

Understanding Learner Variability in Biology Education: Learning Needs and Barriers among University Students in Papua

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ABSTRACT

Understanding learner variability is fundamental to developing inclusive learning environments in higher education, particularly in Biology education where students encounter complex and abstract scientific concepts. However, empirical evidence describing students' learning needs and barriers in underrepresented contexts such as Papua remains limited. This study aimed to explore learner variability by identifying the learning needs and barriers experienced by undergraduate Biology Education students at Universitas Cenderawasih, Indonesia. A qualitative descriptive design was employed using a learning needs questionnaire, focus group discussions, and field observations. Data were analyzed through thematic analysis, while questionnaire responses were used to support and triangulate the qualitative findings. Four major themes emerged from the analysis: learner variability is shaped by diverse educational, sociocultural, and technological backgrounds; understanding abstract biological concepts requires multiple forms of representation; classroom participation is influenced by psychological and instructional factors; and students prefer flexible approaches for demonstrating learning. These findings indicate that learning barriers are closely associated with contextual and instructional factors rather than students' academic ability alone. The study highlights the importance of understanding learner variability prior to designing instructional interventions and emphasizes the need for flexible teaching, learning resources, and assessment practices that accommodate diverse learner characteristics. The findings provide empirical evidence to support more inclusive and equitable Biology education in higher education.

Keywords: Learner Variability; Biology Education; Inclusive Higher Education; Learning Barriers

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INTRODUCTION

Higher education has become increasingly diverse as universities enroll students with wide-ranging academic, cultural, linguistic, and socioeconomic backgrounds. Rather than representing exceptions, learner differences have become an inherent characteristic of contemporary classrooms, requiring instructional practices that acknowledge variability as a normal condition of learning (Ainscow, 2020; Florian & Black-Hawkins, 2011; Hockings, 2010). Students differ not only in their prior knowledge and academic preparedness but also in how they access information, engage with learning activities, and demonstrate their understanding (Florian & Black-Hawkins, 2011; CAST, 2018). Consequently, instructional approaches designed for an "average learner" often fail to accommodate this diversity, creating unnecessary barriers that may hinder meaningful participation and academic success (Bunbury, 2020; Hockings, 2010).

Learner variability is particularly evident in science education, where students are expected to understand complex concepts while simultaneously developing scientific reasoning, problem-solving abilities, and practical competencies. Biology education presents additional challenges because many biological phenomena involve abstract structures, microscopic processes, and specialized scientific terminology that are difficult to visualize and conceptualize. Students therefore require learning experiences that provide multiple opportunities to construct understanding through different forms of representation and interaction (CAST, 2018; Meyer et al., 2014; Tobin & Behling, 2018). However, instructional practices in many higher education settings continue to rely heavily on lecture-based delivery, text-dominated learning materials, and standardized assessment formats, limiting students' opportunities to learn according to their diverse strengths and preferences (Dean et al., 2017; Rogers-Shaw et al., 2018; Sasson et al., 2022).

These challenges become more pronounced in geographically and culturally diverse regions such as Papua, Indonesia. Students entering universities in Papua come from heterogeneous educational environments characterized by differences in schooling experiences, language use, access to educational resources, and exposure to digital technologies (Arantes et al., 2025; Nurbaya, 2024a; Nurbaya, 2024b). Such diversity contributes to considerable variation in academic literacy, technological readiness, confidence in classroom participation, and approaches to learning (Nurbaya, 2023; Arantes et al., 2025). These differences should not be interpreted as individual deficiencies but rather as expressions of learner variability that require responsive educational environments (Ainscow, 2020; Florian & Black-Hawkins, 2011). Nevertheless, empirical evidence describing how these diverse characteristics shape students' learning needs and barriers within higher education remains limited, particularly in Biology Education (Nisa et al., 2023; Riswari et al., 2022).

