast-paced technological growth and complex socioeconomic issues of the late 21st century. In global educational reform, higher-order thinking skills (HOTS) has become a hot issue in Indonesia (Ichsan et al., 2019). These HOTS consist of high-level cognitive skills such as analysis, evaluation and creation, and the ability to solve problems critically and think creatively which are important to solve increasingly complex real-world problems (Aba-Oli, Koyas, & Husen, 2024; Yusuf & Widyaningsih, 2022; Zhou, Gan, Chen, Wijaya, & Li, 2023).

Since 2010, the 21st century education platform has been implemented as a new educational paradigm in Indonesia, including and promoting curricula that promote HOTS (Yusuf, Suhirman, Suastra, & Tokan, 2019) in achieving education that is on par with the globe. HOTS within biology education is relevant because biology is a subject that is relatively hard to study and needs a scientific process. Students are called not only to grasp fundamental concepts but also to apply knowledge to novel situations, analyze complex biological phenomena and create innovative solutions to environmental problems (Nauli, Harisman, Armiati, & Yerizon, 2024). However, research indicates that many Indonesian students still find HOTS questions challenging, especially in science subjects such as biology (Armala, Fauziati, & Asib, 2022; Hariadi et al., 2022; Susantini, Isnawati, & Raharjo, 2022).

The types of stimuli used in questions and students' learning styles are key factors that contribute to these challenges. The question, stimulus, and task can all differ by form including narrative, images (e.g., figures, and charts), tables, or graphs which affect the way students process information and respond to questions (Lee, Seong, Choi, & Lowder, 2019). However, stimuli presented in HOTS assessments as well as assessments in PISA and National Science Competitions are widely used as building blocks for engaging students cognitively. According to previous study arguments (Wang & Wei, 2024) the incorporation of visual elements as part of test item formatting can be conducive to the development of high-order cognitive skills.

The student learning style (visual, auditory or kinaesthetic) is another parameter that affects cognition and the performance of academic competencies. Aligning instructional approaches with learners' strengths can increase motivation and success (Leasa, Corebima, & Batlolona, 2020). However, the relationship between learning styles and academic performance can be inconsistent and is often affected by environmental or contextual factors (Aslaksen & Lorås, 2019). The influence of a questions and stimuli method of learning was that when a person asks a question before being presented with something related to it, their cognition differs, and they have a better understanding of the subject. The use of text-based stimuli may privilege students who think verbally, potentially limiting their engagement during these tasks while limiting the engagement of more visually focused learners such as graph- and model-based figures (Hwang, Wang, & Lai, 2021).

Students' response to HOTS-based questions is a significant predictor of cognitive response, thoroughness, and conceptual understanding. Cognitive or mental responses are behaviours that involve internal cognitive factors such as receiving, processing, storage, and application of information to find solutions through problem-solving behaviour (Flanagan & Dixon, 2014). inclusive of metacognition, conceptual understanding, and scientific reasoning (Sweller, Van Merriënboer, & Paas, 2019; Zohar & Dori, 2012). Similar to tasks that may require analysis and troubleshooting in biology increasingly, thoroughness or students being attentive to detail and working systematically is also a key contributor (Cheng, Coolkens, Ward, & Iserbyt, 2021).

There is a dearth of information regarding the interactions between two types of HOTS stimuli (logical reasoning or physical manipulation) and learning styles on cognitive response, thoroughness, and conceptual understanding in the context of biology education despite significant studies on HOTS, learning styles, and academic performance. Other studies examine single aspects, like the impact of learning styles on achievement (Awla, 2014) or stimuli in the development of critical thinking (Choi, Kim, & Lee, 2021). Therefore, this study is devoted to fill this gap by exploring the HOTS question stimuli (narration, table, picture and chart) in association with students' learning styles in affecting high school biology cognitive response, thoroughness and conceptual understanding.

1.2. Research Questions

This study seeks to answer the following research questions:

1. Do different types of HOTS stimuli significantly affect students' cognitive response, thoroughness, and conceptual understanding?
2. Are there differences in these outcomes among students with visual, auditory, and kinaesthetic learning styles when engaging with various HOTS question types?
3. Does the interaction between HOTS stimuli and learning styles significantly influence students' cognitive response, thoroughness, and conceptual understanding?
4. How do HOTS stimuli and learning styles predict these outcomes in biology learning?

1.3. Significance of the Research

This research can contribute to the development of biology learning strategies, particularly in the implementation of HOTS in secondary schools. The study of the interaction between different types of stimuli and students' learning styles can support teachers in understanding how these combined elements affect the cognitive processes of the students, their thoroughness, and their conceptual understanding. The outcomes will add to the literature in science education as well as provide them with empirical data to create better learning devices that are tailored to further influence various learning styles of students and eventually improve the overall teaching as a whole and the learning outcomes.

Moreover, this study has important practical implications in the context of designing 21st century science education policies which emphasizes higher-order thinking skills. These findings are expected to be a useful reference for policymakers, curriculum developers, and teachers because they could provide empirical evidence on how HOTS stimulus and learning style influence cognitive performance and concept understanding. This, in turn, supports global goals to improve educational competitiveness and place students to address the diverse needs of an evolving world.

2. LITERATURE REVIEW

2.1. Higher- Order Thinking Skills

Higher-order thinking skills (HOTS) is one of the most focused on in modern education which implies the necessity for learners to process information in a manner that goes beyond memorization and recall. According to previous study arguments (Cantona, Suastra, & Ardana, 2023; Suhirman & Ghazali, 2022), HOTS are a type of thinking act that is being used to evaluate problem-solving and critical thinking. They are thinking act such as analysis, evaluation, and creation. In the 21st century, it plays a significant role in education where students are trained on how to utilize knowledge using out-of-the-box thinking (Maxnun, Kristiani, & Sulistyaningrum, 2024).

One widely cited framework is Bloom's taxonomy (Bloom, 1956) which organizes cognitive skills hierarchically. Renowned cognitive researchers such as Krathwohl and Anderson (2010) updated it by considering it as a taxonomy of cognitive processes, which they delineated into six levels: remembering, understanding, applying, analyzing, evaluating, and creating. The top three of the six cognitive levels—analyzing, evaluating, and creating are categorized as HOTS, and differ from the lower-order thinking skills (LOTS) which are the bottom three of the six levels (Krathwohl & Anderson, 2010). This taxonomy is not only used as a model for building curriculum but also as a framework for categorizing and supporting higher-order thinking in students by teachers. Studies show that HOTS is necessary for students to improve their academic performance and also solve complex problems (Tamboto, 2022). Studies support this finding apply through HOTS learning activities that lead students to analyze, evaluate, and create data (Zaiful Shah & Zakaria, 2024). Moreover, HOTS focused on describing higher-order thinking skills that match the latest education reform that demands student-centered in which students behave actively (Yurniwati & Soleh, 2020).

