Advances in Bioscience and Bioengineering
2025, Vol. 13, No. 4, pp. 117-125
https://doi.org/10.11648/j.sjedu.20251304.11

Letter

Improving Students' Engagement Level in Laboratory Activities a Case Study of Second-Year Biology Department Students in the 2025 E.C Academic Year

Chalachew Alemneh[1, *], Tsegasew Munye[2], Nuredin Mohammed[2], Geleta Shasho[1], Eyob Gizaw[3], Zemedkum Siraj[2]

[1]Department of Wildlife and Ecotourism Management, Wolkite University, Addis Ababa, Ethiopia
[2]Department of Biology, Wolkite University, Addis Ababa, Ethiopia
[3]Department of Natural Resource Management, Wolkite Universiy, Addis Ababa, Ethiopia

Abstract

This action research explores strategies to improve student engagement in biology laboratory activities among second-year students at Wolkite University during the 2025 E. C. academic year. The study aimed to enhance student participation and motivation by integrating structured hands-on experiments, real-world problem-solving exercises, virtual simulations, and interactive data tools. The research also examined the role of peer-supported tasks and technology enhanced instruction in fostering engagement. The findings could provide valuable insights into effective pedagogical strategies that stimulate enthusiasm and active involvement, ultimately leading to better learning outcomes. From the total target population of 16 second-year biology students, 8 low achiever's students were selected from the target population based the class attendance, level of participation, and overall academic performance. During the data collection time, pre and post intervention survey was applied. Data was analyzed by descriptive statistics (means and percentages) and Paired-t-test (to compare pre- and postintervention scores of the engagement change). Results indicate that students who participated in hands-on experiments and case-based questions demonstrated increased levels of active participation, critical thinking, and problem-solving skills. The introduction of virtual simulations and interactive data tools significantly reinforced theoretical concepts, providing students with practical applications of classroom knowledge. Peer-supported tasks were shown to boost motivation and foster collaborative learning, enhancing overall engagement in laboratory sessions. Additionally, qualitative data from focus group interviews revealed that students felt more confident in their ability to tackle complex biological concepts when supported by both their peers and technology. The findings suggest that a combination of hands-on, collaborative, and technology-supported approaches not only improves engagement but also positively influences student motivation, learning outcomes, and overall performance in laboratory settings.

Keywords

Student Engagement, Biology Laboratory, Hands-on Experiments, Virtual Simulations, Peer-Supported Learning

[*]Corresponding author: alemnehc899@gmail.com (Chalachew Alemneh)

Received: 27 May 2025; **Accepted:** 18 June 2025; **Published:** 10 July 2025

1. Introduction

Laboratory activities are integral components of biological sciences, serving as the bridge between theoretical knowledge and practical application. According to [7] experiential learning theory, students acquire deeper knowledge when they engage in active, hands-on learning experiences that require them to reflect on concrete experiences. In the context of biology education, laboratory sessions allow students to directly observe and manipulate biological phenomena, thereby reinforcing theoretical concepts learned in the classroom. However, despite the critical role that laboratory activities play in biological sciences, low student engagement during these sessions remains a significant challenge at Wolkite University, particularly among second-year biology students.

Student disengagement in laboratory activities is not a new issue and has been documented in various educational settings. Studies by [4] emphasize that passive learning environments, such as traditional lecture-based teaching, can lead to lower levels of student involvement, which in turn affects their understanding and retention of subject matter. This lack of engagement can manifest in several ways, including reduced participation in laboratory experiments, limited collaboration with peers, and a diminished ability to apply theoretical knowledge in practical contexts [11]. When students are not actively engaged, their critical thinking and problem-solving skills can be undermined, impeding their overall academic performance and readiness for real-world challenges [1].

