

Correlational Study of Learning Styles and Information Processing Patterns among STEM Learners in Biology

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ABSTRACT

This study investigates the correlation between learning styles (Visual, Auditory, Reading/Writing, and Kinesthetic [VARK]) and information processing patterns (Parallel, Sequential, Top-down, and Bottom-up) among Senior High School Science, Technology, Engineering, and Mathematics (STEM) learners, specifically in the context of Biology. The literature review underscores the importance of understanding diverse learning styles and cognitive processing mechanisms, which influence how students engage with complex subject matter in STEM fields. The research aims to fill the gap in the existing literature by focusing on Grade 11 and 12 STEM students in Biology within the Science City of Muñoz, a population that has been underexplored in this context. A descriptive-correlational quantitative design was used, with data collected from 483 STEM students using modified VARK and information processing questionnaires. Results indicate significant relationships between learning styles and information processing patterns. However, given the critiques of learning styles frameworks and the correlational nature of this study, these results should be seen as indicative of learner tendencies rather than prescriptive recommendations for instruction. This study has implications for educators, curriculum developers, and policymakers, advocating for more personalized teaching methods that cater to the cognitive needs of students in STEM disciplines.

KEY WORDS: Biology education, cognitive processing, descriptive-correlational research, information processing patterns, learning styles, senior high school, STEM education, VARK

INTRODUCTION

Background Information

The study of learning styles and information processing patterns is a critical area of research in education, particularly in the context of Science, Technology, Engineering, and Mathematics (STEM) disciplines. As educational systems strive to meet the diverse needs of students, understanding how individuals process and retain information becomes increasingly important. STEM fields, with their complex content and fast-paced advancements, pose unique challenges for learners. This is especially true in Biology, a subject that requires not only the retention of vast amounts of information but also the ability to apply critical thinking and problem-solving skills to real-world scenarios.

In particular, Biology as a STEM subject offers unique challenges that necessitate effective teaching strategies. Biology requires students to not only memorize complex information but also to think critically about biological concepts and apply them in various contexts. Different students may approach this task in varied ways depending on their learning styles and information-processing patterns.

The concept of “learning styles” evolved from the earlier term “cognitive style,” reflecting a shift in focus from general cognitive processes to how these processes influence learning

(Moussa, 2014). To simply put, learning styles refer to the idea that individuals vary in terms of which instructional methods or study approaches work best for them. However, there are some instances wherein learning styles are being confused with multiple intelligence theory. Hence, Cuevas (2015) emphasized that Howard Gardner rejected the notion that his multiple intelligence theory is a subset of the learning styles hypothesis. He emphasized that his theory of multiple intelligences differs from the learning styles hypothesis, as they are distinct psychological constructs. Gardner explained that a learning style refers to an individual’s approach to a task, while intelligence is the “computational power of a mental system.” He acknowledged that there might be a relationship between learning styles and intelligence, but they are not the same concept.

Now, having the idea of how learning styles are different from the concept of multiple intelligence theory, it is also crucial to understand the various learning style theories that exist. To be more specific, there are six influential models and theories for different learning styles: (1) David Kolb and Experiential Learning; (2) Honey and Mumford’s Learning Styles; (3) Anthony Gregorc’s Mind Styles; (4) The Learning Styles Task Force; (5) The Index of Learning Styles (Felder and Silverman Learning Styles); and (6) Visual, Auditory, Reading/Writing, and Kinesthetic (VARK) Learning styles.

These various learning style models provide valuable frameworks for understanding how individuals process and engage with information. Kolb and Kolb (2013) discussed that experiential learning theory emphasizes a cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation, with learners favoring different stages based on their style—diverging, assimilating, converging, or accommodating. Similarly, Rusconi (2023) discusses the Honey and Mumford model, which categorizes learners as Activists, Theorists, Pragmatists, or Reflectors, each with distinct preferences for engagement. Other models, such as the Gregorc Mind Styles Model (The Peak Performance Center, 2017), the NASSP’s broader framework (Mind Tools Content Team, 2024), and the Felder-Silverman Index (Harrington-Atkinson, 2022), offer nuanced classifications based on cognitive, affective, physiological, and perceptual preferences. The VARK model (Broadbent, 2021) further emphasizes the significance of recognizing learning preferences—VARK—to improve study habits and educational outcomes. Each theory highlights the importance of personalized learning experiences and adapting instruction to diverse needs, fostering more effective and inclusive educational environments. However, this study will be focusing on using the VARK learning style in assessing the prominent learning styles for Grades 11 and 12 STEM students.

The importance of addressing diverse learning styles in teaching is highlighted across several studies, emphasizing the need for instructors to adapt their teaching methods to engage all students effectively. Tanner and Allen (2004) argue that to cater to students’ varied learning preferences, teachers should utilize a range of instructional strategies, ensuring that all students can engage with the material in ways that resonate with them. Similarly, Kubat (2018) underscores the significance of recognizing individual differences in students, stressing that grouping students according to their learning styles can enhance the learning experience. By considering whether students thrive in hands-on activities or benefit more from reading, teachers can design more inclusive lessons that support diverse learning needs.

Further supporting the role of teaching methods in influencing student success, Chetty et al. (2019) found that both students’ preferred learning styles and lecturers’ teaching styles had a substantial impact on academic performance, with visual learning being the most favored style among students. Magulod (2019) also examined the relationship between learning styles, study habits, and academic achievement, revealing positive correlations between these factors. The study found that visual, group, and kinesthetic learning styles were particularly common among Filipino university students, highlighting the importance of tailoring instruction to meet these preferences to enhance academic performance.

However, some studies, such as that of Cimermanová (2018), suggest that the relationship between learning styles and academic success may not be as significant as often assumed,

particularly in varying teaching formats. Furthermore, Abidoye and Olorundare (2020) found a negative correlation between students’ performance and visual and kinesthetic learning styles, with a positive correlation for auditory learners, suggesting that some learning styles may not always align with academic success. Despite these contrasting findings, the broader consensus remains that educators should incorporate a range of teaching methods to accommodate the diverse learning styles present in their classrooms, ultimately fostering an environment conducive to academic growth and success.

Meanwhile, Margolis et al. (2022) discuss Information Processing as the series of steps involved in acquiring, storing, organizing, retrieving, presenting, and sharing information. This idea is crucial for understanding how people acquire knowledge and how it shapes their actions. According to Information Processing Theory, individuals actively engage with and process the information they come across instead of simply reacting to it. The theory often compares the human mind to a computer, where information is methodically processed and stored. Information Processing Theory was further explored by Cuncic (2023), beginning with George Miller’s research on the limits of short-term memory. Miller’s findings laid the groundwork for understanding how people acquire, store, and utilize knowledge. Cuncic’s clear and succinct overview of the various forms of information processing, including sequential, parallel, and hierarchical, illuminates different facets of cognitive function.

Indeed, the human brain processes information through various mechanisms, each contributing to how we perceive and interpret stimuli. Li et al. (2020) explain that visual searches can occur through either sequential or parallel processing. Sequential processing handles visual input one item at a time, while parallel processing enables the simultaneous analysis of multiple items. Moreover, as noted by Gençer and Yıldırım (2022), cognitive processing also involves top-down and bottom-up approaches. Top-down processing depends on previous experiences, knowledge, and expectations to interpret sensory input, whereas bottom-up processing focuses on identifying the basic components of a stimulus and building a perception from these details. Together, these processing methods demonstrate the brain’s adaptive ability to handle a variety of sensory information, combining prior knowledge with raw sensory data to form a comprehensive understanding of the environment.

The relationship between learning styles and cognitive processing has been extensively explored, revealing significant insights into how these constructs interact. For instance, Awan et al. (2019) found that the effect of information processing on academic performance is contingent on students’ learning styles, further supporting the need for individualized teaching methods. Finally, Matias (2024) identified a significant relationship between learning styles and information processing patterns within Science, Technology, and Engineering (STE) programs, where higher academic performers preferred

Theorist and Activist learning styles. These learners exhibited advanced processing strategies, such as a blend of top-down and bottom-up approaches and both sequential and parallel processing, suggesting that instructional strategies should account for these distinctions to optimize learning outcomes.