Existing research on inclusive higher education has primarily focused on evaluating instructional interventions, accessibility strategies, or the implementation of Universal Design for Learning (UDL) (Dalton et al., 2019; Fornauf & Erickson, 2020; Tobin & Behling, 2018). Although these studies have demonstrated the potential of inclusive instructional frameworks to improve participation and engagement, relatively little attention has been paid to understanding learner variability before instructional interventions are designed. In other words, while considerable effort has been devoted to developing inclusive pedagogies, fewer studies have investigated the contextual learning needs and barriers that should inform those pedagogical decisions (Florian & Black-Hawkins, 2011; Ainscow, 2020; Rončević & Rieckmann, 2025). This gap is especially apparent in underrepresented educational contexts, where evidence describing students' lived learning experiences is still scarce (Fauziyah et al., 2025; Riswari et al., 2022).

Understanding learner variability is therefore a critical prerequisite for designing responsive and inclusive learning environments (Florian & Black-Hawkins, 2011; Ainscow, 2020). Identifying how students experience learning barriers, what forms of support they require, and how they prefer to engage with learning provides essential evidence for instructional decision-making (CAST, 2018; Meyer et al., 2014). Such evidence enables educators to move beyond generalized assumptions about students and toward learning environments that are grounded in the realities of learners' experiences (Hockings, 2010; Bunbury, 2020). For Biology Education, where conceptual complexity intersects with substantial learner diversity, a systematic understanding of students' learning needs becomes particularly important for improving both access to learning and educational quality (Fornauf & Erickson, 2020; Dalton et al., 2019).

Against this background, the present study explores learner variability among undergraduate Biology Education students at Universitas Cenderawasih, Papua. Rather than evaluating a particular instructional intervention, this study seeks to understand the diversity of students' learning needs and the barriers they encounter during the learning process. Specifically (Ainscow, 2020; Florian & Black-Hawkins, 2011; Riswari et al., 2022), the study addresses the following research questions: (1) What learning needs characterize learner

variability among Biology Education students in Papua? and (2) What learning barriers do these students experience during university learning? By providing empirical evidence from an underrepresented higher education context, this study contributes to the growing literature on inclusive education by demonstrating how contextual understanding of learner variability can inform future instructional design and support more equitable learning opportunities

METHOD

This study employed a qualitative descriptive design to explore learner variability by identifying the learning needs and barriers experienced by undergraduate Biology Education students in Papua (Kim et al., 2017). The study utilized data generated during the needs assessment phase of a broader instructional development project; however, the present article focuses exclusively on understanding students' learning experiences prior to instructional intervention. A qualitative approach was considered appropriate because it enables an in-depth exploration of participants' perspectives, learning challenges, and contextual experiences that cannot be adequately captured through quantitative measures alone (Creswell & Poth, 2018; Merriam & Tisdell, 2016; Patton, 2015).

The study was conducted in the Biology Education Study Program, Faculty of Teacher Training and Education, Universitas Cenderawasih, Papua, Indonesia. The participants were undergraduate students enrolled in the Animal Developmental Structure I course. Participants were selected using purposive sampling to ensure that they had direct experience with the learning context under investigation. Students were eligible to participate if they (1) were officially enrolled in the course during the study period, (2) actively participated in classroom learning activities, and (3) voluntarily agreed to participate in the research. The participants represented diverse educational, cultural, and geographical backgrounds across Papua, providing rich information regarding learner variability in higher education.

Data were collected between March and June 2026 using two complementary techniques: a learning needs questionnaire and Focus Group Discussions (FGDs). The questionnaire was designed to identify students' perceptions of their learning experiences, preferred learning strategies, accessibility to learning resources, classroom participation, assessment preferences, and perceived learning difficulties. The questionnaire primarily served to provide an overview of common patterns of learner variability across participants.

The qualitative data obtained from the FGDs and field notes were analyzed using thematic analysis. The analysis involved (1) familiarization with the data through repeated reading of the transcripts, (2) initial coding of meaningful data segments, (3) searching for patterns among codes, (4) reviewing and refining candidate themes, (5) defining and naming the final themes, and (6) producing an interpretative narrative supported by representative participant quotations (Creswell & Poth, 2018; Saldaña, 2021). Questionnaire responses were analyzed descriptively to identify the frequency of students' perceived learning needs and barriers. Rather than testing hypotheses, the questionnaire findings were used to complement and triangulate the qualitative themes emerging from the FGDs (Miles et al., 2020). Data triangulation between questionnaires, FGDs, and field observations was employed to enhance the credibility of the findings by comparing information obtained from multiple sources (Lincoln & Guba, 1985; Patton, 2015).

