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Exploring students' conceptual understanding and cognitive processes in human anatomy learning in the Biology Education Program Universitas Negeri Medan

Rahmad H. Gultom [1*], Aristo Hardinata[1], Dina Handayani[1], Shofia Lubis[1], Nanda Pratiwi[1]
[1]Department of Biology, Universitas Negeri Medan, Indonesia
*E-mail: rahmad.bioed@unimed.ac.id

Abstract. Human anatomy learning in biology education often faces challenges, including difficulties with 3D spatial visualization, high cognitive load, and persistent misconceptions in topics such as the digestive, circulatory, and respiratory systems, which contribute to low conceptual understanding. Although previous studies have identified these learning difficulties, limited research has examined the relationship between students' conceptual understanding and cognitive processes in anatomy learning, particularly in Biology Education programs in Indonesia. This preliminary study aims to analyze the conceptual understanding and cognitive processes of Biology Education students at Universitas Negeri Medan using an exploratory mixed-methods approach involving 60 students from semesters 4–6. Data were collected through a two-tier diagnostic test (reliability = 0.85), think-aloud protocols based on the revised Bloom's Taxonomy, classroom observations, and semi-structured interviews, and analyzed using SPSS 26. The findings show that most students were in the moderate and low categories of conceptual understanding, with cognitive processes dominated by lower- to mid-level skills (remembering 22%, understanding 30%) and limited higher-order thinking skills (HOTS). Misconceptions were found, including viewing enzyme function only as a metabolic process. Observations and interviews also revealed students' dependence on rote memorization and passive learning. These findings highlight the need for adaptive, AI-based, and visually interactive anatomy learning to foster deeper understanding and support curriculum innovation in biology education.
Keywords: Adaptive learning, Cognitive processes, Conceptual understanding, Human anatomy

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INTRODUCTION

Human anatomy learning constitutes one of the fundamental pillars in the biology education curriculum, particularly for students of the Biology Education Study Program at Universitas Negeri Medan. A comprehensive understanding of the structure and functions of the human body is fundamental not only for building a strong scientific knowledge base but also for fostering the pedagogical competence of future biology teachers, allowing them to effectively incorporate anatomical concepts into science instruction at both elementary and secondary education levels (Chandak et al., 2023; Cofré et al., 2023). However, numerous studies indicate that students often encounter difficulties in achieving optimal conceptual understanding, due to the complexity of three-dimensional spatial visualization, high cognitive load, and limited access to dissection practicum as a result of ethical regulations and laboratory constraints (Jian & Abu Bakar, 2024)

In the context of biology education in Indonesia, human anatomy learning still largely relies on conventional methods such as lectures and textbooks, which tend to promote surface learning rather than deep learning. Initial studies indicate that students' cognitive processes, including knowledge acquisition, schema integration, and knowledge transfer, are often hindered by misconceptions about the learning material (Hendriyanto et al., 2024). The COVID-19 pandemic has intensified this challenge due to the shift toward online learning, in which resources such as virtual cadaver videos and three-dimensional models have demonstrated effectiveness in supporting learning (Diaz et al., 2021). Preliminary analysis is required to map students' conceptual understanding profiles and cognitive processes, as an initial step toward developing adaptive technology-based interventions (Khine, 2024)

The importance of this preliminary analysis lies in the early identification of misconceptions and patterns of cognitive processes, such as spatial ability and information processing, which influence the achievement of intended learning outcomes (Rusli et al., 2025). Recent studies indicate that integrating interactive media such as augmented reality (AR) and virtual laboratories (VL) can enhance conceptual understanding (Altmeyer et al., 2020). However, local adaptation in public universities, such as Universitas Negeri Medan, remains limited. At the national level, this underscores the need for contextual research that bridges cognitive theory with the practice of teaching anatomy (Valcke et al., 2025). Without such analysis, students risk failing to transfer knowledge into educational practice, which in turn affects the quality of future science teachers (Darling-Hammond et al., 2020)

This study aims to analyze the level of conceptual understanding among biology students at Universitas Negeri Medan regarding human anatomy topics using diagnostic instruments, identify dominant cognitive processes based on the revised Bloom's Taxonomy, and formulate recommendations for an adaptive, AI-based learning model. Theoretically, the findings enrich the biology education literature with empirical data. Practically, the recommendations can be adopted by the faculty to enhance the quality of instruction, in alignment with the Merdeka Belajar Kampus Merdeka policy. This introduction emphasizes that the preliminary analysis is not merely a descriptive exploration but rather a strategic foundation for innovation in anatomy education at Universitas Negeri Medan, with potential for replication in other higher education institutions across Indonesia.