The primary objective of this action research is to investigate the factors contributing to student disengagement in laboratory activities and to design and implement interventions that promote a more interactive and engaging learning environment. Building on the principles of active learning, peer collaboration, and the integration of technology, this study aims to foster an environment where students can engage more meaningfully with the material and enhance their learning outcomes. Active learning techniques, such as problem-solving tasks and hands-on experiments, have been shown to increase student engagement by encouraging deeper cognitive involvement and application of knowledge [4]. Furthermore, the integration of technology, such as virtual simulations and multimedia resources, offers new opportunities for students to explore complex concepts in ways that traditional methods cannot provide [1]. Peer collaboration is also a key factor, as it has been demonstrated that collaborative learning not only improves student engagement but also enhances critical thinking and communication skills [11].

This research was exploring the impact of these interventions on student's engagement in laboratory settings and evaluate their influence on students' academic performance and satisfaction with the learning process. By investigating both the challenges and potential solutions to student disengagement.

1.1. Statement of the Problem

Laboratory-based instruction is a critical component of biology education, serving as a practical platform for students to apply theoretical knowledge, develop scientific reasoning, and gain hands-on experience. However, at Wolkite University, a significant challenge has been observed in the 2017 E. C academic year among second-year biology students a consistently low level of engagement in laboratory activities**.** Despite the central role, labs play in fostering deeper understanding and scientific inquiry, many students exhibit minimal participation, limited motivation, and lack the enthusiasm needed to fully benefit from laboratory sessions. In formal assessments and instructor observations suggest that this disengagement stems are from several interrelated issues. These include the dominant use of traditional, instructor-centered teaching methods**,** which limit active involvement and critical thinking; the absence of structured peer collaboration, which otherwise enhances communication, problem-solving, and accountability and the underutilization of educational technology, such as virtual simulations and interactive tools, which are shown to improve engagement and conceptual understanding [1-4, 11].

Such conditions are not only hindering students' ability to engage meaningfully with biological content but also impede the development of essential academic and professional competencies. The lack of innovative, student-centered laboratory instruction limits experiential learning, suppresses student autonomy, and weakens the connection between theory and practice [7].

Conducting this study over the course of a semester was not only foster measurable improvements in student engagement and academic outcomes but was also provide actionable insights to inform laboratory teaching practices within and beyond Wolkite University.

1.2. Objectives

1.2.1. General Objective

To improve student engagement levels during laboratory activities among second-year biology students at Wolkite University.

1.2.2. Specific Objectives

1) To identify specific factors to student's low engagement in laboratory;
2) To implement structured interventions; hands-on experiments, peer collaboration, and technology-enhanced tools;
3) To measure the effectiveness of these interventions through pre and post-intervention comparisons.

1.3. Research Questions

1) What were barriers to student's low-level engagement?

2) How were the intervention implementations carried out?
3) How was the effectiveness intervention during pre and post intervention?

1.4. Significance of the Study

The significance of the study lies in its potential to enhance educational practices within the Biology Department by addressing the critical issue of student engagement in laboratory settings. Focusing on second-year students during the 2017 E. C academic year, the research aims to foster deeper understanding and retention of scientific concepts through improved participation. The findings could provide valuable insights into effective pedagogical strategies that stimulate enthusiasm and active involvement, ultimately leading to better learning outcomes. Additionally, this study may serve as a model for future research in similar educational contexts, contributing to the broader discourse on effective teaching methodologies in science education.

2. Literature Review

The importance of active and experiential learning in laboratory settings has been well documented in educational research. [4] emphasize that active learning strategies, which involve students in activities such as problem-solving, group discussions, and hands-on experiments, are highly effective in improving engagement and academic performance. These strategies challenge students to apply theoretical knowledge to real-world problems, which not only enhances their understanding but also increases their involvement and motivation during laboratory sessions. Active learning creates an environment where students are no longer passive recipients of information but active participants in their learning process. Studies consistently show that such approaches lead to deeper learning and better retention of knowledge.

Experiential Learning Theory further supports the effectiveness of hands-on and interactive learning in laboratory environments [4]. Learning is most effective when it involves a cycle of concrete experiences, reflective observation, abstract conceptualization, and active experimentation. In laboratory settings, students engage directly with biological concepts through experiments, and this tangible interaction with the subject matter is crucial for reinforcing their learning. This process of experiential learning fosters critical thinking and helps students develop practical skills that are essential for their academic and professional growth.