Various pedagogical strategies have been used in educational implementations of HOTS, including project-based learning, inquiry-based learning and the deployment of technology (de Oliveira Biazus & Mahtari, 2022; Huang, Silitonga, Murti, & Wu, 2023; Suryati, Pangga, Habibi, & Azmi, 2025). The implementation of these types of methods effectively creates high motivation and student interaction, and active learning, and strategic skills in the context of the present and future (Prayogi, Bilad, Verawati, & Asy'ari, 2024). In terms of HOTS assessment in education, it is also recognized for teachers to prepare an assessment device to measure HOTS (Melawati, Rochmiyati, & Nurhanurawati, 2022).

2.2. HOTS-Based Question Stimulus Types

Various types of question stimuli such as narrations, tables, pictures, and graphs are effective and practical ways to assess and develop HOTS. Different types serve different educational aims and can greatly enhance students' cognitive engagement and critical thinking skills. This is where narrative stimuli excel at providing context for HOTS inviting students to contextualize processes through identifying character, plot, and theme. If students are presented with a story, they might be asked to analyze character motivations or the meaning of specific happenings within a narrative. This approach will allow students to understand the narrative better, as well as encourage them to relate to it in real-life and develop their stream of consciousness (Setyowati, Priyambudi, & Dewanto, 2023). In addition, narratives could be structured that encourage students to engage in evaluative thinking as they navigate various viewpoints and consequences (Rahmawati et al., 2023).

Tables are a handy mechanism for codifying data and presenting side-to-side comparisons. For example, students can be asked to articulate what the information shows, identify trends, and hypothesize what might occur based on what they have learned from the data given a set of tabular data. The stimulus encourages higher-order thinking where students have to integrate the information and judge whether it is relevant for answering the question or hypothesis they formulate (Santosa et al., 2024). Students can be inspired to practice comparison and contrast in ecology by using images such as a chart (Margana & Widyantoro, 2017).

Visual stimuli like pictures can help support learning of HOTS as they allow students to analyze and evaluate visual data. Requiring students to critically engage with a picture, to analyze elements such as background and contextualization, symbolism, or attention to potential biases inherent in visual representation (Gil-Glazer, Walter, & Eilam, 2019). A picture can also motivate creative thinking because instructions can be given in a way that participants are encouraged to invent stories or even hypotheses from a picture (Taslim, Suaedi, & Ilyas, 2021).

Visual data representation, like graphs is very effectively used in HOTS development through analysis and interpretation. Students need to analyze trends, make inferences, and draw conclusions based on the data represented (Khairunnisa, Sitohang, & Nurmayani, 2023) when presented with graphs. For example, a graph illustrating climate change data can initiate a critical discussion for students regarding the impact of elevated temperatures as well as possible solutions to reduce the negative effects on the environment. Such attempts not only improve the students' critical approach but also the application of their knowledge to real-world problems (Hamzah, Hamzah, & Zulkifli, 2022).

2.3. Learning Styles

Learning styles are the preferred ways in which people absorb, process, and retain information. Visual, auditory, and kinesthetic learning styles are among the most widely recognized (Leite, Svinicki, & Shi, 2010; Sayed, Khafagy, Ali, & Mohamed, 2024). An important concept for the educational sector because knowing these styles will help teachers adapt their teaching methods to the needs of those attending classes, which will also influence the results in learning. A visual learner prefers visual aids to help them with their comprehension and retention. Such as diagrams, charts, graphs, and images, students with a visual learning style are likely to receive information better if it is presented to them visually (Husin & Sii, 2020). Visual aids serve the purpose of a clear understanding of complex concepts (Isa, Omar, Fatzel, Ghazali, & Anas, 2021) and create interest and engagement in such learning processes. Using multimedia resources and facilitating visual note-taking techniques (Ibrahim & Hussein, 2016) can help teachers in working with visual learners.

This means that auditory learners do the best when information is presented in a sound form. This encompasses everything from lectures and discussions to audio recordings. These learners benefit from listening to explanations using verbal interactions (Arrang et al., 2024). Auditory learners have been shown to perform poorly in a traditional reading-based curriculum while doing very well in settings that involve listening to and discussing materials (Agreda, Trinos, & Francisco, 2020; Purwasih, Turmudi, Dahlan, & Ishartono, 2024). It can also include oral communication through group discussions and oral presentations suitable for auditory learners. Moreover, teachers can encourage auditory learners by reading aloud or engaging in class arguments and discussions (Agreda et al., 2020).

Kinesthetic learners learn best through doing things and hands-on experience. They learn more effectively when they are able to move or manipulate materials (Muhaimin, Mukhibin, Mitrayana, & Dasari, 2022). The beauty of this style of learning is that it encourages getting hands-on experience in the process. Kinesthetic learners generally excel in things that utilized hands-on experience, e.g., science experiments (Samarakoon, Fernando, Rodrigo, & Rajapakse, 2013). Teachers can try to add activities like role-playing, simulations, and interactive projects for kinesthetic learners. In order to help students to learn better, offer them a chance to move while learning, let them learn or move during the learning process (Gilakjani, 2012; Nadhiroh, 2023).

2.4. Cognitive Response

Cognitive response is a range of mental processes where the information processing, working memory, attention and focus, decision-making, problem-solving and emotional regulation are some of the key components of cognitive response. Each of these elements contributes to how people engage with their space and interpret their surroundings. It focuses on information processing from how people perceive and interpret to store information. It entails processes such as encoding, information storage, and retrieval. According to information-processing theories, individuals actively build their understanding of the world by filtering and sorting through incoming information based on previous knowledge and experiences (McAvinue et al., 2012; Riviere & Brisson, 2014). Learning only occurs when new information can be integrated with previous knowledge and requiring effective information processing (Rivière, Cordonnier, & Fouasse, 2017).

Cognitive response is important in tasks that require integrating new information with already encoded knowledge (Kawahara & Kihara, 2011). According to research, working memory capacity contributes greatly to perform tasks that involve attention and problem-solving in general (Zivony & Lamy, 2016). For example, individuals with higher working memory capacity perform better in academics because they can handle and manipulate information more adequately (Woo, Park, Lee, & Kweon, 2018).

