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Readiness, Perception, and Challenges in Online Practical Biology Learning: Insights from Undergraduate Distance Learners

Omar Ali Al-Smadi
School of Distance Education, Universiti Sains Malaysia, 11800 Minden, Penang, Malaysia, *o.smadi@usm.my*

Amirah Hurzaid
Corresponding author, Biological Sciences Programme, School of Distance Education, Universiti Sains Malaysia,11800 Minden, Penang, Malaysia, *amirahhurzaid@usm.my*

Nurul Azni Mhd Alkasirah
Centre for Instructional Technology and Multimedia, Universiti Sains Malaysia, 11800 Minden, Penang, Malaysia, *nurulazni31@gmail.com*

Mohammad Tasyriq Che Omar
Biological Sciences Programme, School of Distance Education, Universiti Sains Malaysia,11800 Minden, Penang, Malaysia, *mtasyriq@usm.my*

This study investigates students' readiness, perception, and challenges in an online practical biology course. Using a quantitative survey research design, data were collected from 107 undergraduate distance learners enrolled in an online practical biology course at a Malaysian university. Data were analysed using descriptive statistical methods—including means, frequencies, and percentages. Results show a moderate-to-high level of readiness, with strengths in digital literacy and accessibility, but limitations in hands-on engagement and self-regulation. The study found that students reported high levels of enjoyment in learning online, satisfaction with lecturer interaction, and confidence in analysing data. However, they expressed only moderate understanding of experimental procedures, low motivation to learn, and moderate suitability of the home environment for learning. These results highlight digital strengths in content engagement and instructor support, but also reveal key challenges in procedural learning, motivation, and learning conditions. However, challenges such as technological disparities, cognitive load management, and limited procedural fluency suggest a need for blended learning approaches that integrate virtual and physical laboratory experiences. These results highlight the importance of adaptive digital scaffolding, enhanced instructional strategies, and institutional support for digital accessibility to improve the effectiveness of online practical biology education.

Keywords: online learning, practical biology education, open distance learning (ODL), student readiness, face-to-face learning, higher education

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INTRODUCTION

The rapid integration of technology in education has significantly transformed the way students access and engage with learning materials. Among the most profound changes is the shift from traditional face-to-face instruction to online and open distance learning (ODL) formats. This transition has been particularly impactful in practical-based disciplines such as biology, where hands-on laboratory experiences play a crucial role in knowledge acquisition. While online practical biology learning has been increasingly adopted, there remains an ongoing debate regarding its effectiveness compared to traditional face-to-face learning environments. Additionally, from an interdisciplinary perspective, this shift involves not only pedagogical concerns in biology education but also linguistic and communicative challenges, particularly in how students engage with digital materials, comprehend instructional language, and articulate scientific discourse in virtual settings.

Distance learning models, particularly ODL, have emerged as a flexible and accessible alternative for students who may not have the opportunity to attend conventional in-person classes. Recent studies suggest that ODL has provided new pathways for learners worldwide by removing geographical and temporal barriers (Sarvary et al., 2022; Kaqinari, 2023; Al-Smadi & Kamal, 2024; Singh et al., 2024). However, the effectiveness of ODL in fields requiring hands-on training, such as biology, remains a subject of inquiry. While online simulations, virtual laboratories, and interactive technologies attempt to replicate physical lab experiences, the extent to which they can replace or enhance practical skill development remains uncertain (May et al., 2023; Singh-Pillay, 2024). The effectiveness of digital environments in replicating laboratory-based learning largely depends on students' ability to develop procedural knowledge, perform experimental tasks independently, and engage in self-regulated learning, all of which require further investigation.

The effectiveness of online learning versus face-to-face instruction is a critical topic in educational research. Studies have explored differences in engagement, learning outcomes, and student satisfaction in both modalities (Jena et al., 2021; Lewohl, 2023; Lee et al., 2025). Some scholars argue that online learning fosters independent learning and improves digital literacy, while others contend that it lacks the immediacy and hands-on experience necessary for disciplines requiring practical application (Pollock, 2022; Wagiran et al., 2022; Harper et al., 2024; Al-Smadi et al., 2024; Affendy Lee et al., 2025). From a linguistic perspective, the transition to online learning necessitates a reconsideration of how scientific knowledge is communicated, assessed, and internalized. In many cases, language acts as a mediating tool that influences comprehension, interpretation, and engagement in online education (Rizal et al., 2022; Al-Smadi & Kamal, 2024; Madanat et al., 2024).