The integration of technology in laboratory settings has also been shown to significantly enhance student engagement. [1] highlight the role of virtual simulations, multimedia resources, and interactive tools in making laboratory activities more dynamic and engaging. These technologies offer students the opportunity to explore complex biological processes that may not be easily replicated in a physical lab setting. Virtual simulations, for example, provide a safe, cost-effective, and flexible way to conduct experiments that would otherwise be difficult or dangerous. By incorporating technological tools, educators can create an immersive learning environment that supports various learning styles, helping students visualize abstract concepts and engage with the material in new and meaningful ways.

Moreover, peer collaboration plays a critical role in enhancing student engagement and fostering a collaborative learning environment. [11] argues that peer discussions and group tasks not only promote active engagement but also encourage students to develop critical thinking, communication, and problem-solving skills. Working in teams allows students to share knowledge, challenge each other's ideas, and gain new perspectives, all of which contribute to a deeper understanding of the subject matter. Collaborative learning also creates a sense of community in the classroom, which can reduce feelings of isolation and increase student motivation. When students collaborate, they are more likely to feel accountable for their own learning and for the success of their group, which ultimately leads to higher levels of engagement and academic achievement.

3. Research Method

The research method was employed both quantitative and qualitative data to thoroughly investigate factors influencing student engagement in laboratory activities. This approach enabled the collection of measurable outcomes while also providing in-depth understanding of students' experiences during the intervention period.

3.1. Target Population

The study targeted a group of 16 second-year biology students at Wolkite University, specifically those enrolled during the 2017 E. C. academic year. This sample was purposefully selected as a representative subset, given their active participation in laboratory-based coursework and their direct relevance to the study’s core objective of assessing student engagement in practical learning environments.

3.2. Sample Size and Selection

From the total target population of 16 second-year biology students, 8 low achiever’s students were selected from the target population based on specific inclusion criteria. These criteria included class attendance, level of participation, and overall academic performance. The selection was aimed to reflect a range of student engagement and performance levels in laboratory-based learning. Their involvement in both the data collection and intervention phases provided valuable insights into the effectiveness of the instructional strategies employed.

3.3. Data Collection Methods

Pre-Intervention Survey: Prior to the intervention, a Likert-scale questionnaire was administered to assess baseline engagement levels, perceptions of laboratory work, frequency of participation, and perceived barriers to effective involvement.

Intervention Implementation*:* Three instructional strategies were introduced to enhance laboratory engagement:

1) Structured Laboratory Tasks: Hands-on practical activities were designed to enable students to apply theoretical knowledge through biological experiments.
2) Group-Based Work: Students were organized into small collaborative groups to conduct lab work, fostering peer learning and participation.
3) Technology Use: Multimedia tools and simulations were incorporated to illustrate abstract biological concepts, aiding in visualization and comprehension.

Post-Intervention Survey*:* Following the intervention, the same Likert-scale survey was re-administered to evaluate changes in engagement levels, learning satisfaction, and any improvements observed.

Focus Group Interviews*:* Semi-structured interviews were conducted with the eight participants (2 groups) with low engagement level on pre-survey to delve deeper into their experiences during the intervention, including perceptions of collaboration, task clarity, technology use, and remaining engagement barriers.

3.4. Action Plan and Interventions

1) Hands-on Experiments: Practical sessions enabled students to directly apply theoretical concepts, enhancing scientific reasoning skills through observation and experimentation.
2) Problem-Oriented Tasks: Real-world biological questions were integrated to stimulate analytical thinking and problem-solving during lab activities.
3) Group Assignments and Peer Interaction: Students worked collaboratively in small groups to complete tasks and interpret results, promoting peer learning and increasing motivation through shared responsibilities.
4) Virtual Simulations: Biological simulations were utilized to deepen understanding of complex processes which were not easily replicated in physical labs.

