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Capturing Meaningful Learning in Chemistry Practical Work Using MLLIv2

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Abstract: This study aimed to measure the extent of meaningful learning achieved by students during general chemistry laboratory activities. A descriptive quantitative design was employed with 126 participants, consisting of 51 Chemistry Education and 75 Biology Education students. Data were collected using the Meaningful Learning in the Laboratory Inventory (MLLIv2), which evaluates affective, cognitive, and affective–cognitive aspects. The data were analyzed and categorized into five levels from "very poor" to "very good." The results showed that most students were in the "very good" category (81–100%) across all aspects, with smaller proportions in the "good" category (61–80%). No students were classified as "fair," "poor," or "very poor." Chemistry Education students achieved slightly higher averages (affective = 91%, cognitive = 93%, affective–cognitive = 91%, overall = 92%) compared to Biology Education students (affective = 85%, cognitive = 89%, affective–cognitive = 89%, overall = 88%). These findings indicate that the laboratory effectively fostered meaningful learning by integrating cognitive understanding with affective engagement. The results also emphasize that meaningful learning is shaped not only by conceptual mastery but also by students' emotional responses and their ability to connect laboratory experiences with academic and professional goals.

Keywords: Affective domain; Chemistry laboratory; Cognitive domain; Meaningful learning

Introduction

Laboratory practicum has long been regarded as an essential instructional method in science education because it offers distinct advantages over more conventional approaches. As Gasong (2017) notes, teaching and learning are fundamentally educational acts that must be responsive to learners' needs (Sapulete et al., 2023). Laboratory activities, as emphasized by Mamlok et al. (2012), play an indispensable role in supporting students' conceptual understanding and scientific inquiry in the modern science curriculum (Pratama & Rohaeti, 2024). According to Fakinah et al. (2018), such activities strengthen students' confidence in the validity of conclusions derived from their own experiments, rather than relying solely on teacher explanations or textbook accounts. Practicums also encourage the development of exploratory attitudes toward science and technology (Pasaribu, 2018) and foster important scientific dispositions such as honesty, collaboration (Hadiwangsa et al., 2024), critical thinking (Yusuf, 2022), openness, and tolerance (Zahara et al., 2017). Furthermore, they provide students with direct learning opportunities through hands-on engagement and observation of natural phenomena, enrich learning with realistic and objective content, and promote the development of scientific process skills and scientific reasoning skills (Sumiyarti, 2019). Collectively, these experiences contribute to deeper internalization and longer retention of learning outcomes.

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At the university level, laboratory practicums redefine the role of the lecturer, shifting it from knowledge transmitter to mentor or facilitator (Yanti & Sutrisno, 2024), while students take on the responsibility of actively engaging in experiments to achieve meaningful scientific discoveries (Lubis et al., 2016). As Etiubon et al. (2017) emphasize, practice-oriented science courses demand tactical laboratory activities that immerse students in environments rich with choices and opportunities, thereby enhancing the meaningfulness of learning. Through such engagement, laboratory experiments not only expand students' knowledge but also strengthen their skills, attitudes, and behaviors in alignment with the practices of scientific inquiry (Basir et al., 2024; Tommy et al., 2024).

The laboratory itself is more than a physical space; it is a setting where students, lecturers, and researchers engage in systematic experimental activities (Djamarah, 2005; Raharjo & Harjanto, 2017; Wiratma & Subagia, 2014). Hofstein et al. (2004) and Mukti (2018) argue that laboratories render instruction more meaningful because students are directly involved in observing and interpreting the outcomes of their experiments. In this sense, laboratories are indispensable in modern science education, with chemistry laboratories serving as a particularly vital component of the broader scientific domain.