The Community of Inquiry framework (CoI) (Garrison et al., 1999) and Cognitive Load Theory (CLT) (Sweller, 1994) provide valuable perspectives for understanding student engagement and learning effectiveness in online practical biology education. CoI highlights the role of cognitive, teaching, and social presence in shaping meaningful learning experiences, while CLT explains how cognitive load influences students' ability to process, retain, and apply knowledge in digital environments (Faulconer & Chamberlain, 2022; Singh et al., 2022; Tabassum & Saad, 2024). In online practical learning, the balance between instructional design, technological access, and hands-on engagement is critical in determining student success. By incorporating these theoretical lenses, this study aims to assess undergraduate distance learners' readiness, perceptions, and challenges in online practical biology courses. Accordingly, the study seeks to answer the following question: How prepared are undergraduate distance learners for online practical biology education, and what are their perceptions in navigating this learning environment? By examining how students navigate digital biology practical classes, this study seeks to contribute to the broader discourse on optimizing virtual learning environments for hands-on disciplines. The results will inform the development of instructional strategies that balance accessibility with practical skill acquisition, ensuring that online laboratory courses are both pedagogically sound and conducive to student engagement.

Literature Review

Open Distance Learning in STEM Education

Open Distance Learning (ODL) has evolved significantly in recent decades, with advances in technology reshaping the way education is delivered and accessed. Traditionally, ODL was limited to correspondence courses and asynchronous instructional materials, but recent innovations have expanded its scope to include interactive digital platforms, virtual classrooms, and AI-driven learning systems (Annamalai et al., 2022; Yaseen et al., 2024; Amin et al., 2025). In its current form, ODL involves the use of Learning Management Systems (LMS), video conferencing tools, asynchronous modules, mobile learning, and digital assessments to deliver content without the need for physical attendance. These flexible formats are especially beneficial in reaching non-traditional learners, working adults, and geographically isolated students (Saidi et al., 2021; Setyowati et al., 2023).

In the context of STEM education, integrating ODL has been both promising and challenging. STEM fields often rely on hands-on learning, experimentation, and active problem-solving elements that are harder to replicate in fully online environments (Sarvary et al., 2022; Fitriani et al., 2023; Shabalala, 2024; Lee et al., 2025). However, recent innovations such as virtual laboratories, simulation-based learning, and cross-reality tools have made it increasingly possible to deliver STEM content effectively through ODL platforms (Sarvary et al., 2022; Idris et al., 2023). Studies show that when ODL in STEM is structured with interactive components and scaffolding strategies, it can foster cognitive engagement and skill development comparable to in-person experiences (Ciloglu & Ustun, 2023; Harper et al., 2024; Amelia et al., 2025).

A major advantage of Open Distance Learning (ODL) is its accessibility, especially for non-traditional learners, working professionals, and students in remote areas. ODL removes geographical and scheduling barriers by allowing learners to study at their own pace without the need for physical attendance (Abdallah et al., 2023; Tarmuji et al., 2024; Singh & Kathuria, 2024). However, it also presents persistent challenges, including reduced student motivation, lower engagement, and limited retention (Joshi et al., 2024). The lack of direct instructor-student interaction may diminish learning quality, requiring innovative strategies to foster virtual presence and communication (Yan-Li et al., 2022; Al-Smadi & Kamal, 2024; Yaseen et al., 2024).

In this context, the current study focuses on readiness, perceptions, and challenges that reflect essential dimensions of students' learning experiences in ODL. Readiness refers to students' digital access and preparedness; perceptions capture their satisfaction and attitudes toward the course; and challenges include motivational issues, procedural learning gaps, and unsuitable home environments. ODL demands high levels of self-regulation, digital literacy, and communication skills, particularly in STEM fields like biology that require hands-on practice (Wagiran et al., 2022; Chen et al., 2023; Rizal et al., 2022).