METHOD

Research Design

This study used a sequential explanatory mixed-methods design to analyze students' conceptual understanding and cognitive processes in human anatomy learning. Quantitative data were collected first to identify students' conceptual understanding, followed by qualitative data to explore cognitive processes and misconceptions in greater depth (Ayeh, 2025).

Participants

The participants were 60 Biology Education students (semesters 4-6) at the Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, selected through purposive sampling. All participants had completed the Human Anatomy and Physiology course.

Instruments

Data were collected using four instruments: (1) a 20-item two-tier diagnostic test on the digestive, circulatory, and respiratory systems (Cronbach's $\alpha = 0.85$); (2) think-aloud protocols based on the revised Bloom's Taxonomy; (3) classroom observation sheets; and (4) semi-structured interviews with 15 selected students.

Procedure

The study was conducted over four weeks: diagnostic testing (week 1), think-aloud sessions (week 2), classroom observations (week 3), and interviews (week 4).

Data Analysis

Quantitative data were analyzed descriptively using percentages, means, and standard deviations with SPSS 26. Qualitative data from think-aloud protocols, observations, and interviews were analyzed thematically using the Miles and Huberman framework (Solihin et al., 2025). Data triangulation was applied to strengthen the validity of the findings.

RESULTS AND DISCUSSION

Result

1. Students' Level of Conceptual Understanding

The results of the two-tier diagnostic test indicate that students' conceptual understanding remains varied, with a tendency toward moderate to low levels. The distribution of students' conceptual understanding, summarized in Table 1, shows that only 18% demonstrate a high level of understanding, while the majority (47%) fall into the moderate category, and the remaining 35% into the low category. These findings suggest that most students struggle to integrate fundamental anatomical concepts with scientifically accurate explanations, particularly in topics related to the circulatory and respiratory systems.

Table 1. Distribution of Students' Conceptual Understanding Levels

Level of Understanding	Percentage (%)	Description
High	18%	Students are able to answer both tiers correctly and provide accurate scientific reasoning.
Moderate	47%	The answers are correct, but the reasoning is incomplete or only partially accurate.
Low	35%	Both answers and reasoning are inconsistent with the correct concepts

These findings are consistent with the study by Sembiring & Yusuf (2025) which revealed that students still experience difficulties in comprehending biological concepts holistically, particularly in abstract topics. This highlights the importance of developing more effective instructional strategies to address these challenges.

2. Analysis of Conceptual Errors

Further analysis of students' responses reveals dominant misconceptions across several key concepts. In the digestive system, enzyme functions are often misinterpreted as mechanical processes. In the circulatory system, the fundamental differences between arteries and veins are not yet conceptually understood. Finally, in the respiratory system, gas diffusion is often mediated by active rather than passive processes. These misconceptions indicate a fundamental conceptual gap and require particular attention in the instructional process.

3. Distribution of Cognitive Processes

The think-aloud analysis, as summarized in Table 2, illustrates the distribution of students' cognitive processes while solving the tasks. The results show a dominance of low- to mid-level cognitive processes (remember–understand), while higher-order thinking skills (HOTS) remain limited. The remembering process accounts for 22% of total responses, followed by understanding at 30%. The processes of applying, analyzing, evaluating, and creating account for 18%, 15%, 10%, and 5%, respectively.

Table 2. Distribution of Students' Cognitive Processes

Cognitive Process	Frequency (%)	Example of Verbal Response
Remembering (Remember)	22%	"This is like what's in the book, the function of the stomach..."
Understanding (Understand)	30%	"So it means food is broken down first before being absorbed"
Applying (Apply)	18%	"In this case, it means oxygen enters the bloodstream"
Analyzing (Analyze)	15%	"Why is the flow different between arteries and veins?"
Evaluating (Evaluate)	10%	"This answer seems incorrect because..."
Creating (Create)	5%	"If we made a 3D model, the flow might look like this..."