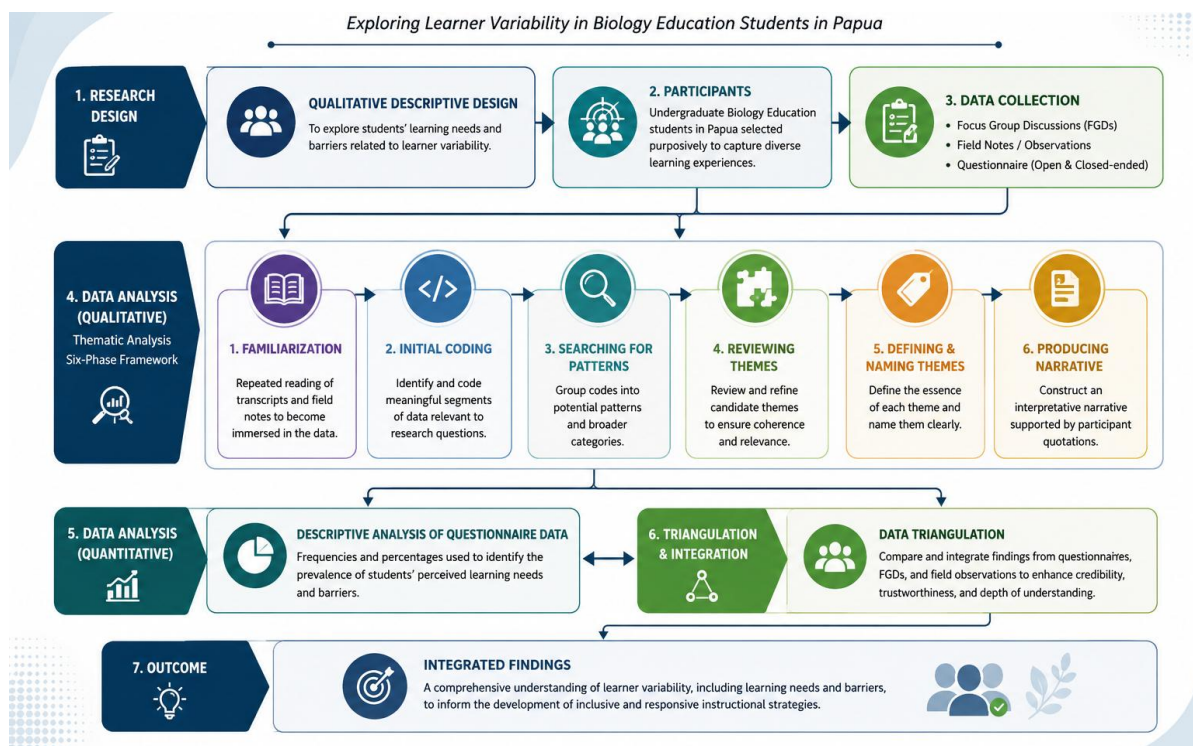


Figure 1. Research Methodology Flowchart

RESULT AND DISCUSSION

Learner Variability Emerges from Diverse Educational Backgrounds

The analysis revealed that learner variability among Biology Education students was strongly influenced by differences in prior educational experiences, geographical origin, language background, and exposure to learning technologies (Ainscow, 2020; Florian & Black-Hawkins, 2011; Arantes et al., 2025). Students entered university with unequal academic preparation, resulting in considerable variation in biological knowledge, learning confidence, and digital competence (Nurbaya, 2023; Nurbaya, 2024a; Nurbaya, 2024b). Rather than representing isolated individual characteristics, these differences collectively shaped how students approached learning in higher education (Hockings, 2010; Kahu, 2013; Riswari et al., 2022).