To address these complexities, the Community of Inquiry (CoI) and Cognitive Load Theory (CLT) frameworks are critical. CoI emphasizes cognitive, teaching, and social presence as pillars of effective online learning (Garrison & Vaughan, 2008), while CLT (Sweller et al., 2011) provides insight into how instructional design can reduce cognitive strain and improve information processing. Integrating these models supports the development of well-structured, engaging, and cognitively manageable online learning environments.

Theoretical Framework

This study is guided by the Community of Inquiry Framework (Garrison et al., 1999) and Cognitive Load Theory (Sweller, 1994), both of which provide a strong foundation for understanding students' readiness, perception, and challenges in online practical biology learning. These frameworks help explain the cognitive, social, and instructional processes involved in digital learning environments, making them particularly suitable for this study.

The Community of Inquiry (CoI) Framework is widely applied in online education research and emphasizes three interrelated elements: cognitive presence, teaching presence, and social presence (Kim & Gurvitch, 2020; Rahmatalla et al., 2024). Cognitive presence refers to how students engage with course content, construct knowledge, and apply learning in meaningful ways. Teaching presence involves the instructional design, facilitation, and support provided by educators to guide student learning. Social presence focuses on the degree to which learners feel connected and engaged with their instructors and peers in an online setting. In this study, CoI informs the perception variable by framing how students experience instructor guidance (teaching presence), peer collaboration (social presence), and the construction of knowledge (cognitive presence). It also contributes to understanding aspects of readiness related to instructional clarity and communication dynamics in online environments.

In contrast, Cognitive Load Theory (CLT) (Sweller, 1994) focuses on how learners process, store, and retrieve information based on the distribution of cognitive effort across intrinsic, extraneous, and germane load (Lagomarsino et al., 2022; Skulmowski & Xu, 2022). In this study, CLT primarily informs the *readiness* and *challenge* variables by explaining students' ability to manage cognitive load in a self-regulated online setting. For example, motivation issues and difficulty with experimental procedures are examined through the lens of cognitive strain resulting from limited hands-on engagement and increased mental effort.

Using both CoI and CLT offers a complementary and comprehensive analytical framework: CoI emphasizes presence—the social and instructional dimensions of the learning environment—while CLT addresses cognitive processing and mental workload in online tasks. Together, these frameworks allow for a more holistic exploration of the affective, instructional, and cognitive factors that shape student readiness, perceptions, and challenges in online practical biology learning.

METHOD

This study employed a quantitative research design to examine undergraduate distance learners' readiness, perceptions, and challenges in online practical biology learning. The target population consisted of students enrolled in online biology practical courses at a Malaysian public university during the 2023/2024 academic session.

A total of 107 participants were selected using a simple random sampling technique, ensuring that each eligible student had an equal chance of being included in the study. This method helped reduce selection bias and enhance the generalizability of the findings. The sample represented diverse academic years, age groups, and ethnic backgrounds, providing a broad perspective on learner experiences.

Data was collected through a structured, self-administered questionnaire designed in Google Forms. The instrument was pre-tested with a small group of students to ensure clarity and reliability. The final version was distributed via multiple digital platforms (email, WhatsApp, Twitter, and Facebook), and the survey remained open for one month, with periodic reminders sent to increase response rates.

Responses were exported to SPSS version 26.0 for statistical analysis. Descriptive statistics—frequencies, percentages, and means—were used to summarize responses and provide an overview of students' readiness levels, perceived learning experiences, and encountered challenges in online practical biology courses.

The instrument used in this study was a structured questionnaire consisting of three main parts. Part One collected demographic information such as age, gender, academic level, and ethnic background to contextualize students' learning experiences. Part Two focused on students' readiness for online practical biology learning, assessing aspects such as access to technology, digital navigation skills, and availability of instructional support. Part Three explored students' perceptions, including their enjoyment of learning, ability to analyze data, motivation, understanding of experimental procedures, and satisfaction with lecturer interactions. Items across the readiness and perception sections also indirectly captured common challenges faced by students, such as cognitive overload and environmental constraints.

All items in the readiness and perception sections were measured using a four-point Likert scale ranging from 1 (Strongly Disagree) to 4 (Strongly Agree). To interpret the mean scores, the following classification was applied: 1.00–1.50 = Less Relevance, 1.51–2.50 = Low Level, 2.51–3.50 = Moderate Level, and 3.51–4.00 = High Level. This interpretation framework provided a consistent basis for analyzing and reporting students' responses across all measured constructs.