Alongside with these, Truong (2016) highlights the potential of adaptive electronic learning systems to integrate learning styles, thus improving personalized learning experiences. These systems can accommodate different cognitive processing preferences, which leads to more effective learning results. However, the integration of technology in this way requires greater research on how learning styles translate into cognitive processing in various contexts. In addition, Balakrishnan and Gan (2016) explore the interaction between learning styles and social networks technology, who find that the different learning styles of students significantly influence their commitment to online platforms for learning. This finding suggests that cognitive processing of information in digital environments is also formed by individual preferences, which underlines the need for personalized educational approaches. Then, Wang and Chough (2014) discuss business learning, emphasizing the adaptability of learning strategies to individual cognitive processing styles. Its analysis implies that understanding these styles can improve personal development strategies, promoting the most effective learning and the application of knowledge in business contexts. On the other hand, Essa et al. (2023) Provide an exhaustive review of personalized adaptive learning technologies that take advantage of automatic learning techniques to identify learning styles. Their findings advocate the need for such technological advances, which can improve cognitive processing by aligning the educational content with the student's favorite style. Together, these studies illustrate the complex interaction between learning styles, cognitive processing, and educational practices, highlighting the implications for future research and applications in educational and personal development strategies.

The reviewed studies emphasize a wealth of research on the relationship between learning styles and cognitive processing across various educational contexts and disciplines. However, there is a notable gap in the literature regarding the specific interplay between learning styles and information-processing patterns among Senior High School students, particularly in the context of Biology. This study, therefore, aims to explore the correlations between learning styles (VARK) and information processing patterns (Parallel, Sequential, Top-down, and Bottom-up) of Senior High School STEM students, which then seeks in offering insights that could inform teaching strategies and curriculum design for more effective learning outcomes.

Research Problem

While substantial insights have been gathered on general student populations and various subjects, including STE, targeted research focusing on Grade 11 and 12 students in Biology—both within the Philippines and globally—is scarce. This lack of focused investigation into this specific educational

segment and subject area underscores an opportunity for further research that could offer valuable insights into optimizing instructional strategies for senior high school biology students based on their unique learning and processing preferences.

Although the VARK model of learning styles (VARK) has been widely utilized to characterize student preferences, recent research has raised concerns about the limited empirical evidence supporting its impact on improving learning outcomes (Pashler et al., 2008; Rogowsky et al., 2020). Consequently, it is important to view learning styles as descriptive tools that offer insight into learner preferences rather than definitive prescriptions for instructional design.

To provide a stronger theoretical basis, this study integrates concepts from cognitive science, particularly Information Processing Theory, which frames learning as an active process involving the acquisition, organization, and retrieval of information (Atkinson and Shiffrin, 1968). This perspective allows a nuanced understanding of how learners engage with biological content beyond preferred modalities. In addition, constructivist theories emphasize the role of prior knowledge and metacognitive strategies in shaping learning experiences, which are essential in the complex domain of biology education (Bransford et al., 2000). Integrating these frameworks offers a comprehensive lens to interpret the interplay between learner preferences and cognitive processing patterns. On the other hand, upon researching the existing literature and studies, it became evident that the study conducted by Matias (2024) is the only study to date that has utilized the model of parallel, sequential, top-down, and bottom-up information processing to assess learners' information processing patterns. However, this study was limited in scope as it concentrated solely on junior high school students within STE curricula and did not target any specific subject area. This leaves a gap in the research regarding the application of this model to other educational levels or subjects, particularly within the context of senior high school STEM learners.

This research aims to fill these gaps by examining the possible correlations in learning styles and information processing patterns among Grade 11 and 12 STEM students in the context of biology, thereby providing more refined investigations to better understand the learning preferences and strategies of these students in a crucial and sophisticated subject like biology.

Research Objectives

This study generally aimed to identify and analyze the learning styles and information processing patterns of Grade 11 and 12 STEM students in Biology, and to explore the relationships between these factors. Specifically, it sought to achieve the following:

1. To describe the learning styles of STEM students with respect to:
 - Visual
 - Auditory
 - Reading/Writing; and
 - Kinesthetic.

2. To describe the information processing patterns of STEM students with respect to:
 - Parallel processing
 - Sequential processing
 - Top-down processing; and
 - Bottom-up processing.
3. To examine if significant relationship exists between STEM students' learning styles and information processing patterns.

Research Hypothesis

H_0 : There is no significant relationship exists between STEM students' learning styles and information processing patterns

H_a : There is a significant relationship exists between STEM students' learning styles and information processing patterns.

Significance of the Study

This study is vital in advancing the understanding of how learning styles and information processing patterns are correlated among Grade 11 and 12 STEM learners in Biology. By exploring the relationship between these factors, the research holds significant implications for various stakeholders in the educational ecosystem.

For teachers, the study provides valuable insights into the different learning styles and information processing patterns of STEM learners in Biology, enabling them to design and implement more personalized and effective teaching strategies. It also assists in identifying how learners in the STEM track process and engage with complex Biology concepts, improving their ability to modify instructional methods to foster better comprehension and retention. In addition, it encourages teachers to incorporate diverse teaching strategies that align with students' cognitive styles, ultimately enhancing student participation and overall learning outcomes.

For students, the study promotes self-awareness by encouraging STEM learners to recognize their individual learning preferences and processing approaches, which can lead to more effective study habits and academic strategies. Students are also able to better understand how their learning style influences their academic performance, which empowers them to take control of their learning experience and select techniques that suit their strengths. This self-awareness can help students optimize their learning by adapting strategies that enhance their information processing, resulting in improved performance in Biology and other STEM subjects.

For schools, the study provides actionable data that can be used to assess the effectiveness of current instructional practices and make informed decisions about curriculum development. The findings support the creation of targeted interventions that address the diverse learning needs of STEM students, fostering a more inclusive and supportive learning environment for all learners. Furthermore, it helps schools identify key factors that influence academic success, enabling them to allocate

resources more efficiently and tailor their support systems to meet the specific needs of STEM learners.

For educational policymakers, the study offers important insights that can inform the development of policies aimed at promoting diversity in teaching and learning. The findings can help ensure that educational practices accommodate various learning styles and information processing patterns, leading to more equitable and effective learning experiences. In addition, the study supports the creation of professional development programs that equip teachers with the knowledge and tools to address the diverse needs of students, particularly those in the STEM fields. This, in turn, can guide policy decisions related to curriculum reforms and teaching methodologies, with the goal of enhancing STEM education outcomes for all learners.

For curriculum developers, the study provides valuable insights into how students in the STEM track engage with and process Biology content. This understanding can guide the development of curricula that cater to a wide range of learning styles and cognitive processes. It encourages the integration of varied instructional approaches and materials into the curriculum, ensuring that all students can access and succeed in Biology, regardless of their learning preferences. Furthermore, the study promotes the inclusion of differentiated learning strategies that improve student engagement and success in STEM subjects, particularly Biology.

For researchers and educational psychologists, this study expands the existing body of knowledge on the relationship between learning styles, information processing patterns, and academic achievement in STEM education. It also lays the groundwork for future studies that investigate how learning styles and information processing influence student outcomes in different disciplines, contributing to ongoing research in educational psychology and pedagogy. The study offers insights into the intersection of cognitive science and education, fostering a deeper understanding of how students learn and process information in the context of Biology and other STEM fields.

METHODOLOGY

Research Design

In this study, the researcher aimed to apply a well-structured research methodology to examine the relationship between learning styles and information processing patterns among STEM learners in Biology. Specifically, this quantitative research followed a descriptive-correlational approach. As noted by Sirisilla (2023), descriptive research design is a valuable tool for gathering data related to a specific group or issue. This approach offers a comprehensive and accurate representation of the characteristics and behaviors of a particular group or subject. In addition, descriptive research enables a deeper understanding of a specific topic through observation and data collection.

The use of quantitative methods in this study allowed for the collection of numerical data, which helped analyze various variables linked to learning styles and information processing

patterns in the context of Biology education. The primary goal of quantitative research is to enhance understanding of the social and educational realms. Quantitative methods were employed to systematically investigate the different variables or factors affecting students' learning styles and information processing. This analysis provided empirical evidence that could be effectively communicated through statistical measures and numerical representations. Quantitative analysis allows for the identification of patterns, averages, predictions, examination of causal relationships, and the ability to generalize findings to larger populations (Williams, 2021).