If laboratory instruction is indeed assumed to provide students with unique learning experiences, then empirical evidence is needed to demonstrate the extent of student learning achieved through such practices (Galloway & Bretz, 2015). While previous studies have outlined the objectives of laboratory learning as defined in the curriculum (Hofstein & Lunetta, 2004), it is equally important to capture students' own perspectives on their laboratory experiences. Just as lecturers are tasked with evaluating students' mastery of content knowledge, students' conceptions of laboratory learning must also be assessed to design meaningful learning strategies that bridge the gap between instructors' intended outcomes and students' expectations (Asni et al., 2020). This evidence should be grounded in systematic assessments of both what students learn and how they learn in the laboratory.

The concept of meaningful learning, as articulated by Ausubel (1963), refers to a process in which students not only acquire new knowledge but also integrate it with their prior experiences, construct deeper meaning, and apply their understanding in real-world contexts. Similarly, Kwangmuang et al. (2021) and Rahmah (2013) state that meaningful learning is learning that trains students to connect new information they encounter in the learning process with concepts, knowledge, and skills they already possess. Rather than relying on rote memorization, meaningful learning enables students to develop a comprehensive understanding of concepts, recognize interrelationships among them, and transfer their knowledge to novel situations. This approach promotes deeper cognitive engagement, cultivates critical thinking skills, and supports the practical application of knowledge in daily life, thereby contributing significantly to intellectual and personal development (Pratama & Sukasih, 2024).

In the context of contemporary education, meaningful learning has increasingly become a central priority for educators. Novak (2010) emphasizes that this form of learning requires students to connect newly acquired knowledge with authentic, lived experiences in order to construct profound and lasting understanding. When students are able to integrate new knowledge with prior experiences and apply it to everyday situations, learning is not only more meaningful but also more impactful in shaping their long-term academic and personal growth (Burhanuddin et al., 2010).

Moreover, according to Muamanah et al. (2020), meaningful learning is a process in which students connect new knowledge with their prior cognitive structures. It does not merely involve acquiring information but also constructing relationships and meaning, making the material easier to understand and remember. In this context, lecturers play a crucial role by designing effective instructional strategies that enable students to integrate concepts efficiently, thereby fostering deeper comprehension and stronger retention. Meaningful learning also equips students with critical thinking skills, solid conceptual understanding, and the ability to apply knowledge in real-world contexts, preparing them to address complex challenges and adapt to change. Assessing the extent to which meaningful learning occurs in laboratory activities necessitates the use of reliable and context-appropriate measurement tools.

The Meaningful Learning in Laboratory Instrument (MLLI), first developed by Galloway et al. (2015), has been widely used to measure meaningful learning in university-level chemistry practicums through 30 items encompassing cognitive, affective, and combined cognitive–affective aspects. Since then, the instrument has been refined into MLLIv2 by Vaughan et al. (2024), in which the number of items was reduced from 30 to 16, focusing only on cognitive and affective domains. This revision was carried out because several items in the original MLLI were considered less effective, as early-year students often struggled to interpret statements with overlapping meanings. In the present study, MLLIv2 was employed as the instrument for data collection to assess meaningful learning in laboratory activities. The advantage of this instrument is that it focuses on the cognitive and affective aspects of students related to laboratory practicums in assessing meaningful learning in laboratory activities (Grove & Bretz, 2007). Thus, MLLIv2 is regarded as a more valid and practical tool for capturing students' meaningful learning experiences in laboratory settings. Accordingly, this study applies MLLIv2 to provide empirical insights into how laboratory work contributes to the development of meaningful learning among university chemistry students.

Building upon these considerations, the present study aims to investigate the extent to which meaningful learning occurs during university-level chemistry laboratory work by employing the MLLIv2 instrument. Specifically, this research seeks to provide empirical insights into how laboratory practices support the development of cognitive and affective aspects of learning, thereby contributing to a deeper understanding of the role of practicum activities in fostering meaningful learning among science education students.

Method

The present study employed a descriptive quantitative design. As noted by Rusandi et al. (2021), descriptive quantitative research is intended to systematically and comprehensively describe a phenomenon or event through the use of quantitative data. This design was considered appropriate because it allows for a detailed depiction of students' meaningful learning outcomes in laboratory activities as measured by the MLLIv2 instrument.