3.5. Data Analysis

Collected data was analyzed by using descriptive statistics, including means and percentages, summarized pre- and post-survey results. Paired-t-test was used to compare pre- and postintervention scores of the engagement change.

3.6. Ethical Considerations

1) Informed Consent: All participants were fully informed about the study's purpose and voluntarily agreed to participate.
2) Confidentiality: Student identities and responses were kept confidential throughout the research process.
3) Anonymity: Data were anonymized in all reports and publications to protect participant privacy.

4. Results and Discussion

This section presents the results in alignment with the stated research objectives, highlighting how structured laboratory tasks, collaborative learning, and technology integration impacted the engagement, participation, motivation, and academic performance of low- achieving second-year biology students at Wolkite University.

4.1. Factors Influencing Student Engagement in Biology Laboratories

Through thematic analysis of focus group discussions and open-ended survey responses conducted before the intervention, several barriers to engagement were identified. From them 6 (75%) students were mentioned Lack of clarity in laboratory instructions, 5 (62.5%) students were mentioned minimal hands-on experience in traditional labs, and limited collaboration, leading to isolation 5 (62.5%) students) and 4 (50%) students were mentioned abstract theoretical content without visual support. These findings underscored that unclear instruction and limited interactivity were key deterrents, especially for students with weaker academic backgrounds. Conversely, factors that promoted engagement after the intervention included: Structured, step by-step experimental tasks, opportunities for meaningful peer collaboration, visual and interactive technologies that clarified complex topics. These facilitating factors helped students feel more confident, supported, and connected to both the material and their peers.

Table 1. *Factors Affecting Student Engagement Before and After the Intervention.*

Factors	Before Intervention (No. of Students)	After Intervention (No. of Students)
Lack of clarity in laboratory instructions	6 (75%)	-
Minimal hands-on experience	5 (62.5%)	-

Factors	Before Intervention (No. of Students)	After Intervention (No. of Students)
Limited collaboration	5 (62.5%)	-
Abstract theoretical content without support	4 (50%)	-
Structured tasks	-	8 (100%)
Visual and technologies interactive	-	6 (75%)

The findings from the action research highlight several key barriers and enablers to student engagement in laboratory settings, which align with and diverge from the findings in other studies. In terms of barriers to engagement, the action research identified several issues, including a lack of clarity in laboratory instructions, minimal hands-on experience, limited collaboration, and abstract theoretical content without visual support. These barriers are consistent with the results found in other research. For example, [4] discovered that students' understanding and engagement in Science, Technology, English and Mathematics courses were often hindered by passive learning environments and unclear instructional methods. Their study suggested that traditional lecture-based teaching methods, which typically lack clear instructions and hands-on experiences, contribute to disengagement and lower academic performance. Similarly, [11] emphasized that students who do not engage in active learning or hands-on activities often struggle to retain information and make meaningful connections with the material. This theme is echoed in the action research, where students expressed challenges with abstract content and passive learning environments. The finding indicated that structured task and technology highly influenced laboratory engagement of students during post intervention this idea agreed with other finding, the action research's use of visual and interactive technologies resonates with [3], findings that visual aids and interactive tools help enhance understanding and foster deeper engagement, particularly when dealing with complex or abstract content.

4.2. Implementation Strategies; Structured Tasks, Peer Collaboration, and Technology on Student Engagement in Laboratory

The intervention strategies collectively contributed to a substantial increase in student motivation and participation. Structured tasks made the labs more accessible and less intimidating. Structured task like giving individual duty during laboratory activity (procedure reading, equipment arranging, time keeping, laboratory report) and asking each student at the end of the activity. All students were reported that clear, stepwise instructions allowed them to understand both the purpose and process of experiments. This clarity helped to connect theoretical knowledge with practical application, a crucial element for enhancing motivation, collaborative learning was especially impactful. Seven students expressed that working in small groups created a supportive atmosphere, reducing anxiety and boosting accountability. Sharing tasks and discussing outcomes within teams enabled them to learn from each other and feel more invested in the outcome. Technology also played a critical role. Six students found that virtual simulations and animations helped them visualize abstract biological concepts. These tools made it easier to understand complex topics. The engaging nature of these resources contributed to higher levels of sustained attention and curiosity, which translated into more enthusiastic participation.