Furthermore, the study employed a correlational approach, which facilitated the exploration of potential connections between learning styles and information processing patterns. Through this methodology, the research aimed to provide insights into how these two factors intersect and influence STEM learners' experiences in Biology, contributing valuable information to the fields of education and teaching practices.

Overall, this study employed a descriptive-correlational design appropriate for exploratory analysis of the relationships between learning styles and information processing patterns among Senior High School STEM students in Biology. While this design allows for the identification of associations and patterns, it does not support causal inferences. The findings should thus be interpreted as providing foundational insights into learner characteristics, which can inform future experimental or mixed-methods research. Such subsequent studies could test instructional interventions based on cognitive processing frameworks to determine their effectiveness in biology education.

Study Sites

This study was conducted in selected schools located in the Science City of Muñoz, Nueva Ecija, Philippines.

School A, established on September 03, 1944, was initially founded to protect young people from the impacts of World War II and ensure their education continued. Starting with two sections, the school has since grown significantly and was nationalized in 1982. It now offers Junior High School (Grades 7–10) and Senior High School tracks, including ABM, HUMSS, STEM, and TVL.

Meanwhile, School B, a laboratory school, it was founded in 1976 and focuses on science and technology education. It offers limited slots for students through a competitive admission process. School B has produced high-quality graduates over its decades of existence.

Lastly, School C, founded in 1965 by the Missionaries of the Sacred Heart, offers both elementary and secondary education. It was initially established as a high school but expanded to include a Senior High School in 2016, offering STEM, HUMSS, and ABM tracks.

Ethical Consideration

Before the study began, it underwent review and approval by the ethics committee. Once approved, the informed consent process was carried out, providing participants with detailed

Table 1: Respondents of the study for the quantitative survey

School	Grade 11 STEM	Grade 12 STEM	Total number of respondents
1. School A	135	134	483
2. School B	62	77	
3. School C	32	43	
Subtotal	229	254	

information about the study's purpose, procedures, risks, and benefits. For minors, informed assent and parental consent were obtained. Participation was voluntary, with no consequences for non-participation.

Data privacy was a key ethical consideration, with informed consent including provisions on data privacy. All data were securely discarded after the study to protect participants' identities and ensure confidentiality.

The study adhered to ethical standards, avoiding plagiarism, AI-generated work, and research misconduct. Data were collected transparently, ensuring reliability and honesty, and maintaining the integrity and credibility of the research.

Respondents and Data Collection

This study employed a complete sampling approach, encompassing all Grade 11 and 12 STEM students enrolled at the selected schools mentioned in table 1 above. As Sekaran and Bougie (2009) explained, complete sampling is a purposive sampling technique where the entire population possessing specific characteristics is included in the study. In this context, all 483 Grade 11 and 12 STEM students constitute the sample, as they represent the complete population of interest in investigating learning styles and information processing patterns in biology within this specific context.

Quantitative data collection utilized a modified VARK Questionnaire (based on VARK Questionnaire version 8.02, available and universally accessible online) to assess learning styles, and a modified questionnaire adapted from the study of Matias (2024) to assess information processing patterns. The administration of these questionnaires took place during regular class hours, with each participant assigned a unique number for anonymity and tracking for the following qualitative part of this research study. Each participant received a small token of appreciation after the survey.

Instrument Used

To collect data and ensure the validity of the adapted and modified questionnaire, the initial stage is the establishment of its content validity. Content validity pertains to the degree to which an instrument adequately encompasses the subjects and facets of the study problem and objectives (Rusticus, 2014). This assessment can be conducted through consultation with professionals (Shrotryia and Dhanda, 2019) as for this case, the researcher's thesis adviser and, as mentioned by Alexandre and Coluci (2011), via studying relevant literature.

Table 2: Level of internal consistency based on Cronbach's alpha

Cronbach's alpha	Internal consistency
0.90 and above	Excellent
0.80–0.89	Good
0.70–0.79	Acceptable
0.60–0.69	Questionable
0.50–0.59	Poor
Below 0.50	Unacceptable

Table 3: Case processing summary for Cronbach's alpha of VARK learning styles questionnaire

Case processing	n	%
Cases valid	30	100.0
Excluded ^a	0	0.0
Total	30	100.0

^aListwise deletion based on all variables in the procedure

Then, since one method for assessing the validity of a survey questionnaire, as discussed by Patel (2019), is through the implementation of pilot testing, the researcher conducted a pilot test with a small sample of respondents similar to the target population. The pilot testing of the instrument to be used was conducted at a National High School – Senior High School Department located at Sto. Domingo, Nueva Ecija by formally seeking permission via writing a request letter to its head. As Tappin (2014) stated in his study, Connelly (2008) asserts that existing literature indicates that in a pilot study for a quantitative study, the sample size should constitute 10% of the more extensive primary study's estimated sample size. However, according to Isaac and Michael (1995), as cited by Tappin (2014), it was indicated that the optimal number of participants for the quantitative research investigation's pilot testing should range from 10 to 30. Hence, the researcher conducted the pilot testing on 30 students of STEM for the quantitative survey.

Afterward, the Cronbach's alpha was utilized to calculate the outcomes for evaluating the reliability of the quantitative instrument. The Cronbach's alpha range values and interpretation are as follows:

The table 2 presents the classification of Cronbach's alpha values. This is employed to assess the internal consistency and reliability of a set of survey items. This statistical metric can be utilized to determine the level of consistency in measuring a specific attribute across a collection of objects. Cronbach's alpha is a statistical metric used to evaluate the level of consensus on a standardized continuum spanning from 0 to 1. Higher values suggest a more vital agreement between the elements (Frost, 2022). Hence, a value of 0.90 and above suggests excellent internal consistency, meaning the items in the test are highly related and consistently measure the same construct. Values between 0.80 and 0.89 indicate good reliability, which is generally acceptable for most research purposes. A range of

Table 4: Case processing summary for Cronbach's alpha of information processing patterns questionnaire

Case processing	n	%
Cases valid	30	100.0
Excluded ^a	0	0.0
Total	30	100.0

^aListwise deletion based on all variables in the procedure

Table 5: Reliability statistics for Cronbach's alpha of VARK learning styles questionnaire

Cronbach's alpha	N of items
0.877	20

Table 6: Reliability statistics for Cronbach's alpha of information processing patterns questionnaire

Cronbach's alpha	N of Items
0.806	20

0.70–0.79 is considered acceptable, though researchers may look for higher values depending on the context. A score between 0.60 and 0.69 is questionable, suggesting that the internal consistency might be inadequate. Scores between 0.50 and 0.59 are classified as poor, indicating weak reliability, while values below 0.50 are unacceptable, reflecting very low consistency among test items. This scale helped the researcher judge the quality and dependability of the measurement instrument of this study. Below was the Cronbach's alpha value computed by a certified statistician for each of the questionnaires:

Table 3 and 4 provides a case processing summary for the Cronbach's Alpha analysis of the VARK Learning Styles and Information Processing Patterns Questionnaire respectively. Out of 30 cases, all were valid and included in the analysis, representing 100% of the data. No cases were excluded, indicating a complete dataset with no missing values. Listwise deletion was used in the analysis, meaning only cases with complete data for all variables were considered (Kang, 2013). The absence of excluded cases reflects high data quality, ensuring the reliability of the internal consistency results.

The Cronbach's alpha value of 0.877, as shown in the table 5, falls within the range of 0.80–0.89 which is classified as "Good" for internal consistency. A good internal consistency score suggests that the questionnaire items are effectively aligned with the underlying constructs of VARK learning styles and that the responses are reliable for measuring how individuals prefer to learn.

The Cronbach's alpha value of 0.806 for the Information Processing Patterns Questionnaire falls within the "Good" range (0.80–0.89) as reflected in Table 6. This indicates that the questionnaire has strong internal consistency, meaning the items are reliably measuring the different information processing patterns—parallel, sequential, top-down, and

Table 7: 4-point Likert scale for VARK learning styles

Rate	Verbal interpretation	Range
4	Strongly Agree (SA)	3.25–4.00
3	Agree (A)	2.50–3.24
2	Disagree (D)	1.75–2.49
1	Strongly Disagree (SD)	1.0–1.74

bottom-up. The result suggests that the tool effectively captures individuals' processing preferences in a consistent manner, making it a reliable instrument for this purpose.