Attention is the ability to concentrate on something in the environment while ignoring the rest of the sensory world. It is characterized by subsystems of selective attention, sustained attention, and divided attention (Zhao & Zhang, 2018; Zhu et al., 2023). Selective attention is the capacity of individuals to focus on information that is relevant and ignore distractions, an essential element of efficient learning and task execution (Hanania & Smith, 2010). Recent research on attentional capacity has shown that it is not a fixed quantity but can instead vary across a lifetime, including through cognitive load (Slessor, Finnerty, Papp, Smith, & Martin, 2019). Sustained attention, (the ability of maintaining attention over a long period) is necessary for performances that require continuous focus over a few hours, such as studying, problem-solving, and complicated tasks (Yang, He, Gao, Deng, & Smola, 2016).

Regardless of the case, problem-solving is a mental process and this involves identifying, analyzing and resolving various kinds of complex issues. It typically includes a series of steps: problem identification, solution generation, alternatives analysis, and problem solution (Schmidt, Rotgans, & Yew, 2011). Problem-solving skills are a combined set of cognitive skills such as critical thinking, creativity, and applying knowledge to the practical world. According to previous studies, the individual who adopts a structured approach to problem- solving tends to reach good solutions (Agustina, Zubaidah, & Susanto, 2024).

Decision-making is the act of choosing a course of action among several alternatives. This process includes evaluating trade-offs and benefits as well as risks and personal values (Lu, Xiong, Parikh, & Socher, 2017). The final component of cognitive response is emotional regulation, which comprises the processes through which individuals influence pending emotions, including how they experience and express emotions. Such strategies may involve methods such as cognitive reappraisal in which one approaches the situation in a different light to alter its emotional meaning or suppression in which emotional expression is minimized (Liu, Yu, Shi, & Ma, 2023; Zhang, Liu, & Lee, 2021). Research has revealed that emotional regulation is a prominent predictor for continued positive development in various life domains, including educational, mental health-related, and socialization outcomes (Tang & He, 2022; Zhao, Fu, Lian, Ye, & Huang, 2021). Students who have good skills in regulating their emotions tend to do better than others academically (De Neve, Bronstein, Leroy, Truyts, & Everaert, 2023; Hilliard, Donelan, Heaney, Kear, & Wong, 2023) because they're better equipped to manage stress and focus on the task when work gets tough.

2.5. Thoroughness

Thoroughness is a learning framework that includes preparation, process, verification, and awareness. The preparation phase includes defining learning goals and collecting resources needed before engaging in the learning activity. By preparing well, you set the foundation for more effective learning experiences, allowing students to engage in tasks with confidence and understanding. It has been shown through research that students who adopt role-playing in the preparation before starting a task tend to lead to better academic performance as they draw on skills in focusing on the problem, selecting the right strategy, allocating attention, etc. as opposed to their peers who did not use role-playing, where this is shown to guide the student for optimal problem-solving during the learning process (Hatifi, Qatey, & Qadiri, 2022). Such a proactive approach does not only helps the understanding of topics in the study but also ensures that the students feel responsible for their learning path.

The very process of teaching involves active practice and the use of multiple strategies to help understand and remember facts. In this phase, learners are encouraged to use metacognitive strategies that include planning, monitoring and evaluating their learning processes (Li et al., 2024; Nosratinia, Saveiy, & Zaker, 2014). Such active engagement empowers students to refine their methods based on feedback and self-evaluation, resulting in enhanced understanding and command of the content. In addition, the use of technology and collaborative learning can enrich the learning process by allowing students to share insights and learn from one another (Imron, Zaharuddin, Susanti, & Imamuddin, 2022).

These components are necessary as they ensure that the learning is comprehensive, verifiable and aware. The third is verification in which an individual evaluates what he/she understood and assesses his/her progress through reflection and feedback to be sure that he/she has met learning objectives (Bahari, Widodo, & Winarno, 2020; Thaintheerasombat & Chookhampaeng, 2022). The practice not only solidifies knowledge but allows you to know what area to focus on. Meanwhile, self-awareness is defined as the capability to recognize the familiarity and emotional reactions of one's strengths and weaknesses in learning (Bektas et al., 2021). It also benefits the learners in consuming knowledge and managing their feelings to motivate themselves and be more resistant toward the setbacks (Khodaei, Hasanvand, Gholami, Mokhayeri, & Amini, 2022). This allows teachers to use what they learn about their students to help build awareness of the students' own learning so they can become better, more independent learners.

2.6. Conceptual Understanding

In science learning, conceptual understanding means students have sufficient knowledge and understanding of a scientific concept to transfer their learning into real-world applications. It goes beyond the knuckle-dragging memorization of facts, encouraging learners to focus on the role of cause and effect, and the relationships between the elements of scientific content. Concepts have an important place in the science curriculum as research shows that achieving conceptual understanding is important for students to engage productively with scientific concepts and develop critical thinking (Kervinen, Roth, Juuti, & Uitto, 2020). Strategies like these — inquiry-based learning, contextualized learning have been shown to improve students' conceptual understanding by prompting students to investigate, question, and relate scientific concepts to everyday life (Salvetti, Rijal, Owusu-Darko, & Prayogi, 2023).

Over time, through active engagement, explorations, and reflection, learners develop deeper concepts and conceptual understanding, which are essential for mastering scientific principles. Learners need to engage with the knowledge and discuss the resources that challenge their ideas and misconceptions (Addido, Burrows, & Slater, 2022; Gunhaart & Srisawasdi, 2012). Engaging students allows them to construct knowledge through hands-on, experience-based, and collaborative learning formats — all of which are instrumental in solidifying their understanding of scientific concepts.

Assessment of conceptual understanding and verification are part and parcel of the learning process. They should employ multiple assessment strategies to assess students understanding and misconceptions that can arise (Khery et al., 2020; Zacharia, 2007). Some of their evidence may consist of tools such as concept maps or reflective journals, which offer insight into how students are thinking, gives teachers the opportunity to change their teaching strategy (Fudin & Purwandari, 2021; Leonor, 2015). This has important ramifications for ensuring students remain scientifically literate and are able to make sound scientific decisions in their daily lives (Rani, Wiyatmo, & Kustanto, 2017; Southerland, Johnston, & Sowell, 2006) and be successful in achieving their educational aspirations in science but it makes it difficult to transfer specific knowledge given the limited time available to learn as much as they can.

3. METHODOLOGY

3.1. Research Design

This study employed a quasi-experimental design using a 4x3 factorial framework to investigate the effects of two independent variables and their interactions on students' outcomes in biology learning. The first independent variable is HOTS question stimulus types (narration, table, image, and graph). The second independent variable is students' learning styles with three conditions: visual, auditory and kinaesthetic. This design allows the research to explore not just the main effects of each variable but also the interaction effects between the types of stimuli and learning styles through the use of a factorial framework.