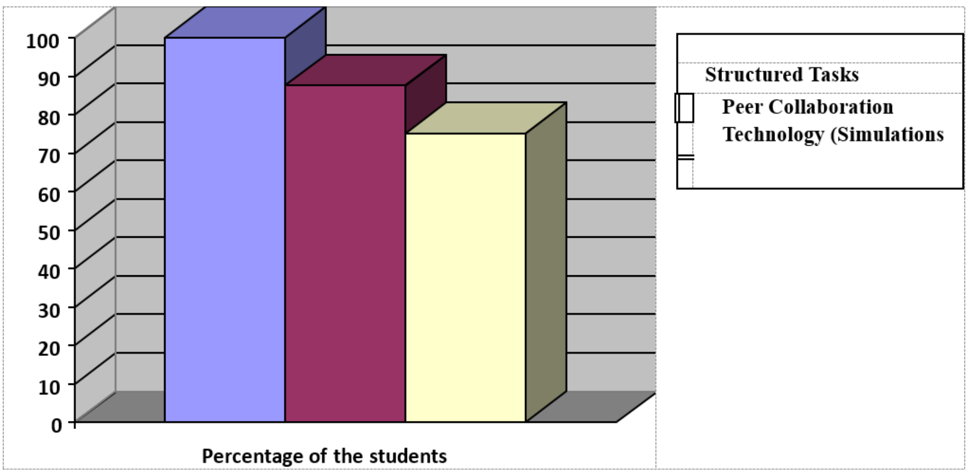

Figure 1. *Effect of Intervention Strategies on student's engagement level.*

The findings of the action research regarding the effect of structured tasks, peer collaboration, and technology on student engagement labs align with several existing studies while also highlighting unique aspects of the intervention in this context.

In terms of *structured tasks*, the action research found that the introduction of clear, stepwise instructions significantly increased student motivation and participation. All of students mentioned that structured task helped them understand both the purpose and process of experiments, facilitating a stronger connection between theoretical knowledge and practical application. The structured and interactive activities fostered greater student engagement, [5]. The importance of clarity in instruction to engage students effectively in lab activities [11]. The well-structured tasks reduced cognitive load and helped students engage more deeply with the material, a finding mirrored in this action research where structured tasks made lab experiences more approachable and manageable [13].

Peer collaboration was another key factor in increasing motivation and participation. Seven students in the action research indicated that working in peer reduced anxiety and boosted accountability. The peer collaboration fosters deeper cognitive engagement, noting that students in cooperative groups participate in richer discussions, which enhances their understanding of the content [16]. This aligns with the action research, which showed that collaboration was particularly impactful in enhancing participation and reducing isolation, especially for students with lower academic performance.

Role of technology; the action research found that virtual simulations and animations helped students visualize abstract biological concepts, contributing to sustained attention and curiosity. Most of students reported that these resources facilitated understanding and increased participation. This finding aligns with [3], who suggested that interactive technologies significantly enhance student engagement by helping them understand complex subjects. The importance of technological tools in bridging gaps in understanding and promoting active learning [4]. The action research corroborates these findings, with students reporting that technology helped them engage more enthusiastically and participate more fully in lab activities. Moreover, [11], highlighted that multimedia learning tools improve retention and understanding, particularly in complex subjects like biology, a conclusion echoed by the positive feedback from students in the action research.