On establishing the questionnaire's validity and reliability, the researcher sought permission by formally submitting a request letter signed by the researcher's thesis adviser to Division Office and to the School Principals of School A, B, and C. Then, subsequently distribute the questionnaires to the targeted participants and conduct focus group discussions on the selected participants for the qualitative part of the study.

Meanwhile, the responses of this study that were gathered using the questionnaire found in Appendix A of this paper served as the significant data that were analyzed by certified statistician and further discussed by researcher, which is composed of the following:

Socio-Demographic Profile of the Participant

This section captures the personal details of the respondents, including their sex, recent grades in Biology, parents' highest educational attainment, and monthly family income. This data aim to create a comprehensive sociodemographic profile of the respondents, helping the researcher analyze how these factors might influence learning styles and information processing patterns.

VARK Learning Styles

This part of the questionnaire is based on the VARK model, which identifies four primary learning styles: VARK. The questions explore how students engage with visual aids, auditory materials, written texts, and hands-on activities to understand and retain biology content. The goal is to identify the dominant learning styles among the students. The table 7 presents a 4-point Likert scale that was used to assess students' learning styles based on the VARK model.

The table presents a 4-point Likert scale that was used to assess students' learning styles based on the VARK model. Each numerical rating corresponds to a verbal interpretation that reflects the respondent's level of agreement with statements related to learning preferences. A rating of 4, which falls within the range of 3.25–4.00 and is labeled "Strongly Agree (SA)," indicates that the respondent feels the described learning style matches their preferences very well. A rating of 3, with a range of 2.50–3.24, is labeled "Agree (A)" and suggests a positive, but less intense, alignment with the learning style. On the other hand, a rating of 2, which falls between 1.75 and 2.49, is labeled "Disagree (D)" and indicates that the respondent does not feel the learning style fits them, though some level

Table 8: 5-point Likert scale for information processing patterns

Rate	Verbal interpretation	Range
5	Always	4.20–5.00
4	Often	3.40–4.19
3	Sometimes	2.60–3.39
2	Rarely	1.80–2.59
1	Never	1.0–1.79

of agreement may still be present. Finally, a rating of 1, with a range of 1.00–1.74, is labeled "Strongly Disagree (SD)," signifying that the respondent feels the described learning style does not align with their preferences at all.

Information Processing Patterns

This part of the survey questionnaire investigates how students process information in Biology. It is divided into four types of information processing patterns: parallel, sequential, top-down, and bottom-up processing. Hence, this helped to explore and distinguish the dominant way on how students approach complex biological concepts, organize information, and make connections between ideas.

The scale on table 8 was used to assess the frequency and strength of students' information processing patterns. Each response option corresponds to a specific level of occurrence and preference for the described behavior. "Always" which ranges from 4.20 to 5.00 reflects the highest level, indicating that the respondent exhibits the pattern frequently and has a strong preference for it. Then, "Often" that ranges from 3.40 to 4.19 suggests a moderate occurrence, signifying that the behavior is present but not as consistent. A response of "Sometimes" with a range of 2.60–3.39 indicates a neutral or middling occurrence, with the behavior appearing occasionally. "Rarely" which ranges from 1.80 to 2.59 implies that the behavior is seldom exhibited, representing a low level of occurrence. Finally, "Never" with 1.00–1.79 range signifies a complete absence of the behavior.

Data Analysis

The study employed quantitative data that were collected through survey questionnaires on learning styles and information processing patterns. The analysis of this data offered a comprehensive and coherent descriptive explanation of the study's findings. The specific tools that were utilized by certified statisticians in this research and mentioned in the table 9 above are as follows:

Frequency Counts and Percentage

A percentage frequency distribution was employed to present data showing the proportion or percentage of observations for each data point or class interval. This method was useful in representing the relative frequency of survey results and other similar data. It was used to determine the percentages related to the respondents' sociodemographic profiles and to analyze the distribution of learning styles and information processing patterns.

Table 9: The data analysis plan of the study

Research objective	Data analysis method	Specific statistical test	Data type
1. To describe the learning styles of STEM students with respect to: a. Visual b. Auditory c. Reading/Writing; and d. Kinesthetic.	Descriptive Statistics Descriptive Statistics	Frequency and percentage, Standard Deviation Weighted Mean and Standard Deviation	Quantitative Quantitative
2. To describe the information processing patterns of STEM students with respect to: a. Parallel processing; b. Sequential processing; c. Top-down processing; and d. Bottom-up processing.			
3. To examine if significant relationship exists between STEM students' learning styles and information processing patterns.	Inferential Statistics	Pearson Correlation	Quantitative

Table 10: Learning styles of STEM students

Parameters	Mean	SD	Description
Visual learning styles			
1. When learning about complex biological processes, I find diagrams, charts, and illustrations very helpful.	3.59	0.54	Strongly Agree
2. I prefer to see a visual representation (e.g., model, picture, animation) of biological structures before reading about them.	3.62	0.54	Strongly Agree
3. I often use colors or highlighters in my Biology notes to organize information and make it more visually appealing.	3.24	0.87	Agree
4. When studying for Biology exams, I find it helpful to create visual aids like mind maps or concept diagrams.	3.22	0.73	Agree
5. I remember information about biological topics better when it is presented visually (e.g., through videos or presentations).	3.43	0.68	Strongly Agree
Pooled mean	3.42	0.43	Strongly Agree
Auditory learning styles			
1. I prefer to learn about Biology concepts through lectures, discussions, and audio recordings.	3.18	0.71	Agree
2. I find it helpful to hear the teacher or classmates explain biological processes aloud.	3.52	0.63	Strongly Agree
3. I often read my Biology notes aloud to myself or explain concepts verbally to others to help me understand them better.	3.12	0.80	Agree
4. I enjoy studying Biology in groups where we can discuss and debate different ideas.	2.91	0.86	Agree
5. I prefer to learn about new biological discoveries through podcasts or audio documentaries.	2.70	0.79	Agree
Pooled mean	3.08	0.47	Agree
Read/write learning styles			
1. I prefer to learn about Biology through textbooks, articles, and written notes.	2.94	0.77	Agree
2. I often create detailed written summaries of Biology concepts to help me understand them better.	3.06	0.83	Agree
3. I find it helpful to rewrite information from Biology lectures or textbooks in my own words.	3.17	0.81	Agree
4. I enjoy taking notes during Biology lessons and refer to them often when studying.	2.99	0.86	Agree
5. I feel most confident about my understanding of a biological topic when I can explain it clearly in writing.	3.14	0.77	Agree
Pooled mean	3.06	0.57	Agree
Kinesthetic Learning Styles			
1. I learn best about biological concepts when I can manipulate objects or perform experiments	3.14	0.74	Agree
2. I prefer to learn about biological structures by building models or dissecting specimens.	2.96	0.83	Agree
3. I find it helpful to take a hands-on approach to Biology (e.g., fieldwork, lab work) rather than just reading or listening.	3.30	0.74	Strongly Agree
4. I often use physical movements or gestures to help me remember information about Biology.	3.10	0.85	Agree
5. I prefer to learn about the applications of Biology in real-world settings (e.g., healthcare, agriculture).	3.35	0.69	Strongly Agree
Pooled mean	3.17	0.57	Agree

1.00–1.75: Strongly disagree, 1.76–2.50: Disagree, 2.51–3.25: Agree, 3.26–4.00: Strongly agree

Standard Deviation

It is a key statistical measure used to assess the degree of variability or dispersion in the data. A higher standard deviation indicates that the data points are more spread out

from the mean, while a lower standard deviation suggests that the values are closely clustered around the mean (Science and Bolotin, 2020). By calculating the standard deviation, the study quantifies the variability in learning styles and

information processing patterns among STEM learners in Biology, providing insight into the consistency or diversity of individual responses within the sample. This measure helps in understanding how much participants' characteristics deviate from the average trends observed in the study.

Weighted Mean

This was used to describe the learning styles and information processing patterns of the STEM students as well as to determine what is dominant among them. The weighted mean was verbally interpreted using the Likert scales above with "Strongly Agree to Strongly Disagree" for learning styles and "Always to Never" for information processing patterns.

Pearson Correlation

This allows for measuring the strength and direction of the linear relationship between continuous variables (Schober et al., 2018). Moreover, Pearson correlation helps to explore how these variables (learning style and information processing pattern) relate to each other. This can identify trends in how different learning styles influence information processing abilities, providing insights into the cognitive processes of STEM learners in Biology, assuming the data meets the assumptions of normality and linearity.