Table 1. Themes, Categories, and Initial Codes Describing Learner Variability among Biology Education Students

Theme	Categories	Initial Codes
Learner variability emerges from diverse educational backgrounds	Diverse educational experiences	Differences in schooling experiences; unequal academic preparation; varied educational opportunities
	Sociocultural diversity	Cultural background; language diversity; geographical differences
	Technological readiness	Unequal digital literacy; limited experience using learning platforms; access to technology

Table 1 illustrates that learner variability among Biology Education students is not confined to differences in academic ability but is shaped by a complex interaction of educational, sociocultural, and technological factors. Students entered university with markedly different educational experiences, reflecting disparities in the quality of prior schooling, exposure to biology learning, and opportunities to develop independent learning skills. These differences were further compounded by the diverse sociocultural backgrounds of students,

including variations in language use, local cultural contexts, and geographical conditions across Papua. In addition, unequal access to digital technologies and differing levels of digital literacy influenced students' readiness to engage with technology-enhanced learning environments. Collectively, these findings indicate that learner variability is embedded within students' lived educational experiences rather than being attributable solely to individual academic performance. The multidimensional nature of learner variability has important implications for instructional planning in higher education (Florian & Black-Hawkins, 2011; Ainscow, 2020; Hockings, 2010). When students possess diverse educational histories, cultural identities, and technological competencies, adopting a uniform instructional approach is unlikely to meet the learning needs of all students (Bunbury, 2020; Heemskerk et al., 2011; Arantes et al., 2025). Instead, effective learning environments should recognize variability as an expected characteristic of the student population and proactively accommodate these differences through flexible instructional strategies and accessible learning resources (CAST, 2018; Meyer et al., 2014; Tobin & Behling, 2018). Understanding learner variability from this broader perspective enables educators to move beyond deficit-oriented assumptions and toward a more inclusive view of learning, in which diversity is regarded as a valuable educational resource rather than a challenge to be overcome (Ainscow, 2020; Florian & Black-Hawkins, 2011; Rončević & Rieckmann, 2025). This perspective provides a critical foundation for designing equitable learning experiences that maximize participation and support meaningful learning outcomes for students with diverse backgrounds (Dalton et al., 2019; Fornauf & Erickson, 2020; Seale, 2014).

Understanding Abstract Biological Concepts Requires Multiple Forms of Representation

Students consistently described conceptual understanding as one of the greatest challenges in Biology learning. Topics involving microscopic structures, embryological development, and complex biological processes were perceived as difficult because they relied heavily on abstract explanations and scientific terminology (Nasri et al., 2021; Nurbaya, 2026). Learning materials dominated by lectures and textual information often limited students' ability to visualize biological processes and construct meaningful conceptual understanding (Rao et al., 2014; Susie L. Gronseth & Dalton, 2020; Ní Dhuinn & Garland, 2022).

Table 2. Themes, Categories, and Initial Codes Related to Students' Conceptual Learning Needs in Biology Education

Theme	Categories	Initial Codes
Understanding abstract biological concepts requires multiple representations	Abstract concepts	Microscopic structures; embryological development; scientific terminology
	Limited instructional representation	Text-based materials; lecture-centered learning; insufficient visualization
	Preferred learning resources	Videos; diagrams; infographics; visual illustrations

Table 2 demonstrates that students' difficulties in learning Biology were primarily associated with the abstract nature of biological concepts and the limited variety of instructional representations available during the learning process. Many participants perceived topics such as microscopic structures, embryological development, and complex biological processes as inherently difficult because these concepts could not be directly observed in everyday life. Learning experiences that relied predominantly on verbal explanations, textbook readings, and static visual materials often limited students' ability to construct meaningful mental models of biological phenomena. Consequently, conceptual understanding became highly dependent on students' capacity to visualize invisible processes, which varied considerably across individuals according to their prior knowledge and learning experiences.