Participants are divided into groups. Each had a combination of two independent variables under a 4×3 factorial design. In other words, students are classified according to their preferred learning style, and then allocated to one of the HOTS four stimulus conditions. Having such a structure leads to 12 different experimental conditions (i.e., 4 stimulus types × 3 learning styles), and thus different learning styles could be taken into consideration in observing the effects of each stimulus type. The dependent variables included cognitive response, thoroughness, and conceptual understanding in biology. This design allowed for the exploration of the main and interaction effects of the independent on the dependent variables.

The experiment was conducted in the following three phases: pre-test, intervention and post-test. During the pre-test phase, students' learning styles were identified. In the intervention phase, four classes in each school were assigned different types of HOTS stimuli. In the post-test phase, cognitive response, thoroughness, and conceptual understanding were assessed using validated instruments. Data analysis involved both descriptive and inferential statistics.

3.2. Participants

The study involved 340 eleventh-grade students from three senior high schools (SHS) in West Nusa Tenggara Province, Indonesia: SHS-2 Pujut in Central Lombok, SHS-2 Bayan in North Lombok, and SHS-NW (Nahdlatul Wathan) Narmada in West Lombok. These schools were selected to ensure geographic diversity. Participants were selected through cluster random sampling yielding a total of 12 classes with four classes assigned to each stimulus type.

The sample represented a diverse group of students in terms of their learning styles (visual, auditory, and kinaesthetic), ensuring a balanced distribution across the experimental groups. This diversity provided a representative dataset to analyze the interaction effects of HOTS stimuli and learning styles on the dependent variables.

3.3. Research Procedures

This was followed by a pre-test when students filled out a form on a learning styles questionnaire based on which they were classified into different learning styles. This tool was modified from Sayed et al. (2024) indicator, which can then be adjusted to fit the local Indonesian context. The pre-test served to classify participants not just on whether the students were visual, auditory, or kinaesthetic learners but was also used to classify students for other experimental conditions moving forward. This was the first step to ensure that the learning style of every student has been recorded precisely for its in-depth analysis to see how these styles interact with one or the other HOTS stimuli.

After the pre-test, the study continued with the intervention. Students in this phase were grouped into four groups based on the four types of HOTS question stimuli (narration, table, image, and graph). Subsequently, both groups were administered a HOTS biology assessment task which was carefully developed following the revised Bloom's Taxonomy (Krathwohl & Anderson, 2010). The test consisted of 15 multiple-choice questions and three essay questions related to ecosystems and environmental change. The preparatory framework of the test was shaped to activate high-order cognitive processes in the students without bounding them to a fixed type of question stimuli through matching to Bloom's Taxonomy.

After the intervention, the post-test phase was performed where students were asked to fill out cognitive response and diligence questionnaires. Instruments were adapted from earlier studies to measure students' mental processes, problem-solving, and systematic approaches to HOTS questions (Thomas, 2012; Zohar & Dori, 2012). Data collection after the test served as a critical component in analyzing the immediate influence that the varied stimuli and learning styles had on students' cognitive functionality and conceptual comprehension. The three phases together comprised a rich framework for addressing the relationship between HOTS stimuli and learning styles in a systematic and rigorous way.

3.4. Research Instruments

The main instruments consisted of HOTS biology tests, a learning styles questionnaire, a cognitive response questionnaire, and a thoroughness questionnaire. Hot tests were based on the revised Bloom's taxonomy and contained the four stimulus types utilized in this study. The tests assessed higher-order thinking skills using both multiple-choice and essay formats.

The learning styles questionnaire adapted Sayed et al. (2024) validated instrument for the Indonesian context, consisting of 15 items measured on a 4-point Likert scale to classify students as visual, auditory or kinaesthetic learners. The cognitive response questionnaire adopted from previous studies (Thomas, 2012; Zohar & Dori, 2012) measured six aspects which are as follows: information processing, working memory, attention, problem-solving, decision-making, and emotional regulation using 12 items. The thoroughness questionnaire addressed the following four aspects: preparation, process, verification, and self-awareness which consisted of 20 items on a 4-point Likert scale.

All instruments underwent a two-stage validation process. Content validity was established through expert review by two biology education specialists, and construct validity was tested through pilot testing with 93 students. The validation results are summarized in Table 1.

Table 1. The results of the instrument validation.

Instruments	Total item	CVR	r-Pearson	Valid items	Invalid items	r-Cronbach's alpha
HOTS test items	20	0.75	0.32 – 0.63	18	2	0.9
Learning styles questionnaire	17	0.88	0.26 – 0.81	14	3	0.88
Cognitive response questionnaire	15	0.73	0.33 – 0.77	12	3	0.80
Thoroughness questionnaire	20	0.85	0.51 – 0.84	20	0	0.98

Some items were excluded due to low validity while the final instruments demonstrated high reliability. The final versions included 18 HOTS test items, 14 learning styles items, 12 cognitive response items, and 20 thoroughness items.

3.5. Data Analysis

Data analysis involved descriptive and inferential statistics. Descriptive statistics summarized key parameters such as mean, standard deviation, variable categorization, and graphical representation. The dependent variables—cognitive response, thoroughness and conceptual understanding were categorized into performance levels to facilitate interpretation. For cognitive response, the performance levels were defined as very good (66–80), good (51–65), moderate (36–50), and poor (20–35). Thoroughness was categorized as very thorough (86–100), thorough (71–85), moderately thorough (56–70), less thorough (41–55) and not thorough ($\leq$40). Conceptual understanding was classified into very good (86–100), good (71–85), (56–70), poor (41–55), and very poor ($\leq$40). These categorizations provided a clear framework for interpreting students' performance across the variables.

Inferential statistics utilized two-way MANOVA to examine the main and interaction effects of stimulus types and learning styles on the three dependent variables. This analysis identified whether the independent variables significantly influenced students' cognitive responses, thoroughness, and conceptual understanding. Post-hoc Tukey's HSD tests were conducted to identify specific group differences when significant effects were detected. Partial eta squared (η^2) was calculated and interpreted based on standard thresholds: weak effect ($\eta^2 < 0.10$), modest effect ($0.11 < \eta^2 < 0.30$), and strong effect ($\eta^2 \geq 0.50$) to measure the magnitude of the effects.

Before conducting MANOVA, assumptions of normality and homogeneity of variance were tested to ensure the validity of the analysis. Normality was assessed using the Shapiro-Wilk test, while homogeneity of variance was evaluated using Levene's test. All statistical analyses were performed using SPSS version 26.0 with the significance level set at $\alpha = 0.05$. This rigorous approach ensured the reliability and accuracy of the findings.