RESULTS AND DISCUSSION

This section of this study presents an in-depth analysis of the data collected, offering insights into the key findings and their implications in relation to the research objectives. Above and beyond, this section first provides a detailed description of the results, including statistical analyses and patterns observed in the data. Following this, the findings are discussed in the context of existing literature, highlighting how they contribute to the current understanding of the topic. In addition, the implications of these results are explored, with a focus on their relevance to the field and potential applications. This discussion aims to interpret the findings within a broader framework, addressing any unexpected outcomes and suggesting areas for future research.

Learning Styles of STEM Students

Visual

Visual learners in STEM, particularly in biology, grasp and retain information better when presented visually. The data on table 10 reveal a strong preference for visual aids, such as models and animations, with a mean score of 3.62 for the statement, "I prefer to see a visual representation of biological structures before reading about them." This suggests that visual learners benefit from seeing concepts before reading about them. Rau (2017) highlights how visual representations improve learning by simplifying abstract ideas, while Felder and Brent (2024) assert that incorporating visual aids enhances student understanding and retention in STEM education.

In addition, visual learners often use color coding and highlighters to organize their notes (mean score = 3.24). This habit aligns with findings from Taylor (2014), who notes that

visual learners often struggle with verbal instructions but excel with visual tools like color. Nishimura and Kuwahara (2015) show that highlighting can improve attention, memory retention, and information processing. Visual learners also create visual aids, like mind maps, which help them study for exams (mean score = 3.22). Arneson and Offerdahl (2018) emphasize the role of visual literacy in navigating complex biological systems, and Evagorou et al. (2015) highlight the importance of visual representations in generating scientific knowledge and facilitating the scientific method.

To support visual learners, integrating diagrams, charts, and illustrations in teaching is highly effective, with a mean score of 3.59. Liu et al. (2014) and Cromley and Mara (2018) demonstrate that using diagrams improves understanding and examination performance. Griffard (2013) points out that complex diagrams require decoding, which enhances representational competence. Providing videos and presentations also improves memory retention (mean score = 3.43). Brame (2017) highlights the effectiveness of educational videos in maximizing learning outcomes.

The data clearly indicate that visual learning strategies, like using diagrams, models, and videos, improve understanding of complex biological concepts, enhance memory retention, and contribute to better academic performance. Min et al. (2014) and Qasserras (2024) show that visual aids in engineering and education engage students and improve comprehension of abstract concepts. Brown (2004) affirms that graphics and animations enhance learning in science and engineering, underscoring the positive impact of visual learning across various fields.

Auditory

Auditory learners in STEM, particularly in biology, retain information better through listening. Data on table 10 above reveals a strong preference for lectures, discussions, and audio recordings, with a mean score of 3.18 for the statement, "I prefer to learn about Biology concepts through lectures, discussions, and audio recordings." This suggests that auditory learners benefit from verbal explanations, which align with their cognitive processing. Kayalar and Kayalar (2017) note that auditory learners prefer oral instructions, enhancing their learning, especially in language acquisition. Glaser and Schwan (2015) also show that verbal signals improve understanding when paired with visual materials, offering context and clarity.

These learners also find it helpful to hear explanations aloud, reflected by a mean score of 3.52, reinforcing their understanding. Auditory learners tend to read their notes aloud (mean score = 3.12) to internalize information, demonstrating the effectiveness of verbal repetition. A smaller group enjoys studying in groups where they can discuss ideas (mean = 2.91), which also benefits auditory learners through dynamic exchanges that promote critical thinking. Lakey (2020) underscores the value of group learning, while Kayalar and Kayalar (2017) suggest that individual discussions allow for deeper reflection. However, Rogowsky et al. (2020) caution

that aligning educational strategies with learning preferences does not always guarantee better learning outcomes, indicating a limitation for group debates and individual discussions.

Although auditory learners show less preference for learning through podcasts or audio documentaries (mean = 2.70), some are still open to exploring audio-based content. Alexander et al. (2023) demonstrate that daily exposure to auditory content enhances linguistic skills, which can improve retention in biology. Lillico (2022) supports this by showing how student-centered podcasts promote a deeper understanding of biological content. However, Mollett et al. (2017) warn that the lack of visual aids in podcasts may hinder comprehension for some students, and Stoss (2020) highlights accessibility as a key factor in broadening reach.

Auditory learning significantly impacts STEM students' performance. The preference for verbal explanations (mean = 3.18) shows that auditory learners grasp complex biological concepts better when taught through lectures and discussions. The data indicates that verbal repetition, like reading notes aloud (mean = 3.12), enhances retention. The high agreement with hearing explanations (mean = 3.52) underscores the importance of peer communication for deep comprehension. While podcasts and audio documentaries are less preferred (mean = 2.70), incorporating them can still offer additional learning resources. Previous studies support these findings, such as Abidoye and Olorundare (2020), which found a positive correlation between auditory learning and biology performance. Brown et al. (2018) demonstrated that students who listened to audio lectures performed better on quizzes, while Ifeoma (2024) noted that group discussions positively correlate with improved biology performance. These studies highlight the effectiveness of auditory learning strategies in enhancing comprehension and retention in biology education.

Reading/Writing

Reading/writing learners excel in environments with text-based materials such as textbooks, articles, and notes. On table 10, data show these learners prefer learning biology through reading and writing, with a mean score of 2.94 for the statement, *"I prefer to learn about Biology through textbooks, articles, and written notes."* This highlights the importance of reading and writing in their academic approach. Amin (2019) emphasizes that effective reading strategies help students develop analytical skills, while Agustin et al. (2021) found a significant link between writing and academic performance, as it encourages clarity of thought. Sadiku (2015) adds that reading and writing complement each other to enhance knowledge retention.

These learners often create detailed written summaries (mean = 3.06) to reinforce understanding. Rewriting information in their own words (mean = 3.17) further supports this, as writing helps them internalize and retain concepts. Davis (2017) notes that summaries distill complex ideas into manageable content, improving learning outcomes. Teachers can guide students to develop structured summaries to consolidate learning.

Reading/writing learners also take notes during lessons (mean = 2.99) and refer to them frequently, reinforcing their learning. Mazur (2015) suggests that regular review of notes strengthens memory and cognitive processing. In addition, these learners feel confident in their understanding when they can explain concepts in writing (mean = 3.14), validating their comprehension. Chen (2021) states that systematic note-taking enhances understanding and retention of complex information. Halim et al. (2018) emphasize that writing assignments help students correct misunderstandings and deepen their grasp of the material.

Reading/writing strategies positively impact STEM students' performance in biology. Learners who engage with text-based materials (mean = 2.94) better understand and retain biological concepts. Creating written summaries (mean = 3.06) helps synthesize the material, and rewriting information (mean = 3.17) promotes retention. The habit of note-taking (mean = 2.99) enhances memory recall. Finally, students' confidence in explaining concepts in writing (mean = 3.14) boosts their examination and assignment performance. Ching and Mao (2025) confirm that strong writing and reading skills improve students' ability to navigate complex STEM texts, enhancing understanding and retention, which are crucial for academic success.

Kinesthetic

Kinesthetic learners excel when they can physically engage with the material. In fact, data on table 10 shows a strong preference for learning through manipulation and experimentation, with a mean score of 3.14 for the statement, *"I learn best about biological concepts when I can manipulate objects or perform experiments."* This preference highlights the importance of hands-on activities in their learning. Supporting this, Schwichow et al. (2016) found that active engagement helps students internalize complex concepts more effectively than passive learning, indicating the need for direct interaction with biological specimens or models in teaching.

Moreover, kinesthetic learners also prefer building models or dissecting specimens, reflected by a mean score of 2.96, suggesting a significant preference for these activities. For instance, Zhang (2019) underscores that physical manipulation deepens understanding of scientific concepts, which implies that teachers should incorporate physical models and dissections into lessons to enhance learning.

In addition, the mean score of 3.30 for the statement, *"I find it helpful to take a hands-on approach to Biology (e.g., fieldwork, lab work) rather than just reading or listening,"* shows that kinesthetic learners value active participation. This is further supported by Fedesco et al. (2020), who emphasize that fieldwork promotes experiential learning, which deepens understanding and retention.