The analysis further revealed that students consistently expressed a preference for learning resources that incorporated multiple forms of representation, including instructional

videos, diagrams, animations, infographics, and other visual learning media. Rather than seeking simplified content, students emphasized the need for instructional approaches that presented scientific concepts through diverse modalities to facilitate deeper conceptual understanding (Arantes, 2023; Nurbaya et al., 2025). These findings suggest that effective Biology instruction should move beyond a single mode of content delivery and instead provide multiple pathways through which learners can access, process, and interpret complex scientific information (Ainscow et al., 2006; Idham Azwar et al., 2024). Accommodating different representational preferences is therefore essential not only for improving conceptual comprehension but also for reducing learning barriers experienced by students with diverse educational backgrounds and learning characteristics (Strayhorn, 2019; Nurbaya et al., 2024).

Classroom Participation Is Influenced by Psychological and Instructional Factors

The findings demonstrated that classroom participation was shaped not only by students' conceptual understanding but also by psychological and instructional conditions (Kahu, 2013; Strayhorn, 2019). Many students reported reluctance to contribute during classroom discussions because of low confidence, fear of giving incorrect answers, and uncertainty regarding their understanding of course materials (Seale, 2014; Hockings, 2010; Bunbury, 2020). These factors reduced active engagement despite students' willingness to participate (Florian & Black-Hawkins, 2011; Kahu, 2013).

Table 3. Themes, Categories, and Initial Codes Describing Factors Influencing Classroom Participation

Theme	Categories	Initial Codes
Classroom participation is influenced by psychological and instructional factors	Psychological barriers	Lack of confidence; fear of making mistakes; anxiety
	Learning readiness	Limited understanding; uncertainty; low self-efficacy
	Classroom environment	Limited interaction; passive learning; discussion opportunities

Table 3 indicates that students' participation in Biology learning was influenced by an interplay of psychological, cognitive, and instructional factors rather than by academic competence alone. Although many students demonstrated an interest in engaging with classroom activities, they frequently reported hesitation to express their ideas or ask questions due to a lack of confidence, fear of making mistakes, and uncertainty about the accuracy of their understanding. These psychological barriers were closely related to students' varying levels of learning readiness, as differences in prior knowledge and conceptual understanding often affected their willingness to actively participate in discussions. Consequently, classroom participation emerged as a reflection of both students' perceived competence and the learning conditions that either encouraged or inhibited engagement.

The findings also highlight the significant role of the classroom environment in shaping students' participation (Florian & Black-Hawkins, 2011; Hockings, 2010; Seale, 2014). Learning experiences characterized by teacher-centred instruction and limited opportunities for interaction tended to reinforce passive learning behaviours, particularly among students who already lacked confidence in their academic abilities (Dean et al., 2017; Heemskerk et al., 2011; Kahu, 2013). Conversely, participants expressed a preference for more interactive learning environments that encouraged discussion, collaboration, and constructive feedback without fear of negative judgment (Ainscow, 2020; Sasson et al., 2022; Ní Dhuinn & Garland, 2022). These findings suggest that fostering active participation requires more than improving students' conceptual knowledge; it also involves creating psychologically safe and inclusive learning environments where diverse learners feel valued, supported, and confident to contribute (Bunbury, 2020; Fornauf & Erickson, 2020; Dalton et al., 2019). Such environments are particularly important in Biology education, where collaborative inquiry and scientific communication are integral components of meaningful learning (Nurbaya et al., 2025; Tobin & Behling, 2018).

Students Prefer Flexible Ways to Demonstrate Their Learning

Another prominent finding concerned assessment practices. Students perceived conventional written examinations as providing limited opportunities to demonstrate their actual understanding (CAST, 2018; Bunbury, 2020; Rao et al., 2014). Participants expressed preferences for multiple assessment formats that allowed them to communicate learning according to their individual strengths (Meyer et al., 2014; Tobin & Behling, 2018; Rogers-Shaw et al., 2018).