4. RESULTS

Descriptive analysis was conducted on data from 340 students, divided into four HOTS stimulus type groups: narration (86), table (87), picture (71), and chart (96), as well as by learning styles: visual, auditory, and kinaesthetic. Measurements of cognitive response and thoroughness variables were performed immediately after students completed the assigned HOTS test items. The HOTS test results reflected students' comprehension of the tested material. Table 2 presents the descriptive statistics for each variable analyzed. The mean differences for each group are visually presented in Figure 1.

Table 2. Descriptive statistics of students' cognitive response, thoroughness, and conceptual understanding for each HOTS stimulus type.

Variables	Stimulus types	N	Mean	Category	SD
Cognitive response	Narration	86	69.17	Moderate	14.4
	Table	87	69.49	Moderate	9.7
	Picture	71	71.11	Good	8.4
	Chart	96	70.45	Good	9.0
Thoroughness	Narration	86	55.88	Less thorough	12.4
	Table	87	54.20	Less thorough	14.8
	Picture	71	71.11	Thorough	8.4
	Chart	96	58.23	Less thorough	9.8
Conceptual understanding	Narration	86	57.98	Moderate	25.08
	Table	87	27.26	Very poor	13.3
	Picture	71	53.77	Poor	25.6
	Chart	96	31.36	Very poor	19.0

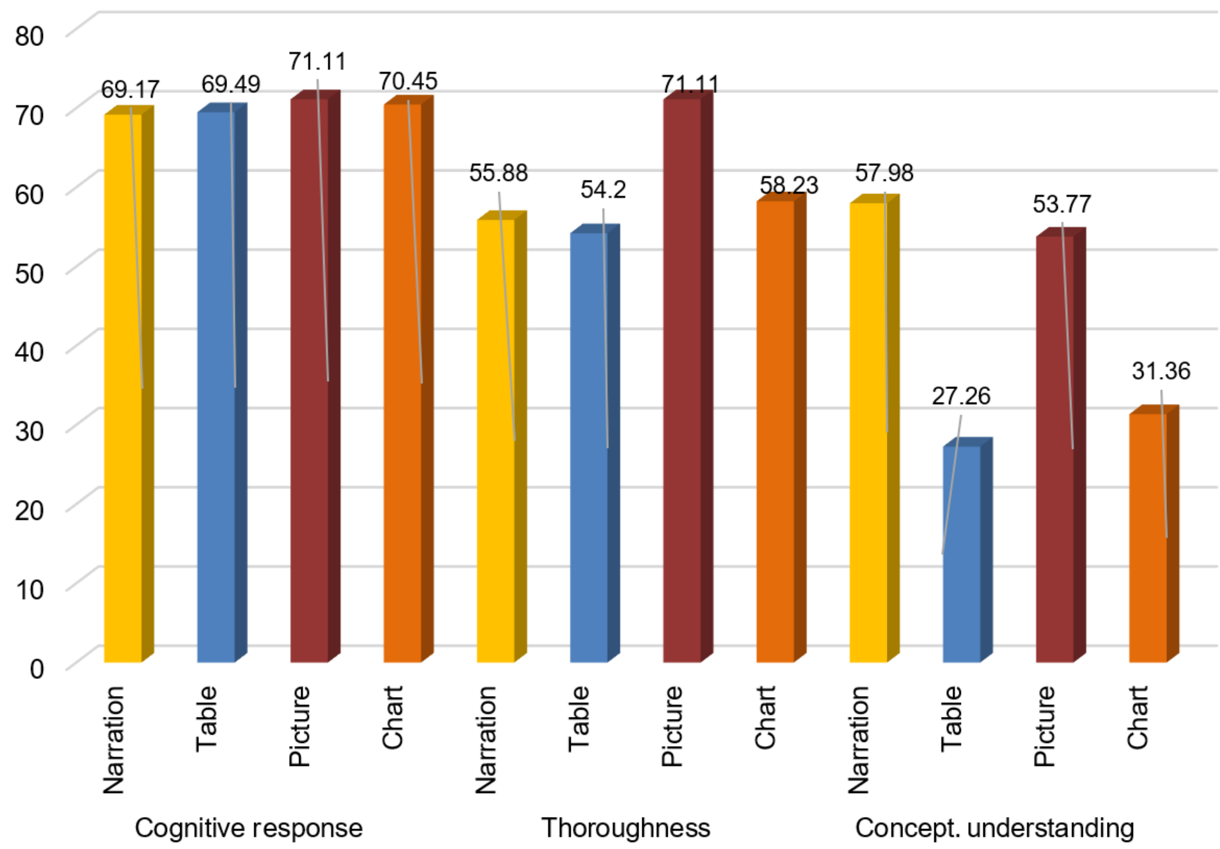

Figure 1. Comparison of mean scores for dependent variables across different HOTS stimulus types.

The differences in the mean scores for the three variables, namely, cognitive response, thoroughness, and conceptual understanding have been exhibited in Table 2 and Figure 1. The highest response at the cognitive level in the group exposed to picture stimuli was rated as "good". Good students can apply concepts and perform analyses effectively. On the other hand, the narration stimuli group, classified as "moderate," demonstrated the lowest cognitive response. The "moderate" category indicates that students understand and can use basic concepts but need help with higher-order analyses.

The highest level of thoroughness was among students exposed to picture stimuli (thorough students) while the lowest was students exposed to table stimuli (less thorough students). In "thorough", students will solve problems methodically and will make very few mistakes due to carelessness. On the other hand, the "less thorough" category suggests challenges in the analysis and evaluation of HOTS questions.

For conceptual understanding, the mean of the highest observed was in the group with narration stimuli where they were categorized as "moderate," then the mean of the lowest was in the group with chart stimuli where they categorized as "very poor." The "moderate" category indicates that students are aware of basic concepts but have difficulty applying them to more complicated contexts. On the other hand, the "very poor" category, means that students have not sufficiently mastered basic concepts.

In addition, this study also finds the difference between students' stimulus of HOTS questions for students who have visual, auditory, and kinaesthetic learning styles. The results of these analyses are reported in Tables 3, 4, and 5.

Table 3. Descriptive statistics of students' cognitive response across HOTS stimulus types and different learning styles.