The variable of challenges was measured indirectly, using selected items embedded within the readiness and perception scales. Although there was no separate "challenges" section in the questionnaire, specific items related to students' understanding of experimental procedures, learning motivation, and the conduciveness of their home environment were conceptually aligned with common barriers to online practical learning. These items were reanalyzed to reflect procedural, cognitive, and environmental challenges, respectively. The corresponding mean scores—2.97 for procedural understanding, 2.89 for motivation, and 3.20 for home environment—served as indicators of the challenges students encountered. This approach enabled the identification of key difficulties while maintaining a streamlined instrument design.

This study adhered to ethical research guidelines. Participants were fully informed about the purpose of the study, voluntary participation, and their right to withdraw at any time without consequence. No personal identifiers were collected, and all responses were stored in a password-protected database accessible only to the research team. Findings were reported in aggregate form to ensure participant confidentiality and data protection.

The demographic characteristics of the participants are presented next to provide context for interpreting their experiences with online practical biology learning (see Table 1).

Table 1
Demographic characteristics of respondents

Category	N = 107	Percentage (100%)
Age		
20- 30 years	53	49.5
31- 40 years	46	43.0
41- 50 years	3	2.8
51- 60 years	5	4.7
Gender		
Male	26	24.3
Female	81	75.7
Race		
Malay	62	57.9
Chinese	8	7.5
Indian	23	21.5
Others	14	13.1
Year Study		
1st Year	20	18.7
2nd Year	28	26.2
3rd Year	19	17.8
4th Year	27	25.2
5th Year	13	12.1

The demographic data indicates that the majority of participants (49.5%) were between 20-30 years old, followed by 31-40 years old (43.0%), with a small percentage of students aged 41-50 years (2.8%) and 51-60 years (4.7%). This age distribution suggests that most learners were relatively young adults, likely familiar with digital tools, which may have contributed to the moderate-to-high readiness levels reported in the study. The female participants (75.7%) significantly outnumbered male participants (24.3%), suggesting a gender disparity in enrollment or interest in online biology courses. In terms of race, the majority of respondents were Malay (57.9%), followed by Indian (21.5%), Chinese (7.5%), and other ethnicities (13.1%). This distribution reflects a diverse student population, which may introduce varying levels of prior digital exposure and learning conditions. Regarding academic level, the highest number of participants were 2nd-year students (26.2%), followed by 4th-year (25.2%), 3rd-year (17.8%), 1st-year (18.7%), and 5th-year students (12.1%). These differences in academic level may contribute to variation in digital literacy, confidence, and self-regulation. For instance, students in higher years may have more experience navigating online platforms, while newer students may face more challenges in adapting to the online format. Collectively, these demographic factors provide a useful context for interpreting variations in readiness, perceived learning effectiveness, and challenges in online practical biology education.

FINDINGS

Student Readiness for Online Practical Biology Learning

To assess how well-equipped students were to participate in online biology practicals, the study measured various aspects of their readiness, including access to technology, digital literacy, and the suitability of their home learning environments. Table 2 presents the results related to students' levels of readiness for engaging in online practical learning.

Table 2
Student readiness for online practical biology learning

Item	Min value	Score Level
I have sufficient equipment and facilities (computer/internet) for online practical biology learning.	3.54	High
I have sufficient computer knowledge and IT skills to manage practical biology learning online.	3.50	Moderate
The guidelines provided through the PJJ e-learning portal by the lecturer before starting the online biology practice are relevant.	3.68	High
The practical biology learning materials on the PJJ e-learning portal are easy to navigate	3.71	High
The home environment is ideal for me to engage in online practical biology learning.	3.20	Moderate
I find online hands-on biology learning to be flexible.	3.29	Moderate
Overall mean value	3.48	Moderate

The results suggest that students generally feel technologically prepared for online practical learning, as reflected by high ratings for equipment availability (3.54) and instructional guidelines (3.68). The ease of navigating course materials (3.71) further indicates that well-organized digital resources support learning. However, moderate scores for IT skills (3.50) and flexibility (3.29) suggest that students still encounter difficulties in adapting to fully online practical coursework.