While the action research largely aligns with existing literature, one area of divergence lies in the combination of these strategies. The research underscores the synergistic effect of structured tasks, peer collaboration, and technology in motivating students and enhancing participation, suggesting that the integration of these factors had a more profound impact than any single intervention alone. This contrasts with studies such as [4, 5] which primarily focus on one or two of these elements in isolation. The action research highlights that the combination of these strategies was particularly effective in creating an engaging and supportive learning environment. This is consistent with [15] who also noted that blending structured tasks with technology and peer collaboration enhances student engagement. Thus, the action research suggests that a holistic approach, integrating multiple interventions, may be the most effective strategy for improving student motivation and participation in laboratory settings.

4.3. Effect of Intervention on Students Engagement in Laboratory Activities (Pre- and Post-Comparison)

All eight second-year biology students showed higher engagement scores after the laboratory intervention. The mean pre-intervention score was 2.225, and the mean post-intervention score was 4.138, yielding a mean increase (post–pre) of 1.9125 points (SD = 0.1553). A paired sample t-test was conducted on the pre- and post-intervention scores to assess the significance of the observed change. The test yielded a mean difference of 1.9125 (SD = 0.1553) with a t-statistic of **t** (7) = 34.84. The corresponding two-tailed p-value was $4.16 \times 10{-}9$ ($p < 0.0001$), indicating that the increase in engagement scores was statistically significant.

Table 2. *Pre- and Post-Intervention Engagement Scores and Paired t-test Results.*

Student / Statistic	Pre-intervention Score	Post-intervention Score	Difference (Post−Pre)
Student 1	2.0	3.8	1.8
Student 2	2.5	4.2	1.7
Student 3	1.8	4.0	2.2
Student 4	2.3	4.1	1.8
Student 5	2.1	4.0	1.9
Student 6	2.4	4.3	1.9
Student 7	2.2	4.2	2.0

Student / Statistic	Pre-intervention Score	Post-intervention Score	Difference (Post−Pre)
Student 8	2.5	4.5	2.0
Mean difference (post–pre)	2.225	4.138	1.9125
Std. Dev. of differences			0.1553
t statistic (df = 7)			34.84
p-value			4.16×10^{-9}

The effects of inquiry-based laboratory instruction on middle and high school students, finding a moderate yet statistically significant improvement in engagement and understanding, with a reported t-value of approximately 3.5 and a p-value less than 0.01 [12-18]. While their results indicate meaningful progress, the effect size was lower than that of the current study. This discrepancy could be attributed to a broader and more diverse student population or to a less structured intervention design. Their study's more variable implementation might have contributed to smaller gains compared to the uniform, focused approach observed in your laboratory intervention [17].

Learning by Design (LBD) framework, incorporated iterative, and project-based learning to promote student engagement are vital for student's participation improvement [8-10]. Although their mixed-methods study showed positive outcomes in affective engagement and conceptual understanding, the average engagement gain ranged between 0.8 and 1.2 again, less than the mean increases of 1.9125 reported in your study. A key difference lies in the controlled pre/postintervention design of your research, which offers clearer statistical evidence of impact, whereas the LBD framework emphasized broader instructional reform with potentially more varied effects.

The use of web-based inquiry environments in European science classrooms are well known and practiced for academic change of students [2]. Their findings revealed a pre/post t-value of approximately 5.2 and a p-value below 0.001, showing moderate improvements in both cognitive and behavioral engagement. However, their results displayed greater variability, likely due to inconsistencies in digital literacy among students. In contrast, the low standard deviation (SD = 0.1553) and large t-value (t = 34.84) in your study suggest a highly consistent effect, reflecting the focused nature of your intervention and possibly better control of external [2].

A quasi-experimental study assessing science inquiry facilitated through digital media [9]. They reported engagement gains with a mean difference of 1.3 ($p < 0.01$), indicating a successful outcome, though not as substantial as yours. One explanation may be the uneven integration of technology in their classrooms, which could have diluted the intervention's effectiveness. While both studies underline the value of active, hands-on learning, your simpler and potentially more cohesive laboratory strategy produced a larger and more consistent improvement in student engagement [9].