Variables	Stimulus types	Learning styles	N	Mean	SD
Cognitive response	Narration	Visual	26	70.42	15.4
		Auditory	34	69.97	14.7
		Kinaesthetic	26	66.88	13.5
	Table	Visual	25	66.68	11.2
		Auditory	34	68.05	9.4
		Kinaesthetic	28	73.75	7.3
	Picture	Visual	22	73.86	5.8
		Auditory	28	67.42	9.5
		Kinesthetic	21	73.14	7.4
	Chart	Visual	34	69.70	9.05
		Auditory	29	73.06	7.6
		Kinesthetic	33	68.93	9.8

Table 3 shows that for narration stimuli, students with visual learning styles demonstrated higher cognitive responses compared to the other two learning styles. For table stimuli, students with kinaesthetic learning styles exhibited higher cognitive responses compared to those with visual and auditory learning styles. For picture stimuli, students with visual learning styles had higher cognitive responses than those with auditory and kinaesthetic styles. Meanwhile, for chart stimuli, students with auditory learning styles showed higher cognitive responses compared to those with visual and kinaesthetic styles.

Students with visual learning styles performed better in cognitive responses for HOTS questions with narration and picture stimuli based on Table 3. Students with auditory learning styles excelled in cognitive responses for HOTS questions with chart stimuli, while students with kinaesthetic learning styles demonstrated better cognitive responses for HOTS questions with table stimuli.

Table 4. Descriptive statistics of students' thoroughness across HOTS stimulus types and different learning styles.

Variables	Stimulus types	Learning styles	N	Mean	SD
Thoroughness	Narration	Visual	26	53.19	14.03
		Auditory	34	54.35	11.7
		Kinesthetic	26	60.57	10.5
	Table	Visual	25	53.24	17.80
		Auditory	34	51.38	15.1
		Kinesthetic	28	58.50	10.4
	Picture	Visual	22	52.81	11.4
		Auditory	28	54.25	11.2
		Kinesthetic	21	56.76	13.2
	Chart	Visual	34	56.38	10.7
		Auditory	29	58.62	8.3
		Kinesthetic	33	59.81	10.2

Table 4 indicates a tendency for students with kinaesthetic learning styles to exhibit greater thoroughness compared to those with visual and auditory learning styles. Students with visual learning styles demonstrated less thoroughness than those with kinaesthetic and auditory learning styles when dealing with HOTS questions across all types of stimuli.

Table 5. Descriptive statistics of students' conceptual understanding across HOTS stimulus types and different learning styles.

Variables	Stimulus types	Learning styles	N	Mean	SD
Conceptual understanding	Narration	Visual	26	53.00	26.8
		Auditory	34	65.17	22.3
		Kinesthetic	26	53.57	25.3
	Table	Visual	25	26.96	12.8
		Auditory	34	31.26	13.2
		Kinesthetic	28	22.67	12.6
	Picture	Visual	22	52.72	23.7
		Auditory	28	56.85	27.2
		Kinesthetic	21	50.76	26.4
	Chart	Visual	34	26.08	16.6
		Auditory	29	38.17	22.4
		Kinesthetic	33	30.81	17.2

Table 5 indicates a tendency for students with auditory learning styles to have higher conceptual understanding compared to those with visual and kinesthetic learning styles. Students with kinaesthetic learning styles demonstrated lower conceptual understanding when responding to HOTS questions with picture and chart stimuli.

An inferential analysis was conducted after presenting the data with descriptive statistics. The prerequisites for inferential analysis are presented in Tables 6 and 7.

Table 6. Homogeneity test results.

Variables	Levene statistic	df1	df2	Sig.
Cognitive response	1.038	11	328	0.412
Thoroughness	1.502	11	328	0.129
Conceptual understanding	1.181	11	328	0.319

Table 6 shows that the Levene's test for equality of variances produced a Levene statistic with a sig. value greater than 0.05. Therefore, the groups were determined to have homogeneous variance.

Table 7. Normality test results.

Variables	Stimulus types	Kolmogorov-Smirnov		
		Statistic	df	Sig.
Cognitive response	Narration	0.097	86	0.200
	Table	0.134	87	0.060
	Picture	0.101	71	0.184
	Chart	0.086	96	0.200
Thoroughness	Narration	0.080	86	0.200*
	Table	0.088	87	0.200
	Picture	0.072	71	0.200*
	Chart	0.065	96	0.200*
Conceptual understanding	Narration	0.094	86	0.200
	Table	0.112	87	0.060
	Picture	0.112	71	0.062
	Chart	0.066	96	0.200

Note: *) Indicates that the p-value (Sig.) is greater than 0.200 and has been rounded to 0.200.

Based on Table 7, the four treatments had statistical values with sig. values greater than 0.05. Therefore, the data for all treatments were declared to be normally distributed.

After confirming that the data were normal and homogeneous, hypothesis testing was conducted using MANOVA in SPSS 26.0 to examine the main effects and simple effects at a significance level of 0.05. The results of the analysis are presented in Table 8.

Table 8. Test results of between-subjects effects.

Sources	Dependent variables	Mean square	F	Sig.
Corrected model	Cognitive response	189.859	1.693	0.074
	Thoroughness	266.326	1.777	0.057
	Conceptual understanding	6216.250	14.233	0.000
Intercept	Cognitive response	1631555.391	14549.493	0.000
	Thoroughness	1032947.929	6890.264	0.000
	Conceptual understanding	594198.002	1360.458	0.000
Stimulus types	Cognitive response	90.338	0.806	0.491
	Thoroughness	284.897	1.900	0.129
	Conceptual understanding	19414.879	44.452	0.000
Learning styles	Cognitive response	31.335	0.279	0.756
	Thoroughness	778.417	5.192	0.006
	Conceptual understanding	2679.599	6.135	0.002
Stimulus types* Learning styles	Cognitive response	309.151	2.757	0.013
	Thoroughness	70.562	0.471	0.830
	Conceptual understanding	200.536	0.459	0.838

Stimulus types had a significant effect on conceptual understanding but did not significantly affect cognitive response or thoroughness based on Table 8. Learning styles significantly influenced students' thoroughness and conceptual understanding but did not have a significant effect on cognitive response. The interaction between stimulus types and learning styles had a significant effect on cognitive response but did not significantly influence thoroughness or conceptual understanding. The effect sizes of these variables are presented in Table 9.

Table 9. Effect size analysis.

Sources	Dependent variables	η^2	Category
Stimulus types	Conceptual understanding	0.289	Modest effect
Learning styles	Thoroughness	0.031	Weak effect
	Conceptual understanding	0.036	Weak effect
Stimulus types*Learning styles	Cognitive response	0.048	Weak effect

Table 9 shows that the effect of stimulus types on conceptual understanding falls under the category of a modest effect. This indicates that 28.9% of the variance in conceptual understanding is influenced by stimulus types. The effect of learning styles on thoroughness and conceptual understanding is categorized as a weak effect, meaning that 3.1% of the variance in thoroughness and 3.6% of the variance in conceptual understanding is influenced by learning styles.