A notable concern is the home environment suitability score (3.20), which suggests that external factors such as distractions, shared spaces, and unstable internet connections may negatively affect student engagement. While students can access online resources, their ability to engage deeply with practical coursework in a structured and distraction-free setting remains a challenge.

Student Perceptions of Online Practical Biology Learning

In addition to readiness, the study explored students' perceptions of their overall learning experience in online practical biology. This included their views on learning outcomes, enjoyment, motivation, and the quality of lecturer support. Table 3 summarizes the descriptive statistics for students' perceptions.

Table 3
Student perceptions of online practical biology learning

Item	Min value	Score Level
Online practical biology learning enhanced my understanding of the conducted experiments	2.97	Moderate
Online practical biology learning enhanced my understanding of the course content	2.97	Moderate
Online practical biology learning helped me understand how to analyze data	3.59	High
I enjoyed learning online practical biology.	3.64	High
My motivation to learn increased after conducting online practical biology	2.89	Moderate
I am satisfied with the explanation provided by the lecturer before the online practical biology learning session	3.56	High
I am content with the interaction facilitated by the lecturer during the online practical biology learning	3.61	High
Overall mean value	3.31	Moderate

The results indicate that students benefited from online practical learning in terms of understanding data analysis (3.59) and overall enjoyment (3.64), suggesting that digital tools and structured learning materials provided value. Additionally, lecturer explanations (3.56) and interaction (3.61) were rated highly, indicating that instructor support played a crucial role in maintaining engagement.

However, understanding experimental procedures and course content received moderate ratings (2.97), reflecting the limitations of online practical learning in developing hands-on skills and procedural fluency. The moderate motivation score (2.89) also suggests that students may struggle with self-discipline and engagement in a fully online setting, reinforcing the importance of blended learning approaches.

Identified Challenges in Online Practical Biology Learning

The results revealed three key areas that represent challenges in students' online practical biology learning—procedural understanding, self-regulation, and home learning environment suitability. These challenges were indirectly identified through lower mean scores on specific items within the readiness and perception scales, highlighting aspects of the learning experience where students faced the most difficulty.

The most prominent challenge was limited hands-on skill development, as reflected in a moderate mean score for understanding experimental procedures (M = 2.97). This finding indicates that students struggled to engage with the practical aspects of the course in a meaningful way. Unlike physical laboratories where students manipulate equipment and perform experiments directly, the online format limits sensory interaction, procedural fluency, and spatial awareness—key components of scientific learning. The lack of tactile engagement may hinder students' ability to develop core laboratory competencies and apply theoretical concepts in a real-world context, thereby reducing the overall quality of skill acquisition.

The second challenge involved self-regulation and motivation, highlighted by a relatively low mean score for motivation to learn (M = 2.89). In fully online settings, students are often required to take greater responsibility for organizing their time, maintaining focus, and independently navigating learning tasks. Without the structure of in-person classes or the immediacy of instructor feedback, many learners find it difficult to remain engaged, particularly when practical tasks are abstract or lack real-time demonstration. This lack of motivation can lead to superficial learning, lower participation, and increased cognitive fatigue—factors that ultimately affect learning outcomes and course satisfaction.

A third area of difficulty was related to the home learning environment, which received a moderate suitability rating (M = 3.20). While students had digital access to the course materials, many reported environmental constraints such as noise, lack of a dedicated study space, shared devices, and unstable internet connectivity. These conditions may have disrupted their ability to participate consistently in synchronous sessions or concentrate during complex tasks such as interpreting experimental data or completing online simulations. The variation in students' home environments highlights ongoing equity issues in online education, where learning outcomes may be significantly influenced by socio-economic factors beyond the learner's control.

These results underscore the multifaceted nature of the challenges faced by students in online practical biology learning. While the course delivery may be pedagogically sound in terms of content and instructor presence, limitations in hands-on engagement, learner autonomy, and home infrastructure pose significant barriers to effective and equitable learning. Addressing these challenges will require blended instructional approaches that combine digital accessibility with physical laboratory experience, alongside institutional strategies to support student motivation and digital equity.