Furthermore, kinesthetic learners also use physical movements or gestures to aid memory (mean = 3.10), which means educators can leverage this by designing interactive activities that involve movement or role-playing. As highlighted by

Table 11: Information processing patterns of STEM students

Parameters	Mean	SD	Description
Parallel Processing			
1. I can easily handle multiple sources of information in biology lessons simultaneously and process them effectively.	3.37	0.84	Sometimes
2. I enjoy learning biology through open-ended activities and experiments.	3.98	0.84	Often
3. I quickly see connections and patterns between different biological concepts.	3.58	0.86	Often
4. When learning biology, I can quickly understand complex situations and make decisions.	3.20	0.87	Sometimes
5. I can easily switch between different biology concepts without losing focus.	3.05	0.90	Sometimes
Pooled mean	3.43	0.63	Sometimes
Sequential Processing			
1. When learning a biological process, I prefer to follow it step-by-step, mastering each stage before moving on.	4.27	0.80	Always
2. I prefer biology lessons with a clear structure, outlining the beginning, middle, and end of a topic.	4.41	0.78	Always
3. I carefully follow lab procedures or instructions to ensure I don't miss any crucial details.	4.37	0.78	Always
4. I organize my biology notes and study materials in lists or outlines to help me learn.	3.93	0.95	Often
5. I find it challenging to focus on a biology task if new information or interruptions arise.	3.87	0.99	Often
Pooled mean	4.17	0.58	Often
Top-down Processing			
1. When learning a new biology concept, I first think about how it relates to what I already know.	3.88	0.91	Often
2. I find it helpful to organize biology information into categories or groups based on my existing knowledge.	3.93	0.92	Often
3. I find it helpful to organize biology information into categories based on my existing knowledge.	3.87	0.87	Often
4. I can apply general principles in biology to solve specific problems or answer questions.	3.63	0.90	Often
5. I learn new biology concepts easier when they connect to things I already understand.	4.24	0.80	Always
Pooled mean	3.91	0.66	Often
Bottom-up Processing			
1. I focus on specific biological details (e.g., cell structures) before trying to understand the big picture.	3.92	0.86	Often
2. I prefer to learn new biology topics by starting with concrete examples and then generalizing.	3.87	0.96	Often
3. I break down complex biological processes (e.g., photosynthesis) into smaller, more manageable steps.	3.89	0.93	Often
4. I rely on my senses (e.g., observations in dissections) to learn about biological structures and functions.	3.77	0.91	Often
5. I feel most confident in my biology knowledge when I have a strong foundation of facts and details.	4.29	0.89	Always
Pooled mean	3.95	0.65	Often

1.00–1.80: Never, 1.80–2.60: Rarely, 2.61–3.40: Sometimes, 3.41–4.20: Often, 4.21–5.00: Always

Schnarr (2016), incorporating kinesthetic intelligence in elementary classrooms promotes engagement, and Chapman (2023) discusses how movement aids in knowledge acquisition, further demonstrating the importance of kinesthetic learning.

Kinesthetic learners are particularly interested in the real-world applications of biology, such as healthcare and agriculture, with a mean score of 3.35. This is aligned with Lodico's (2020) suggestion that incorporating real-world examples enhances kinesthetic involvement, making the material more engaging and relevant to students' experiences.

Overall, kinesthetic learning significantly enhances STEM students' performance, particularly in biology. The preference for hands-on activities (mean = 3.14) and active participation (mean = 3.30) shows that kinesthetic learners understand complex biological concepts better when physically engaged. These learners benefit from lab work, field experiments, and interactive experiences. In addition, the use of gestures to aid memory (mean = 3.10) helps with retention, and the focus on real-world applications (mean = 3.35) increases motivation. Studies by Olimpo and Esparza (2020), Dickson and Stephens (2014), and Pratiwi (2021) confirm that active learning strategies improve performance and critical thinking in biology, particularly for kinesthetic learners.

Integrated Findings

Visual learners benefit from tools like diagrams, models, and videos, which simplify complex concepts and improve retention. Auditory learners excel with lectures and discussions, where verbal explanations and repetition enhance understanding. Reading/writing learners thrive with text-based materials, using writing strategies such as summarizing and rewriting to reinforce their comprehension. Kinesthetic learners, on the other hand, engage more effectively through hands-on activities like fieldwork and lab experiments, which help them better understand biological concepts.

Information Processing Patterns of STEM Students

Parallel information processing pattern

The mean scores for parallel information processing among STEM students in biology range from 3.05 to 3.98, indicating "Sometimes" to "Often" based on the table 11 above. For example, the statement "*I can easily handle multiple sources of information in biology lessons*" scored 3.37, suggesting students occasionally handle multiple sources. In contrast, "*I enjoy learning biology through open-ended activities*" scored 3.98, indicating frequent enjoyment of interactive learning. This aligns with Kapici et al. (2019), who found that a mix of practical and virtual laboratories all at once enhances

knowledge and skill acquisition, promoting deeper cognitive engagement.

However, students struggle more with complex tasks, such as switching between concepts, with the statement *“I can easily switch between different biology concepts”* scoring the lowest at 3.05. The overall pooled mean score of 3.43 indicates that students engage in parallel processing sometimes but not consistently or effectively across all learning aspects.

This suggests that while interactive activities promote parallel processing, tasks requiring multitasking or cognitive flexibility, like switching concepts or understanding complex situations, are more challenging. Research by Bowman et al. (2015) and Carrier et al. (2015) suggests that multitasking can overload cognitive processes, reducing attention and academic performance. Thus, strategies to improve focus and cognitive flexibility could help students manage information more effectively, improving their STEM performance.

Sequential information processing pattern

As can be gleaned from table 11, the mean scores for sequential processing in STEM students in biology range from 3.87 to 4.41, indicating “Often” to “Always” behavior. For example, the statement *“I prefer to follow a step-by-step process when learning a biological process”* scored 4.27, suggesting students consistently prefer structured learning. Similarly, the statement *“I prefer biology lessons with a clear structure”* scored 4.41, showing students strongly favor organized content. The statement *“I follow lab procedures to avoid missing details”* scored 4.37, reflecting a high preference for clear instructions. However, *“I organize my biology notes in lists or outlines”* scored 3.93, and *“I find it challenging to focus when new information arises”* scored 3.87, indicating less consistency in these behaviors.

The pooled mean score of 4.17 suggests that STEM students predominantly engage in sequential processing when learning biology. This is supported by Sebesta and Bray Speth (2017), who noted that organizing materials helps self-regulated learning, improving exam preparation. Studies by Schmoker (2018) and Felder and Brent (2024) highlight that clear, structured instruction enhances understanding and maintains student interest. Similarly, Suskie (2018) emphasized the value of organized learning experiences in improving evaluation outcomes.

However, students show less consistency in organizing study materials, indicating room for improvement. Educators can use metacognitive strategies to promote self-regulation and organization, as suggested by Cottrell (2024) and Weinstein and Underwood (2014). The challenge students face with interruptions suggests the need for strategies to minimize distractions, especially in digital environments, as emphasized by Cheong et al. (2016) and Schmidt (2020). Interventions to address these distractions could improve concentration and overall learning, as argued by Cho (2016) and Rivera Vargas and Cobo Romani (2020).

Thus, while sequential processing is the dominant strategy for STEM students, challenges with organizing materials

and staying focused under interruptions suggest areas for improvement. Structured learning environments and strategies to enhance focus and organization could boost students’ performance in STEM subjects.

Top-down information processing pattern

The mean scores for top-down processing in STEM students in biology range from 3.63 to 4.24 as reflected in table 11 above, indicating that students often use prior knowledge to understand new concepts. For instance, *“I first think about how a new biology concept relates to what I already know”* scored 3.88, showing students frequently use their previous knowledge. *“I find it helpful to organize biology information into categories”* scored 3.93, and *“I can apply general principles to solve specific problems”* scored 3.63, both indicating regular reliance on prior knowledge for organizing and solving problems. The highest score of 4.24 was for *“I learn new biology concepts easier when they connect to things I already understand,”* showing that students always benefit from connecting new information to existing knowledge.