4. Learning Observation

Practicum observations conducted during human anatomy learning sessions reveal several important patterns related to students' learning behaviors and engagement. The findings indicate that many students tend to adopt passive learning approaches, particularly during practical activities that require independent exploration and conceptual analysis. Instead of actively investigating anatomical structures through observation and discussion, students often wait for direct instructions or explanations from lecturers before engaging with the material. This dependency suggests that students have not yet developed sufficient autonomy in constructing their own understanding of anatomical concepts.

In addition, students rely heavily on textbooks as their primary source of information. While textbooks provide essential theoretical knowledge, their overuse often limits students' opportunities to explore anatomy through more dynamic and visual learning experiences. During practicum sessions, students frequently focus on following procedural steps rather than critically analyzing the anatomical structures being observed. Their attention is often directed toward completing tasks rather than understanding the relationships between structure and function.

Another notable observation is that students' visualization of anatomical structures remains predominantly two-dimensional, often in the form of textbook illustrations or static presentation slides. This limitation poses significant challenges in anatomy learning, as the subject inherently requires strong spatial reasoning and the ability to mentally reconstruct three-dimensional forms. As a result, many students struggle to accurately interpret the orientation, location, and interconnections of organs and body systems.

Furthermore, classroom interactions among students are largely procedural rather than conceptual. Discussions are often centered on "what to do" rather than "why it happens" or "how it works." This indicates that students may be more focused on task completion than on achieving deeper conceptual understanding. Such learning behavior may contribute to fragmented knowledge and misconceptions, particularly when dealing with complex anatomical systems. Overall, these observations suggest that students' learning styles are generally passive, highly dependent on external guidance, and less oriented toward active knowledge construction. The findings emphasize the need for instructional improvements, particularly through the integration of interactive, technology-supported, and visually rich learning media. Such innovations could promote greater student engagement, encourage independent exploration, and facilitate deeper conceptual understanding of human anatomy.

5. Interview Results

The interview results provide further insights into the challenges students face in learning human anatomy. Several recurring themes emerged from the interviews, including difficulties in visualization, reliance on memorization, and the perceived need for more interactive learning media. These findings complement the observation results and offer a deeper understanding of students' cognitive experiences during anatomy learning.

The first major theme identified was the difficulty of visualizing anatomical structures, especially in three-dimensional forms. Many students reported that they often find it challenging to imagine the actual shapes, positions, and spatial relationships of organs solely from textbook images or lecturer explanations. For example, students expressed confusion when trying to understand how organs are layered, connected, or oriented within the human body. This challenge becomes even more pronounced when learning systems are highly complex, such as the nervous, circulatory, or digestive systems.

The second theme relates to students' heavy reliance on memorization as their primary learning strategy. Most participants admitted that they tend to memorize the names, parts, and functions of organs without fully understanding their interrelationships. While memorization can help in recalling factual information, students acknowledged that it often becomes ineffective when they are required to explain physiological mechanisms or apply anatomical knowledge to solve problems. This indicates that learning is still dominated by surface-level cognitive processes rather than deeper conceptual processing.

Another important finding is the students' recognition of the limitations of current learning resources. Several participants stated that conventional learning materials, such as printed diagrams and lecture slides, are insufficient for helping them build a comprehensive understanding of complex anatomical systems. Students expressed strong interest in interactive, technology-based learning media, particularly augmented reality (AR), virtual simulations, and 3D anatomical models. They believe that such tools would make learning more engaging, improve visualization, and help bridge the gap between abstract concepts and concrete understanding.

Overall, the interview findings highlight that students experience both cognitive and instructional barriers in anatomy learning. Their difficulties in spatial visualization and tendency to rely on rote memorization indicate the need for more innovative teaching approaches. Integrating interactive digital media could potentially enhance conceptual understanding, foster active learning, and reduce misconceptions in human anatomy education.