Table 4. Themes, Categories, and Initial Codes Related to Students' Preferences for Flexible Assessment Practices

Theme	Categories	Initial Codes
Students prefer flexible ways to demonstrate learning	Assessment limitations	Written tests; single assessment format
	Alternative assessment preferences	Presentations; posters; videos; projects
	Student autonomy	Choice; flexibility; self-expression

Table 4 reveals that students perceived conventional assessment practices as providing limited opportunities to fully demonstrate their knowledge and learning achievements. Most participants viewed written examinations as emphasizing a single mode of performance that did not adequately accommodate differences in learning preferences, communication styles, and individual strengths. Students acknowledged that while traditional assessments remain important for evaluating academic achievement, relying exclusively on written tests often constrained their ability to express conceptual understanding, particularly when dealing with complex biological topics. These findings suggest that assessment itself can become a learning barrier when students are required to demonstrate their knowledge through only one predetermined format. Participants consistently expressed a preference for more flexible assessment approaches that offered multiple opportunities to demonstrate learning, such as oral presentations, project-based assignments, posters, videos, and other authentic assessment tasks (CAST, 2018; Meyer et al., 2014; Tobin & Behling, 2018). Importantly, students did not perceive flexibility as a reduction in academic expectations but rather as a means of providing equitable opportunities to achieve the same learning outcomes through different forms of expression (Dalton et al., 2019; Fornauf & Erickson, 2020; Bunbury, 2020). This preference reflects the diversity of students' abilities and learning characteristics, indicating that assessment practices should acknowledge learner variability alongside instructional design (Florian & Black-Hawkins, 2011; Ainscow, 2020; Rončević & Rieckmann, 2025). Providing multiple assessment pathways enables educators to evaluate students' conceptual understanding more comprehensively while creating a more inclusive learning environment that supports active participation, learner autonomy, and meaningful engagement in Biology education (Rogers-Shaw et al., 2018; Susie L. Gronseth & Dalton, 2020; Nurbaya, 2026).

The present study demonstrates that learner variability among Biology Education students extends far beyond differences in academic ability. The findings indicate that students entered higher education with diverse educational experiences, sociocultural backgrounds, and levels of technological readiness, all of which shaped how they approached learning (Ainscow, 2020; Florian & Black-Hawkins, 2011; Arantes et al., 2025). This finding reinforces the view that learner variability should be understood as an inherent characteristic of higher education rather than as an exception associated with a small group of students (Hockings, 2010; Ainscow et al., 2006). As university classrooms become increasingly diverse, students inevitably bring different prior learning experiences, learning strategies, and opportunities to engage with educational resources (Bunbury, 2020; Seale, 2014). Consequently, assuming that all learners possess similar levels of preparedness risks overlooking important differences that influence learning participation and achievement (Kahu, 2013; Strayhorn, 2019).

The findings also highlight that learner variability is strongly influenced by contextual factors before students even enter university. Differences in previous schooling, language use, geographical location, and access to digital resources contributed to unequal learning readiness among participants (Arantes et al., 2025; Nurbaya, 2023; Nurbaya, 2024a). This suggests that variability is not simply the result of individual capability but reflects broader educational inequalities that accumulate throughout students' learning journeys (Fauziyah et al., 2025; Riswari et al., 2022). Such an interpretation aligns with contemporary perspectives on inclusive education, which argue that learning barriers often emerge from interactions between learners and their educational environments rather than from learners' characteristics alone (Ainscow, 2020; Florian & Black-Hawkins, 2011; Rončević & Rieckmann, 2025). Recognizing learner variability as a contextual phenomenon encourages educators to shift from deficit-oriented assumptions toward instructional approaches that acknowledge diversity as a normal and valuable feature of the learning process (Ainscow et al., 2006; Hockings, 2010).