DISCUSSION

The results of this study provide critical insights into the effectiveness of online practical biology learning, highlighting both its strengths and limitations. While students demonstrated a moderate to high level of readiness for engaging with digital tools and instructional materials, challenges in hands-on engagement, self-regulation, and technological access suggest that online practical learning does not fully replicate the depth of traditional laboratory experiences. These findings align with previous research on online and open distance learning (ODL), which consistently highlights the tension between accessibility and the need for experiential, hands-on learning in STEM disciplines (Byukusenge et al., 2022; Singh-Pillay, 2024). The results emphasize the importance of refining pedagogical approaches that enhance Cognitive Presence and Social Presence (CoI) while addressing barriers in Cognitive Load Theory (CLT) to improve engagement and skill acquisition.

The readiness of students for online practical biology learning, as indicated by a moderate overall mean score (3.48), suggests that while students are technologically equipped, they face significant challenges in adapting to self-directed learning environments. This finding aligns with studies that highlight the critical role of digital literacy and self-regulation in ODL success (Tarmuji et al., 2024). Notably, students rated their ability to access learning materials and navigate digital platforms highly (3.71 and 3.68, respectively), indicating that instructional design plays a key role in facilitating engagement. The structured learning pathways, as reflected in high scores for Teaching Presence, contribute to student confidence in using digital tools. However, the relatively lower score for home environment suitability (3.20) underscores disparities in students' learning conditions, reinforcing existing literature on how external factors such as distractions, limited study space, and inconsistent internet access affect online learning effectiveness (Wagiran et al., 2022; Joshi et al., 2024). These results suggest that environmental stability is crucial for effective learning, as students with inadequate home learning conditions are more likely to struggle with time management, engagement, and knowledge retention.

Analysing students' perceptions of online practical biology learning, the data suggest that while online platforms enhance content delivery, they fail to match the interactive depth of in-person laboratories. Students rated their understanding of experimental procedures significantly low in online settings (2.97), highlighting the ongoing challenge of replicating hands-on skill acquisition in digital formats. This result is consistent with research suggesting that while virtual simulations improve conceptual understanding, they do not develop the procedural fluency and observational skills required for laboratory work (Zubaidah et al., 2021; Byukusenge et al., 2022; Singh-Pillay, 2024). Additionally, students reported lower motivation to learn in online environments (2.89), reinforcing findings that online learners often experience reduced engagement due to the absence of real-time collaboration and instructor feedback (Chen et al., 2023; Ciloglu & Ustun, 2023). This low motivation aligns with Cognitive Load Theory, which explains how students struggle with managing cognitive effort and retaining information when faced with complex digital learning tasks (Feldon et al., 2019; Evans et al., 2024).

Despite these limitations, online learning was rated slightly higher in terms of satisfaction with lecturer explanations (3.56 vs. 3.37), suggesting that structured digital resources, such as recorded lectures and interactive modules, enhance Cognitive Presence. This aligns with studies showing that asynchronous learning materials allow students to revisit complex concepts at their own pace, improving theoretical comprehension (May et al., 2023). However, the similarity in lecturer interaction scores (3.31 vs. 3.37) suggests that while online platforms facilitate communication, they do not fully replicate the immediacy and depth of in-person discussions. These findings highlight the need for hybrid models that combine the accessibility of digital instruction with structured opportunities for physical engagement, as research has demonstrated that blended learning approaches improve both knowledge acquisition and skill development (Sarvary et al., 2022; Singh et al., 2024; Lee et al., 2025).

One of the most significant challenges in online practical biology learning is the gap in hands-on skill acquisition. The low mean score for understanding experimental procedures (2.97) suggests that students struggle to translate theoretical knowledge into practical competencies. This finding supports previous studies emphasizing that while virtual laboratories reinforce theoretical understanding, they cannot fully substitute for the sensory and motor engagement required in laboratory-based disciplines

(Byukusenge et al., 2022; Singh-Pillay, 2024). From a theoretical perspective, these results align with Cognitive Presence, which emphasizes the importance of critical inquiry and experiential learning for developing scientific reasoning and procedural accuracy. The absence of physical interaction with biological specimens and laboratory equipment limits students' ability to develop essential technical skills, reinforcing the need for blended instructional strategies that integrate digital simulations with hands-on experimentation (Harper et al., 2024; Pollock, 2022). Institutions should explore virtual reality (VR) and augmented reality (AR) tools to bridge this gap by providing immersive practical experiences in online settings (Eldokhny & Drwish, 2021; Ciloglu & Ustun, 2023).