Changes in Academic Performance and Satisfaction Following the Intervention: A Quantitative Assessment of Student Progress

Low achievers, in particular, benefited from the intervention, with average scores increasing from 54% to 72%. The results of the action research indicated a notable improvement in student engagement, motivation, academic performance, and satisfaction following the intervention, particularly among low and medium achievers. These outcomes align with existing studies but also highlight unique aspects of the intervention's impact.

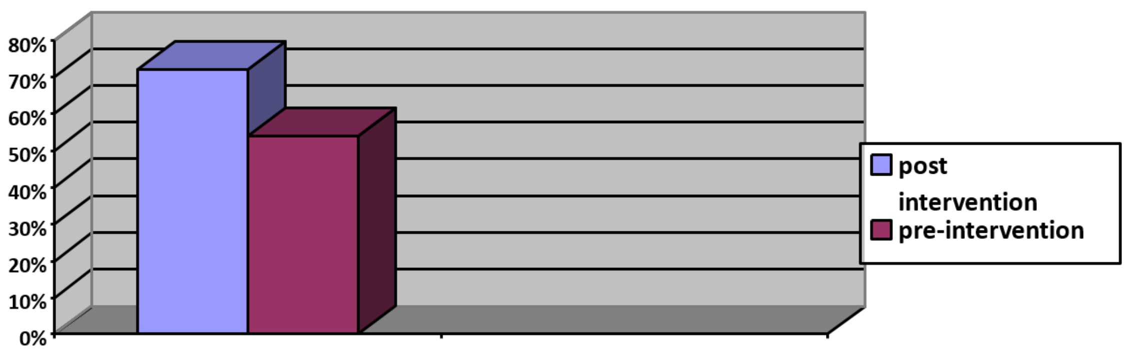

Figure 2. *Changes in Academic Performance and Satisfaction.*

This improvement suggests that the intervention was particularly effective for students who had previously struggled, helping to narrow the achievement gap. Similar findings were observed by [5] who reported that active learning and structured tasks were particularly successful in closing achievement gaps in Science, Technology, English and Mathematics courses. They found that students engaging with active, structured tasks and collaborative learning experienced higher academic outcomes, especially those who had underperformed in traditional settings. This is consistent with the results of the action research, where low achievers experienced greater academic success due to the clarity and structure provided by the intervention.

However, [4] found that while active learning methods generally improved engagement and performance, they did not always close achievement gaps. Their study indicated that the effectiveness of active learning varied across student groups, suggesting that factors like the nature of the intervention, students' academic backgrounds, and the level of support could influence outcomes. These points to the possibility that while the intervention in the action research was highly successful for low and medium achievers, its success may be contingent on these contextual factors.

The action research also highlighted significant student satisfaction and engagement. All eight students reported enjoying the new format of the lab instruction, appreciating the hands-on experiences, peer support, and the clearer understanding of course content. These findings align with [3], principles of good practice in undergraduate education, which emphasized the importance of active learning environments for enhancing student satisfaction and engagement. Furthermore, the action research's use of peer support mirrors the findings of [6], who highlighted that cooperative learning environments foster a sense of belonging and collective responsibility, increasing student motivation. Additionally, six students, who had previously avoided leadership roles, began to take more initiative in-group tasks, indicating a rise in self-confidence and academic independence. This is in line with Tinto's [14], theory of student persistence, which posited that engaging in collaborative tasks promotes student ownership of learning and enhances self-confidence.

5. Conclusion

The integration of structured instructional design, peer collaboration, and educational technology into biology laboratory instruction presents a transformative approach to addressing the learning needs of underperforming students in higher education. The findings from this study provide compelling evidence that when learners are supported with clear, stepwise experimental protocols, collaborative learning opportunities, and multimodal technological tools, their levels of engagement, motivation, and academic achievement significantly increase. These outcomes are particularly salient for low- and medium-achieving students, who often face challenges in navigating abstract scientific content and traditional didactic instruction.