Another important finding concerns the nature of Biology learning itself. Students consistently identified abstract biological concepts as one of the most significant challenges they encountered during learning. Topics involving microscopic structures, developmental processes, and complex biological systems require learners to construct mental representations of phenomena that cannot be directly observed. When instruction relies predominantly on verbal explanations or text-based materials, students with different cognitive preferences and prior knowledge may experience considerable difficulty in developing accurate conceptual understanding (Nasri et al., 2021; Nurbaya, 2026; Rao et al., 2014). These findings suggest that the complexity of Biology education amplifies the effects of learner variability because students differ substantially in their ability to process abstract scientific information (Meyer et al., 2014; Tobin & Behling, 2018). The preference for videos, diagrams, animations, and other visual learning resources further illustrates that students require multiple forms of representation to support conceptual understanding (CAST, 2018; Susie L. Gronseth & Dalton, 2020; Rogers-Shaw et al., 2018). Importantly, these preferences should not be interpreted as requests for simplified learning but rather as evidence that learners construct scientific knowledge through different cognitive pathways (Arantes, 2023; Nurbaya et al., 2025). Providing diverse representations enables students to connect abstract concepts with meaningful visual and contextual experiences, thereby facilitating deeper understanding (Ní Dhuinn & Garland, 2022; Heemskerk et al., 2011). This finding supports constructivist perspectives on learning, which emphasize that conceptual development is enhanced when learners interact with knowledge through multiple representations and actively integrate new information with their existing understanding. Consequently, instructional flexibility becomes essential for accommodating learner variability without compromising academic expectations (Dalton et al., 2019; Fornauf & Erickson, 2020). Taken together, the findings suggest that understanding learner variability constitutes a critical foundation for designing inclusive Biology education (Florian & Black-Hawkins, 2011; Ainscow, 2020). Before selecting instructional strategies, learning technologies, or assessment methods, educators must first understand who their learners are, what barriers they experience, and how they prefer to engage with learning (CAST, 2018; Meyer et al., 2014; Tobin & Behling, 2018). The present study therefore extends existing discussions on inclusive higher education by demonstrating that identifying students' learning needs is not merely a preliminary step in instructional planning but an essential process for reducing learning barriers and promoting equitable participation (Fornauf & Erickson, 2020; Dalton et al., 2019; Riswari et al., 2022). In the context of Biology education, acknowledging learner variability enables educators to design learning environments that are responsive to students' diverse educational experiences while supporting meaningful conceptual understanding for all learners (Nurbaya et al., 2025; Bunbury, 2020; Seale, 2014).

DISCUSSION

The present study offers several important contributions to the literature on inclusive higher education. Unlike most previous studies that primarily evaluate the implementation of Universal Design for Learning (UDL), inclusive pedagogy, or accessibility interventions after

instructional strategies have been introduced, this study focuses on understanding learner variability before instructional design decisions are made. By exploring students' learning needs and barriers in Biology Education within the underrepresented context of Papua, Indonesia, this research positions learner variability as the starting point for inclusive instructional planning rather than as a consideration introduced during or after intervention implementation (Ainscow, 2020; Florian & Black-Hawkins, 2011; Fornauf & Erickson, 2020; Dalton et al., 2019; Rončević & Rieckmann, 2025; Riswari et al., 2022). This perspective extends current discussions by emphasizing that inclusive instruction should be informed by empirical evidence regarding learners' contextual experiences before teaching strategies are selected.

The findings demonstrate that learner variability among Biology Education students is shaped by a complex interaction of educational, sociocultural, and technological factors that influence how students engage with learning. Rather than representing differences in academic ability alone, learner variability was reflected in students' readiness for university learning, approaches to understanding abstract biological concepts, confidence in classroom participation, and preferred ways of demonstrating learning. Collectively, these findings suggest that learning barriers are closely associated with students' prior educational experiences and the instructional contexts in which learning occurs, highlighting the importance of viewing learner diversity as an inherent characteristic of higher education rather than as an individual deficit (Ainscow, 2020; Florian & Black-Hawkins, 2011; Hockings, 2010). The study further indicates that understanding learner variability should precede instructional decision-making. Students consistently emphasized the need for multiple representations of biological concepts, psychologically supportive learning environments, and flexible assessment opportunities that enabled them to demonstrate learning through different forms of expression. These findings reinforce the view that equitable learning is achieved not by lowering academic expectations but by providing responsive learning experiences that accommodate diverse learner characteristics. Consequently, identifying students' learning needs before designing instruction represents a critical step toward developing more inclusive and effective Biology education (CAST, 2018; Meyer et al., 2014; Tobin & Behling, 2018; Fornauf & Erickson, 2020).