The pooled mean score of 3.91 reflects a strong tendency for students to engage in top-down processing. This suggests they rely on their existing knowledge to make sense of new biology content. As Etobro and Fabinu (2017) note, leveraging prior knowledge helps students understand complex biological principles. Generative learning strategies, such as organizing new information effectively, are also key, as seen in the use of conceptual maps (Fiorella and Mayer, 2016). In addition, cognitive tools like mental maps can enhance understanding by helping students integrate new and old knowledge (Jonassen and Carr, 2020).

However, students showed slightly lower scores for applying general principles to specific problems, suggesting some struggle with the complexity of biological systems. As Gause (2019) notes, the complexity of biological systems can make it difficult to apply principles in real-world scenarios. Traditional teaching methods can limit engagement with complex systems, but guided discovery and scaffolding techniques, as suggested by Janssen et al. (2014), can improve understanding. Tools like drawing models can also help visualize complex relationships in biology (Quillin and Thomas, 2015).

The high score for connecting new concepts to prior knowledge highlights the importance of constructivist learning, where building on existing knowledge promotes deeper understanding and retention (Bada and Olusegun, 2015). Abdi (2014) supports this, showing that inquiry-based learning based on prior knowledge enhances academic performance in science.

Hence, top-down processing is a key strategy for STEM students in biology. While students often apply general principles, further reinforcement of these skills could enhance their ability to connect broad principles to specific scenarios. Strengthening prior knowledge integration is essential to improving students’ ability to solve biological problems effectively.

Bottom-up information processing pattern

As can be seen from table 11 above, the mean scores for bottom-up processing in STEM students in biology range from 3.77 to 4.29, indicating that students often focus on details before understanding broader concepts. For instance, “I focus on specific biological details before trying to understand the big picture” scored 3.92, showing that students frequently start with details. Similarly, “I prefer to learn new biology topics by starting with concrete examples and then generalizing” scored 3.87, and “I break down complex biological processes into smaller steps” scored 3.89, both indicating a tendency to break down complex ideas. Furthermore, “I rely on my senses to learn about biological structures” scored 3.77, suggesting sensory experiences are a frequent but secondary approach. The highest score, 4.29, was for “I feel most confident in my biology knowledge when I have a strong foundation of facts and details,” indicating that students value a solid factual base.

Then, the pooled mean score of 3.95 reflects the general tendency to engage in bottom-up processing, where students focus on details before generalizing. This approach helps them form connections that lead to a broader understanding, as noted by Dansereau (2014) and Buehl (2023), who emphasize the value of focusing on details to understand larger concepts. In support of this, Killen and O’Toole (2023) argue that engaging with details fosters deeper understanding, while Nisbet and Shucksmith (2017) further assert that it promotes critical thinking.

Moreover, the high score for confidence in having a strong factual foundation supports Maclellan’s (2014) argument that confidence in one’s knowledge encourages active participation and risk-taking in learning. On the other hand, although sensory observations play a role in learning, the lower score for “I rely on my senses” (3.77) suggests that it is not always the primary method, though still valuable. In this regard, Beery and Jørgensen (2018) emphasize the importance of sensory involvement in learning, while Hayati et al. (2021) show that lab activities based on sensory systems improve scientific skills. Similarly, McMahon and Kovach advocate for using art to develop observational skills, and Tsybsky and Sinai (2022) highlight the benefits of integrating IoT (Internet of Things) for experiential learning.

However, despite these benefits, Bourcier and Babin (2024) note that sensory methods should be combined with structured approaches for deeper cognitive understanding. This suggests that while sensory observation is beneficial, it must be integrated with other strategies to maximize its effectiveness.

Therefore, bottom-up processing is an effective strategy for STEM students in biology, as it helps build confidence and understanding through a strong factual foundation and attention to detail. Nevertheless, there is potential to further integrate sensory and experiential learning to enrich this approach, ultimately enhancing students’ ability to understand complex biological concepts.

Table 12: Relationship between STEM students’ learning styles and information processing patterns

VARK learning styles	Information processing patterns			
	Parallel	Sequential	Top-down	Bottom-up
Visual	0.280**	0.332**	0.402**	0.367**
Auditory	0.325**	0.222**	0.370**	0.249**
Read/Write	0.297**	0.312**	0.329**	0.379**
Kinesthetic	0.324**	0.304**	0.252**	0.448**

**Relationship is significant at 0.01 level (2-tailed)

Key Findings

The study reveals distinct information processing patterns among STEM students in biology, highlighting preferences for parallel, sequential, top-down, and bottom-up processing. Parallel processing is used occasionally, with students enjoying interactive activities but struggling with multitasking and switching between concepts. Sequential processing is favored, with students preferring structured, step-by-step learning, though challenges in organizing study materials persist. Top-down processing shows students leveraging prior knowledge for new concepts, particularly in applying general principles, but struggle with complex biological systems. Bottom-up processing emphasizes focusing on details before generalizing, which builds confidence, though sensory observation remains secondary.

Correlation between Learning Styles and Information Processing Patterns

Table 12 presents the Pearson correlation coefficients computed to examine the relationship between STEM students’ learning styles, based on the VARK model, and their information processing patterns (Parallel, Sequential, Top-down, Bottom-up). The correlation analysis was conducted at the 0.01 level of significance (2-tailed). Preliminary assumption testing was performed to assess normality and homogeneity of variance, among other conditions, and no serious violations were detected.

For Visual learners, the data reveals moderate to strong correlations with several information processing patterns. The strongest correlation is with the Top-down processing pattern (0.402), indicating that visual learners tend to process information in a holistic and conceptual manner, beginning with general ideas before focusing on specific details. This approach aligns with the understanding that visual representations play a crucial role in scientific practices, facilitating both conceptual understanding and the generation of knowledge (Evagorou et al., 2015). Starting from general concepts, visual students can create framework to integrate more intricate biological data later. Knoll et al. (2017) as well, emphasize that visual students benefit particularly from an initial approach to general concepts. Renkl and Scheiter (2017) support even more this by illustrating that effective instruction should prioritize general ideas on visual screens, facilitating a more cohesive understanding of the content. Furthermore, Schneider et al. (2020) discovered

that decorative images serve as effective memory signs that can encourage students to recover information by connecting specific details back to general issues. Also, Coffrin et al. (2014) illustrated how students' participation and performance visualizations could even more improve understanding by maintaining a focus on general learning patterns. Collectively, these studies underline the critical role of holistic processing in the learning strategies of visual students.

The Bottom-up processing pattern also shows a moderate correlation (0.367), suggesting that visual learners are capable of focusing on specifics first and then forming broader concepts. Visual learners have a distinctive approach to the assimilation of information, prioritizing details such as visual details to build a complete understanding of wider concepts. This preference for concrete images often facilitates cognitive treatment and increased retention. Research has shown that the creation of visual explanations considerably strengthens the learning results, as it encourages learners to synthesize detailed information in coherent stories (Bobek and Tversky, 2016). As Offerdahl et al. (2017) further discuss the scaffolding of visual literacy in biochemistry, suggesting that an understanding of complex details can facilitate the understanding of complex general principles. To add, Rau (2017) addresses the effectiveness of multiple visual representations, arguing that they improve the results of STEM learning, encouraging students to recognize standards and relationships between biological systems. Together, these studies claim that attention to the details promoted in visual students is fundamental to their understanding of broader biological concepts.

In addition, moderate positive correlations with the Parallel (0.280) and Sequential (0.332) patterns indicate that visual learners can also process information in parallel or in a step-by-step manner, though these tendencies are less pronounced. Parallel treatment allows learners to simultaneously integrate several visual stimuli, promoting a more holistic understanding of complex subjects. For example, Akakura and Kano (2023) highlighted the effectiveness of visual learning aids in legal education, stressing how students could grasp interconnected concepts through two-dimensional learning models. However, this method can overwhelm certain learners, causing cognitive overload (Langer et al., 2017). On the other hand, step-by-step treatment facilitates structured learning by presenting information in sequential and manageable segments. This approach can improve understanding and retention, especially for learners who prefer a guided path (Jamulia, 2018). However, it can limit the ability to synthesize ideas in wider contexts, which is crucial for disciplines that require critical thinking and creativity (Liu et al., 2023).

Auditory learners show a notable correlation with top-down processing (0.370), which is similar to visual learners. This suggests that auditory learners are more likely to grasp general concepts first. The Parallel processing pattern (0.325) also shows a moderate correlation, indicating that auditory learners tend to process information simultaneously in various ways.