Stimulus types and learning styles have a partial eta squared (η^2) value of 0.048 for cognitive response which is categorized as a weak effect. This indicates that 4.8% of the variance in cognitive response is influenced by the interaction between stimulus types and learning styles.

Table 10. Results of multiple comparisons for stimulus types.

Dependent variables	Stimulus types(I)	Stimulus types(J)	Mean difference (I-J)	Std. error	Sig.
Conceptual understanding	Narration	Table	30.724*	3.178	0.000
		Picture	4.214	3.351	0.210
		Chart	26.624*	3.103	0.000
	Table	Narration	-30.724*	3.178	0.000
		Picture	-26.510*	3.342	0.000
		Chart	-4.100	3.094	0.186
	Picture	Narration	-4.214	3.351	0.210
		Table	26.510*	3.342	0.000
		Chart	22.410*	3.271	0.000
	Chart	Narration	-26.624*	3.103	0.000
		Table	4.100	3.094	0.186
		Picture	-22.410*	3.271	0.000

Note: *) Indicates a statistically significant mean difference ($p < 0.05$).

The follow-up multiple comparisons test in Table 10 shows that students who completed HOTS test questions with narration stimuli had significantly better conceptual understanding compared to those who worked on questions with table, picture, and chart stimuli.

Table 11. Results of multiple comparisons for learning styles.

Dependent variables	Learning styles(I)	Learning styles(J)	Mean diff. (I-J)	Std. error	Sig.
Thoroughness	Visual	Auditory	-0.372	1.613	0.818
		Kinesthetic	-4.925*	1.670	0.003
	Auditory	Visual	0.372	1.613	0.818
		Kinesthetic	-4.553*	1.609	0.005
	Kinesthetic	Visual	4.925*	1.670	0.003
		Auditory	4.553*	1.609	0.005
Conceptual understanding	Visual	Auditory	-9.514*	2.752	0.001
		Kinesthetic	0.244	2.851	0.932
	Auditory	Visual	9.516*	2.752	0.001
		Kinesthetic	9.759*	2.747	0.000
	Kinesthetic	Visual	-0.244	2.851	0.932
		Auditory	-9.759*	2.746	0.000

Note: *) Indicates a statistically significant mean difference ($p < 0.05$).

The multiple comparisons test results in Table 11 indicate that students with kinesthetic learning styles demonstrated significantly better thoroughness in completing HOTS test questions compared to those with visual and auditory learning styles. Additionally, students with auditory learning styles exhibited significantly better thoroughness compared to those with visual learning styles.

5. DISCUSSION

5.1. The Effect of Stimulus Types

The findings indicated that HOTS question stimulus types had a significant effect ($p<0.05$) on conceptual understanding but they did not have a significant effect on either that cognitive response or on thoroughness given by each HOTS question asked to high school biology students. The narration stimulus generated the highest scoring with respect to conceptual understanding (moderate) and the chart had the lowest (very poor). A score in the "moderate" category indicates that students demonstrate some understanding of basic concepts, but generally have difficulty with more complex applications; a "very poor" score indicates that students are unable to demonstrate adequate understanding of fundamental concepts. Therefore, narrative stimuli are superior to visual representations, for example, in the form of charts with rows of animal organelles, for helping students understand tested biological concepts.

One suggests HOTS questions with narrative which provide information in a contextual, sequential, rich and meaningful manner and also develop their conceptual understanding. Narratives help students' link abstract notions to real-life events, allowing for a firmer grasp and retention of the material. These HOTS questions were narrated about environmental problems that students knew to support logical reasoning, analyzing the problems, and finding the right answer. Students activate prior knowledge and draw connections to new information and their experiences through narratives (Woolfolk, 2019). Intriguingly, these results contrast with prior results (Hu & Chen, 2021) that emphasized the benefits of visual representations in service of science learning. Charts and graphs are tools that help students visualize relationships between concepts and understand complex patterns. The differing results could be because of the characteristics of the material, different learning styles among students or differences in the quality of visual representations.

The study results concluded that the type of stimulus had little effect on cognitive response or thoroughness. The result shows that providing conceptual understanding is not enough for a good performance in solving SCI and scientific problems because of the SCI's complexity, and the factor that contributes the most is the practical process of solving. Evidence from previous studies also suggests that cognitive engagement is more closely influenced by internal factors such as motivation, self-efficacy and metacognitive strategies (Zhang, Basham, & Yang, 2020).

The narrating group's observed "moderate" category shows that students can understand basic concepts but struggle to apply them in complicated scenarios. This is a common finding from science learning where students can recast definitions and principles but have difficulties in drawing on knowledge when they are presented with a new or complicated problem (Vaughn, Brown, & Johnson, 2020). However, the overall histogram in the "very poor" category indicates major problems with basic conceptual understanding in the chart stimulus group. This can be attributed either to the absence of skills that allow students to make sense of and use visual information effectively or to a disconnect between the visual representation's complexity and students' cognitive levels (Serrano Rodríguez, Amor Almedina, Guzman Cedeño, & Guerrero-Casado, 2020). Research shows that students rarely experience graph work in science education and also that the visual stimuli learnt in textbooks are primarily image and table-based where graphs and charts were infrequently employed. This corresponds with results from other research (Inaltekin & Goksu, 2019). The impact of this study on pedagogy is profound. Hence, teachers should utilize multimodal approaches to the presentation of material, particularly narratives for foundational conceptual understanding. At the same time, students should regularly be trained to interpret visuals (images, graphs, or tables) as stimuli to be used in exercising higher- order thought. External stimuli to adjust information processing and working memory capacity (Xu, Church, Sasaki, & Watanabe, 2021).

The results of this multiple comparisons test show that students working on HOTS questions with narration stimuli had a better conceptual understanding with a mean of 78.80 than students working on HOTS questions with table stimuli (45.93), picture stimuli (38.67), and chart stimuli (35.60) with a significance of 0.000. Similar to previous study, Widana (2017) stated that narratives assisted students to comprehend the contextual aspect of a problem which expose organized and substantial information. Narratives allow learners to develop richer mental models of problem situations that support problem analysis, evaluation, and solutions development.

Whereas text questions can be solved with the linear analytical process (examine the question, find the answer) images would require a layered analytical process (peeling the layers of why first to understand the parts, next to analyze relationships and follow their meanings in the stimulus object). It takes more time and energy to get to the right answers through these processes. Similar to earlier research (Wang & Wei, 2024) learners require systematic permutations for translation between pictures, graphs and other visual representations for deeper cognition.