These findings are generally consistent with previous studies reporting that learner diversity significantly influences participation, engagement, and academic success in higher education. Ainscow (2020), Florian and Black-Hawkins (2011), and Hockings (2010) similarly argue that learner diversity should be regarded as a normal characteristic of higher education rather than an exception requiring individual remediation. Likewise, studies examining UDL implementation have consistently reported that flexible instructional approaches, multiple representations, and varied assessment opportunities improve accessibility and learner engagement (CAST, 2018; Rao et al., 2014; Tobin & Behling, 2018; Rogers-Shaw et al., 2018; Dean et al., 2017; Sasson et al., 2022). The present findings therefore reinforce a growing body of evidence demonstrating that responsive instructional design is essential for supporting increasingly diverse student populations. Despite these similarities, the present study also reveals several important contextual differences. Whereas previous studies have predominantly examined inclusive practices in relatively well-resourced educational settings or evaluated the effectiveness of specific instructional interventions, the current study identifies substantial learner variability that already exists before instructional intervention begins. Students' learning experiences were strongly influenced by differences in previous schooling, geographical location, cultural background, language use, and digital access. These contextual characteristics were particularly evident within Papua, where educational opportunities remain highly heterogeneous (Arantes et al., 2025; Fauziyah et al., 2025; Nurbaya, 2023; Nurbaya, 2024a; Nurbaya, 2024b). These findings suggest that the sources of learner variability may differ across educational contexts, emphasizing the importance of context-sensitive instructional planning rather than assuming that inclusive strategies developed elsewhere can be transferred directly.

The principal contribution of this study lies in reconceptualizing learner variability as an empirical foundation for instructional design rather than merely as a characteristic addressed through inclusive teaching frameworks. Existing literature has largely emphasized how educators should implement inclusive pedagogies, whereas considerably less attention has

been devoted to systematically identifying learners' needs before designing instruction (Florian & Black-Hawkins, 2011; Fornauf & Erickson, 2020). By integrating evidence regarding educational background, conceptual learning, classroom participation, and assessment preferences within a single qualitative framework, this study provides a more comprehensive understanding of learner variability in Biology Education. This integrated perspective offers a practical evidence base for developing instructional models that are responsive to diverse learner characteristics.

The findings also have important practical implications for higher education institutions and Biology educators. Rather than relying on standardized instructional approaches, educators should begin instructional planning by identifying students' learning characteristics, prior educational experiences, and potential barriers to participation. Such information can guide the selection of appropriate instructional representations, classroom interaction strategies, learning technologies, and assessment methods that better accommodate learner diversity (CAST, 2018; Meyer et al., 2014; Dalton et al., 2019; Tobin & Behling, 2018). At the institutional level, universities may also consider incorporating learner variability analyses into curriculum development, academic support services, and professional development programs for lecturers to strengthen inclusive educational practices.

Future research should extend these findings by examining how instructional interventions specifically designed around identified learner variability influence conceptual understanding, engagement, and academic achievement across different scientific disciplines and higher education contexts. Comparative studies involving universities from different geographical regions would also contribute to a broader understanding of how contextual factors shape learner variability. Ultimately, this study demonstrates that understanding who learners are, what barriers they experience, and how they prefer to learn should constitute the first stage of inclusive instructional design. Recognizing learner variability before developing teaching strategies provides a stronger empirical foundation for creating equitable, meaningful, and sustainable learning experiences in Biology education.

CONCLUSION

This study demonstrates that learner variability among Biology Education students in Papua is influenced by diverse educational experiences, sociocultural backgrounds, and technological readiness, which collectively shape students' learning needs and create different learning barriers. The findings further indicate that the abstract nature of biological concepts, together with limited instructional representations, affects students' conceptual understanding, while flexible learning resources and assessment approaches are considered essential to support diverse learners. These findings emphasize that understanding learner variability should be the starting point for designing inclusive learning environments in higher education. Future research should examine the implementation of instructional strategies that address the identified learning needs across different disciplines and educational contexts, thereby strengthening evidence-based practices for inclusive and equitable teaching and learning.

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