Grounded in the principles of social constructivism, this study affirms that learning is most effective when students are actively involved in constructing knowledge through meaningful social interaction and contextualized experiences. The scaffolding provided by structured laboratory tasks helped students bridge the gap between theory and practice, reducing cognitive overload and making complex biological processes more accessible. Peer collaboration facilitated a sense of belonging and collective responsibility, contributing to a psychologically safe learning environment that encourages risk-taking, question-asking, and mutual support. The use of educational technology particularly animations and simulations further enriched the learning experience by visualizing dynamic processes that are otherwise difficult to conceptualize, thereby fostering deeper conceptual understanding and sustained attention.

The notable improvements in academic performance particularly the 18% gain among low achievers indicate that such interventions not only support knowledge acquisition but also contribute to narrowing the performance gap. Additionally, the increase in student satisfaction and emergence of leadership roles among previously passive learners suggest that the intervention fostered greater academic agency and confidence, both of which are critical for long-term success in Science, Technology, English and Mathematics fields.

In the broader context of science education reform, these findings underscore the urgent need to move beyond traditional, lecture-centered laboratory models toward learner-centered, inclusive, and technologically enhanced pedagogies. By reimagining laboratory instruction as active, collaborative, and supportive learning environment, educators can better engage diverse learners, enhance learning outcomes, and promote equity in science education. This study thus contributes to a growing body of evidence advocating for instructional innovation as a pathway to educational equity, retention, and excellence in undergraduate biology education.

Abbreviations

LBD	Learning by Design

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Baker, E. A., & Hargis, J. (2016). Encouraging student engagement with technology-based learning tools. International Journal of Teaching and Learning in Higher Education, 28(1), 90–98.

[2] Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2010). Collaborative inquiry learning: Models, tools, and challenges. *International Journal of Science Education*, 32(3), 349–377.

[3] Chickering, A. W., & Gamson, Z. F. (1987). Seven Principles for Good Practice in Undergraduate Education. *AAHE Bulletin*, *39*(7), 3-7.

[4] Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., &Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, **111**(23), 8410-8415.

[5] Haak, D. C., et al. (2011). Increasing STEM retention: The role of faculty members in fostering an inclusive and engaging learning environment. *CBE—Life Sciences Education*, 10(2), 118-128.

[6] Johnson, D. W., Johnson, R. T., & Smith, K. A. (2007). The state of cooperative learning in postsecondary and professional settings. *Educational Psychology Review, 19*(1), 15-29. https://doi.org/10.1007/s10648-006-9038-8

[7] Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Prentice-Hall.

[8] Kolodner, J. L., Camp, P. J., Crismond, D., et al. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting Learning by Design into practice. *Journal of the Learning Sciences*, 12(4), 495–547.

[9] Liu, X., Horton, L., Olmanson, J., & Toprac, P. (2009). A study of learning and motivation in a new media enriched environment for middle school science. *Educational Technology Research and Development*, 57(5), 527–552.

[10] Mayer, R. E. (2013). Multimedia instruction. In *Handbook of research on educational communications and technology* (pp. 385-399). New York, NY: Springer New York.

[11] Michael, J. (2006). Where's the evidence that active learning works. *Advances in physiology education* 30(4), 159–167. https://doi.org/10.1152/advan.00053.2006

[12] Michael, J., & Modell, H. I. (2003). *Active learning in secondary and college science classrooms: A working model for helping the learner to learn*. Routledge.

[13] Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223-231.

[14] Tinto, V. (1997). Classrooms as communities: Exploring the educational character of student persistence. *Journal of Higher Education, 68*(6), 599-623.

[15] Toppinen, A., et al. (2013). Blended learning in higher education: The impact on student engagement. *Computers & Education*, 63, 75-85.

[16] Webb, N. M. (2009). The impact of peer collaboration on learning. *International Journal of Educational Psychology*, 2(3), 355-381.

[17] White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, 16(1), 3–118.

[18] Frederiksen, J. R., & White, B. Y. (1998). Teaching and learning generic modeling and reasoning skills. *Interactive Learning Environments*, *5*(1), 33-51.