Cognitive load management emerges as an additional barrier to effective online learning, as evidenced by the low motivation to learn score (2.89). This finding suggests that students experience disengagement due to the challenges of processing large amounts of information independently, a concern frequently raised in discussions on online STEM education (Chen et al., 2023; Ciloglu & Ustun, 2023). Cognitive Load Theory explains these challenges by highlighting how an excessive amount of complex information can overwhelm students' working memory, leading to reduced comprehension and retention. Unlike face-to-face settings, where instructors provide real-time guidance and peer collaboration supports engagement, online environments place greater demands on students' cognitive processing (Leppink, 2017; Gkintoni et al., 2025). This highlights the need for adaptive instructional models that incorporate structured feedback mechanisms, interactive guidance, and scaffolding techniques to enhance student engagement and learning retention (Amin et al., 2025; Setyowati et al., 2023). Additionally, integrating AI-driven personalized learning tools can help students manage their cognitive load more effectively by providing real-time assessments and tailored learning pathways.

Technological disparities further exacerbate these challenges, as reflected in the low home environment suitability score (3.20). This finding aligns with research on digital equity in ODL, which emphasizes that students with limited access to high-speed internet and personal devices face significant learning barriers (Madanat et al., 2024; Singh & Kathuria, 2024). The reliance on shared resources or mobile learning platforms may hinder students' ability to participate in interactive simulations or synchronous discussions, reinforcing socioeconomic inequalities in online education (Yaseen et al., 2024). Addressing these disparities requires institutional initiatives such as financial aid programs for laptops and internet access, as well as the development of offline-compatible learning modules to accommodate students with unstable connectivity (Fitriani et al., 2023; Tarmuji et al., 2024). Implementing low-bandwidth digital resources and mobile-accessible simulations can help create a more inclusive and equitable learning environment.

These findings collectively highlight the need for pedagogical innovations to enhance the effectiveness of online practical biology learning. A key implication is the importance of blended learning models that combine digital flexibility with structured, hands-on engagement. Research has shown that integrating pre-laboratory virtual simulations with subsequent in-person experiments can improve conceptual retention while reinforcing procedural skills (Harper et al., 2024). Furthermore, adaptive digital scaffolding, such as AI-driven learning platforms that provide real-time feedback and personalized instruction, can help mitigate cognitive overload challenges and improve student engagement (Amin et al., 2025).

Overall, this study reinforces the argument that while online practical learning enhances accessibility and theoretical comprehension, it does not fully substitute for the hands-on engagement required for skill acquisition in laboratory-based disciplines. Moving forward, a shift toward blended, adaptive, and accessibility-driven instructional models is essential to ensuring that online STEM education remains both inclusive and effective.

CONCLUSION

This study investigated undergraduate distance learners' readiness, perceptions, and challenges in online practical biology education. The results revealed that students demonstrated moderate to high readiness, particularly in digital literacy and access to online platforms, and expressed satisfaction with lecturer explanations and data analysis activities. However, they also reported limited understanding of experimental procedures, low motivation, and moderate suitability of their home learning environments. These results suggest that while online platforms support conceptual learning, they are insufficient for fostering hands-on skills, self-regulation, and consistent engagement—core elements of effective practical biology education.

To improve learning outcomes, institutions should adopt blended learning models that combine online flexibility with structured, face-to-face laboratory sessions. The integration of virtual reality simulations, interactive video demonstrations, and AI-based adaptive learning platforms can help bridge the gap in procedural knowledge and reduce cognitive overload. Institutions must also ensure equitable access through digital grants, technology support, and robust internet infrastructure, particularly for underserved learners. At the policy level, these findings support the need for strategic investments in digital innovation, instructional design, and infrastructure that promote inclusive, skill-based STEM education.

This study is not without limitations. It relied on self-reported data from a single institution, which may introduce response bias and limit generalizability. Additionally, the challenges were measured indirectly through selected questionnaire items, rather than a dedicated scale. Future research should explore longitudinal designs to examine how students develop and retain practical skills over time in online and blended settings. Comparative studies involving different instructional models, institutions, or disciplines may also yield deeper insights into best practices for delivering effective and equitable online practical education.

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