5.2. The Effect of Learning Styles

The study found learning styles had a significant impact on students' thoroughness and conceptual understanding, but not on cognitive response. This can help to discuss student learning styles towards HOTS question (higher- order thinking skills) in light of their academic performance. Then, students with kinesthetic learning styles were significantly more thorough in answering HOTS questions than students with visual learning styles and students with auditory learning styles based on results of the multiple comparisons test. Auditory method students perform significantly better for thoroughness compared with visual method students. These results align with earlier research that suggested kinesthetic learners are more systematic and detail-oriented in the completion of complex tasks (Gowda & D'Mello, 2019; Purbayani, Nugraha, & Ali, 2024). This sensitivity has something to do with the kinesthetic learners' tendency to take a "learning by doing" approach and their high consciousness of the processes in which they take part. Kinesthetic learners tend to go through their work and make sure they do each step right in their learning (Purbayani et al., 2024). This quality is especially useful while solving HOTS questions that require in-depth analysis and step-by-step problem solving.

Another interesting finding was that visual learners displayed a greater degree of thoroughness than auditory learners. This type of learner is phenomenal at processing and memorizing sequential information which is very useful in HOTS problem solving questions because they require stepwise approach to the solution. In addition, they frequently use "self-talk" or internal verbalization while working on problems to help them monitor and to validate their answers. This outcome is contrary to previous studies indicating that visual learners are most likely to perform best on visual item analyses (Machromah et al., 2021). The difference may be related to some attributes of the HOTS problems included in this study or contextual factors.

While learning styles had a considerable impact on thoroughness and conceptual understanding, they did not impact cognitive response. This is probably due to cognitive response being more affected by variables, including prior knowledge, motivation and metacognitive strategies (Wang & Wei, 2024). Similarly, learning styles impact the processing of information, not the content (Khan, 2021). Students who adapt their learning styles to what a given task requires tend to do better on the task overall. It underscores that different learning styles are not necessarily better than others and that regardless of a person's learning style preference, being able to adopt multiple learning methods to suit the context is crucial.

Insights gained from these findings have very important implications for daily teaching. Instructional activities and assessments, especially those that involve performance at high levels of thoroughness, should take into account students' learning styles. Still, accommodating students' learning styles shouldn't be a way of minimizing their encounter with various learning modalities. Not only will this help them in the workplace, but it will also encourage them to practice such strategies, no matter which learning strategies fit them.

5.3. The Effect of Interaction between Stimulus Types and Learning Styles

The results of the study showed a significant interaction between juxtaposing stimuli types with different styles of learning. However, its interaction in thoroughness and conceptual understanding was not considered significant. These findings suggest that the alignment of information presentations with the learning styles of students affects how they cognitively process information. Accordingly, a match between the modality of information presentation and students' learning preferences prevents shallow cognitive processing leading to faster reading and deeper processing of the information. This supports prior studies that indicate that the interaction of stimuli and learning styles moderate the way in which the brain processes information (Cheng et al., 2021). Employing neuroimaging technology, they discovered that when the type of stimulus corresponds with the learning style for the individual, certain areas of the brain activate in a more pronounced manner. Cognitive response variation is thus dependent on the premises of the stimuli and the return from each of the learning styles.

In terms of thoroughness and concept understanding, this makes perfect sense as motivation, perseverance and other metacognitive strategies have been found to outweigh the effects of learning styles and stimulus attribution. This means that highly motivated students using effective learning strategies can compensate for misalignments between stimuli and their learning preferences. While cognitive response is generally more instant and impulsive (Otero & Alonso, 2023) thoroughness and conceptual understanding are characterized by deeper, more complex processes (Brassil & Couch, 2019) that depend on additional conditions including past experiences, analytical skillset and solution-finding techniques.

Students may have certain learning style preferences and show different cognitive responses to different types of stimuli, but they also have an ability to adjust and formulate compensatory strategies when a task calls for more comprehensive and deeper understanding. It is the brain's plasticity and adaptability (Stee & Peigneux, 2021) that allows learners to counteract the mismatch between the stimuli and their style of learning, especially with tasks requiring high levels of thoroughness and conceptual understanding. This could potentially explain the lack of an interaction between stimulus types and learning styles concerning thoroughness or conceptual understanding.

6. CONCLUSION

The results of this study show that HOTS question stimulus types and learning styles possibly highly affect elements of high school biology students' performance. The student's conceptual understanding ($\eta^2 = 0.289$) was strongly influenced by the type of stimulus whereas the cognitive response or thoroughness was not. Among stimulus types, narration had the most significant effect, helping students to reach improved conceptual understanding versus table, picture, and chart stimuli. According to the authors, narratives display information in a contextual and sequential manner. Students can understand the relevance of abstract concepts to the real world through narratives. Unlike visual files like charts, these stimuli need higher visual literacy and analytical skills that were less developed in students. There were also significant effects of learning styles on thoroughness ($\eta^2 = 0.031$) and conceptual understanding ($\eta^2 = 0.036$) but no significant impact on cognitive response. For HOTS tasks, kinesthetic students were the most systematic followed by auditory learners than visual learners. Auditory learners scored well in systematic processing as they were backed up by their skills of processing information in an ordered manner and using internal verbalization strategies (Jensen, 2008). Moreover, the interaction effect of stimulus types and learning styles was observed in terms of cognitive response ($\eta^2 = 0.048$) indicating that the learning design taking into consideration students' learning styles led to significant cognitive response. However, this is a weak correlation and did not have a strong impact on thoroughness or conceptual understanding suggesting that outcomes such as these are more reliant on extrinsic factors such as motivation persistence, and metacognitive strategies. These findings highlight the need to adapt educational approaches to address the wide range of learning preferences while motivating learners to achieve effective adaptive learning behaviours for work requiring high completion and deep understanding.

7. RECOMMENDATIONS

In the case of biology learning, the need for a diverse representation of stimuli to incorporate into the teaching and assessment process is paramount due to the diversity of students' learning styles and, because biology teaching is made up of a number of different foundational components. Training in metacognitive strategies is essential for enhancing students' thoroughness regardless of the used stimulus. Intervention programs specifically targeted at developing HOTS of kinesthetic learners should also be planned. Replication studies with larger and more diverse samples are suggested for future studies to enhance the generalizability of the findings. Cross-cultural studies may identify how effects vary across different educational settings. Although this study only included biological data, investigations of HOTS question stimuli and learning styles in other disciplines could provide a broader perspective of the relationship between these variables. Lastly, different methods need to be examined to get more insights into variability in answering HOTS questions.

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Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
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