However, the correlation with sequential processing is weaker (0.222), and the relationship with Bottom-up processing is the weakest of all (0.249), suggesting that auditory learners are less focused on detailed, step-by-step analysis – according to Putra et al. (2020), some studies indicate that auditory learners may struggle with detailed analysis, with only 1 in 5 reaching higher levels of proportional reasoning. However, these learners are more likely to take a broader, holistic approach. As Sreenidhi and Helena (2017) explained, auditory students tend to prioritize a holistic understanding of the concepts, often avoiding a detailed analysis in favor of establishing broader connections between ideas. This trend allows them to understand general issues more quickly than their visual counterparts, which generally trust visual stimuli and detailed representations.

For Read/Write learners, the correlations show a preference for more structured and linear processing patterns. The strongest correlations are with the Sequential (0.312) and Top-down (0.329) processing patterns, highlighting that these learners are inclined to process information in an organized, step-by-step fashion while also approaching information from a broader conceptual perspective. The correlation with Parallel processing is moderate (0.297), suggesting that read/write learners may also process information in parallel but likely in a more methodical and ordered manner. To support this result, Spires et al. (2019) argue that disciplinary literacy, which combines reading and writing strategies, can improve the understanding of students of complex ideas by maintaining a structured approach to learning. Aside from that, Greenleaf et al. (2023) highlight how the reading of the apprenticeship can facilitate a deeper understanding of the content, allowing students to pass between detailed analyses and holistic synthesis. These results suggest that effective learning strategies should not only consider the cognitive processing preferences of reading/writing students but also to encourage environments that promote sequential approaches and integrate with learning, improving general educational practices.

Kinesthetic learners exhibit the most balanced correlations across all information processing patterns. The strongest correlation is with bottom-up processing (0.448), which indicates that kinesthetic learners tend to focus on specific details before making broader conclusions. Educators have noted that kinesthetic strategies facilitate more in-depth learning because these approaches allow students to link theoretical knowledge to practical applications (Mosley, 2022). This is followed by a moderate correlation with Sequential processing (0.304), suggesting a step-by-step approach. The parallel (0.324) and top-down (0.252) patterns also show moderate correlations, indicating that kinesthetic learners can handle parallel processing and conceptualize ideas in a broader sense, though to a lesser degree than the bottom-up and sequential patterns. As known, kinesthetic students develop information through physical movement and interaction, which improve their conceptual understanding of biology. The research indicates that the incorporation of movement in lessons can support this learning style (Taduran and Nasol, 2021). For example, the use of

models and simulations allows these students to view biological processes, promoting a deeper understanding (Mnguni, 2014). In addition, actions embodied in the learning environments, as discussed by DeSutter and Stieff (2017), facilitate space thought and the connection of concepts through active participation.

Overall, the study revealed significant correlations between learning style preferences and information processing patterns, suggesting that learners engage with biological content in diverse ways. However, given the critiques of learning styles frameworks and the correlational nature of this study, these results should be seen as indicative of learner tendencies rather than prescriptive recommendations for instruction.

Educational practice can benefit from acknowledging these preferences while emphasizing evidence-based cognitive strategies, such as scaffolding prior knowledge, fostering metacognitive awareness, and managing cognitive load. Future research should explore how these strategies interact with learner characteristics to optimize biology instruction. Ultimately, a balanced approach that combines learner preferences with established cognitive principles is likely to yield the most effective educational outcomes in STEM contexts.

CONCLUSION

This study successfully achieved its objectives by identifying and analyzing the learning styles and information processing patterns of Grade 11 and 12 STEM students in Biology.

To Describe the Learning Styles of STEM Students with Respect to

Visual learning style

With a pooled mean of 3.42, which falls under the “Strongly Agree” category, STEM students demonstrated a clear preference for visual learning. They found diagrams, charts, and illustrations extremely helpful in understanding complex biological concepts. Visual aids, such as mind maps and concept diagrams, were also frequently used by these students to enhance their understanding, indicating that visual representations are crucial to their learning process.

Auditory learning style

The pooled mean of 3.08, categorized as “Agree,” suggests that auditory learners in STEM prefer learning through lectures, discussions, and audio recordings. Although this group showed a moderate preference for auditory learning strategies, they still benefit from listening to explanations and discussing topics with peers, especially for better comprehension of biological processes. Auditory learners, while agreeing with the benefits of group discussions and audio resources, did not exhibit as strong a preference as visual learners did for auditory-based materials.

Read/write learning style

With a pooled mean of 3.06, categorized as “Agree,” read/write learners in STEM students preferred text-based materials such as textbooks, articles, and written notes. They were inclined to take detailed written notes and create written

summaries to consolidate their learning. This suggests that read/write learners favor a structured approach to learning through writing, which helps them better understand and retain biological concepts.

Kinesthetic learning style

The pooled mean of 3.17, categorized as “Agree,” indicates that kinesthetic learners also prefer hands-on experiences to understand biological concepts. These students enjoy engaging in lab work, field activities, and experiments to reinforce their learning. Their strong preference for real-world applications and practical experiences highlights the importance of incorporating interactive and experiential learning opportunities in STEM education.

To Describe the Information Processing Patterns of STEM Students with Respect to

Parallel processing

The pooled mean of 3.43, categorized as “Sometimes,” indicates that students occasionally engage in parallel processing. While they are able to manage multiple information streams at once, such as integrating various biological concepts simultaneously, they do not consistently exhibit this ability. Students enjoy interactive and open-ended activities, like experiments, which can encourage parallel processing. However, they may struggle when tasks become more complex or require quick transitions between concepts.

Sequential processing

With a pooled mean of 4.17, categorized as “Often,” sequential processing was the most frequently used pattern among STEM students. These students preferred structured learning environments where they could follow biological processes in a step-by-step manner. They paid attention to detail and typically adhered to organized study materials, such as outlines or lists. This indicates that STEM students find sequential learning methods highly effective, as they help ensure that each concept is mastered before moving on to the next.

Top-down processing

The pooled mean of 3.91, categorized as “Often,” indicates that students frequently used top-down processing when learning biology. They relied on their prior knowledge and conceptual frameworks to understand new biological concepts. This suggests that students benefit from learning new material by connecting it to what they already know, which allows them to apply general principles to specific biological problems.

Bottom-up processing

The pooled mean of 3.95, categorized as “Often,” suggests that students frequently used bottom-up processing. They focused on specific details, such as cell structures or steps in a biological process, before understanding the broader concepts. This method allowed students to build a strong foundation of facts, which they could later apply to understand more complex ideas. Students’ confidence in their knowledge was strongly tied to a solid understanding of foundational details, which helped them piece together broader biological concepts.

To Examine if a Significant Relationship Exists between STEM Students' Learning Styles and Information Processing Patterns

- Visual learners showed strong correlations with top-down processing (0.402) and bottom-up processing (0.367). This suggests that visual learners tend to process information both holistically (top-down) and in detail (bottom-up), making visual aids, such as diagrams and charts, crucial in supporting their cognitive processing.
- Auditory learners were most closely aligned with top-down processing (0.370), indicating that they process information more holistically and benefit from listening to general concepts before diving into specific details. They also showed moderate correlations with parallel processing (0.325), suggesting they can manage simultaneous streams of auditory information.
- Read/write learners had moderate correlations with sequential processing (0.312) and top-down processing (0.329), indicating that they prefer structured, linear information processing while also organizing new information by connecting it to existing knowledge.
- Kinesthetic learners demonstrated the strongest correlation with bottom-up processing (0.448), as they tend to focus on specific details and build up their understanding through hands-on experiences. They also showed moderate correlations with sequential processing (0.304) and parallel processing (0.324), indicating that while they may prefer hands-on learning, they can also engage in structured and simultaneous processing of information when needed.

From the findings, since these correlations are significant (with p -values < 0.01), the null hypothesis (H_0), which states that “there is no significant relationship between STEM students' learning styles and information processing patterns,” would be rejected.

Thus, the alternative hypothesis (H_a), which states “*there is a significant relationship between STEM students' learning styles and information processing patterns,*” was accepted based on the significant correlation results.

Therefore, the study successfully described the learning styles and information processing patterns of STEM students and examined the relationships between these factors. Though, considering the criticisms of learning styles theories specifically, the VARK and the study's correlational design, the findings should be interpreted as reflecting general learner preferences rather than direct guidance for teaching methods.

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