Discussion

The findings of this study demonstrate that students' conceptual understanding of human anatomy learning remains predominantly at moderate and low levels. These findings are consistent with the study by Silldorff & Robinson (2023), which demonstrates that critical thinking skills make a significant contribution to the understanding of biological concepts. The dominance of lower-level cognitive processes indicates the need for instructional interventions that place greater emphasis on the development of higher-order thinking skills (HOTS) (Ghanizadeh et al., 2020). The fact that only 18% of students achieved a high level of understanding indicates that many students still struggle to connect factual knowledge with scientific reasoning. This condition suggests that anatomy learning has not yet fully facilitated meaningful conceptual construction. According to constructivist learning theory, conceptual understanding is developed when students actively integrate prior knowledge with new experiences (Lascsakova, 2024). However, the results indicate that students tend to focus more on memorization than on conceptual integration (Abdillah & Pertiwi, 2025). This finding aligns with the study of Banks et al. (2023), which emphasized that biological concepts, especially abstract and complex ones, are often difficult to understand holistically.

The analysis of conceptual errors further reveals significant misconceptions in the digestive, circulatory, and respiratory systems. Misunderstandings about enzyme functions, blood vessel differentiation, and gas diffusion mechanisms suggest that students often oversimplify biological processes or incorrectly transfer prior knowledge into new contexts. These misconceptions are critical because they may persist and hinder future learning. In biology education, misconceptions are known to be resistant to change unless explicitly addressed through conceptual change strategies. Therefore, instructional approaches that encourage confrontation of incorrect ideas, such as inquiry-based learning or problem-based learning, are necessary (Šmida & Čipková, 2026).

The distribution of cognitive processes shows a strong dominance of lower-order thinking skills, particularly remembering and understanding, which together account for more than half of the responses. In contrast, higher-order cognitive processes such as analyzing, evaluating, and creating remain significantly limited. This pattern indicates that students are primarily engaged in surface-level learning rather than deep conceptual processing. The low percentage of creation (5%) reflects limited opportunities for students to synthesize and reconstruct anatomical knowledge in innovative ways. These findings support Aisyah and

Kurniawati (2026), who highlighted that critical thinking skills contribute significantly to mastery of biological concepts. The dominance of lower cognitive levels suggests that anatomy instruction should be redesigned to include activities that stimulate analysis, evaluation, and creative problem-solving.

Learning observations strengthen these findings by showing that students remain passive during practicum activities and remain highly dependent on lecturers and textbooks (Apriani & Sudrajat, 2025). Such dependency limits independent exploration and reduces students' opportunities to construct their own understanding. The reliance on two-dimensional anatomical representations may also contribute to difficulties in visualizing organ systems and their interactions (Miranda & Wibowo, 2023; Putra & Suhartini, 2025). Human anatomy is inherently spatial and complex; therefore, inadequate visualization can reduce students' comprehension of structural relationships.

The interview results further confirm these issues by highlighting students' difficulties in visualizing anatomical structures, their dependence on memorization, and their demand for interactive learning media. These findings indicate that the challenges in anatomy learning are not solely cognitive but also related to instructional media and learning design. The students' preference for technology-based media such as augmented reality (AR) and 3D models suggests a potential direction for improving anatomy instruction. Previous studies have shown that immersive and interactive visualization tools can enhance conceptual understanding, reduce misconceptions, and improve engagement in science learning.

CONCLUSION

This study reveals that students' conceptual understanding of human anatomy in the Biology Education Program remains predominantly at moderate and low levels, indicating persistent difficulties in connecting anatomical concepts with scientific reasoning. The findings also identify several major misconceptions in the digestive, circulatory, and respiratory systems, which reflect gaps in fundamental biological understanding. The analysis of cognitive processes shows that students are still dominated by lower-order thinking skills, particularly remembering and understanding, while higher-order thinking skills such as analyzing, evaluating, and creating are less frequently demonstrated. This condition is further supported by learning observations and interview results, which indicate passive learning habits, strong reliance on memorization, and difficulties in visualizing complex anatomical structures. These findings suggest that human anatomy instruction should be improved through more innovative, student-centered learning approaches. The integration of interactive learning media, such as augmented reality (AR) and 3D models, along with strategies that promote active learning and higher-order thinking skills, may help strengthen students' conceptual understanding and reduce misconceptions. Future studies are recommended to develop and evaluate such instructional interventions to improve the quality of anatomy education.

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