In line with this design, the study recruited a specific cohort of participants to provide a representative picture of students' experiences. A total of 126 first-year students from the 2024 cohorts participated in the study, consisting of 51 Chemistry Education students and 75 Biology Education students at FKIP UNTAN. All participants were enrolled in general chemistry laboratory activities during the odd semester.

To capture their learning experiences, data were obtained through a standardized instrument tailored to the laboratory context. Data were collected using a questionnaire designed to assess students' experiences of meaningful learning in the laboratory setting. The instrument used was the Meaningful Learning in the Laboratory Instrument version 2 (MLLIv2), originally developed by Galloway et al. (2015) and subsequently revised and validated by Vaughan et al. (2024). MLLIv2 is a psychometrically validated tool that assesses both cognitive and affective dimensions of learning through a total of 16 items, comprising nine positively worded items (Supporting Expectations) and seven negatively worded items (Detracting Expectations). The Supporting Expectations domain reflects productive learning attitudes such as conceptual engagement and reflective thinking, whereas the Detracting Expectations domain captures procedural or disengaged mindsets.

For this study, the instrument was translated into Indonesian and validated by two English language lecturers and two chemistry lecturers to make sure it was clear, had the same meaning as the original, and suitable for research context. The results of the validation confirmed that MLLIv2 was valid and appropriate for data collection.

The MLLIv2 responses were analyzed using a five-point Likert scale (Strongly Agree = 5; Agree = 4; Neutral = 3; Disagree = 2; Strongly Disagree = 1). The data were then converted into percentages using the following formula:

$$P = \frac{F}{n} \times 100\% \quad (1)$$

Description:
P = percentage
F = score obtained
n = maximum score

The percentage values obtained are then categorized based on the interpretation category in Table 1.

Table 1. Meaningful Learning Criteria

Percentage (%)	Meaningful learning criteria
≤ 20	Very Poor
21-40	Poor
41-60	Fair
61-80	Good
81-100	Very good

Table 1 presents five categories for interpreting the MLLIv2 data, ranging from Very Good to Very Poor. Meaningful learning is considered achieved when the results fall into the Good or Very Good categories, with a minimum percentage of 61% and up to 100%.

Result and Discussion

The MLLIv2 instrument comprises 16 items—nine phrased positively and seven negatively—designed to assess students' experiences of meaningful learning across three domains: cognitive, affective, and a combined cognitive-affective dimension. Table 2 outlines the distribution of items across these categories. The instrument was administered after students completed the after students completed the General Chemistry laboratory sessions.

Table 2. The Statements of MLLIv2

No	Statements	Aspe
When performing experiments in my chemistry laboratory, I expect...		
1.	To learn chemistry that will be useful in my life.	Affective-cognitiv
2.	To make decisions about what data to collect.	Cognitiv
3.	To experience moments of insight.	Cognitiv
4.	To be excited to do chemistry.	Affectiv
5.	To develop confidence in the laboratory.	Affectiv
6.	To interpret my data beyond only doing calculations.	Cognitiv
7.	To use my observations to understand the behaviour of atoms and molecules.	Cognitiv
8.	To be intrigued by the instruments.	Affective-cognitiv
9.	To learn problem-solving skills.	Cognitiv
10.	To feel unsure about the purpose of the procedures.	Affective-cognitiv
11.	To be confused about how the instruments work.	Cognitiv
12.	To feel disorganized.	Affective-cognitiv
13.	To be confused about the underlying concepts.	Cognitiv
14.	To be frustrated.	Affectiv
15.	To feel intimidated.	Affectiv
16.	To be confused about what my data mean.	Cognitiv

This research data was obtained through MLLI results and interviews. Every student who fills out the MLLIv2 will be grouped based on a certain percentage range in each aspect. Statements in the MLLIv2 are grouped based on their aspects, namely affective, cognitive, and affective-cognitive, which is then calculated using a previously established formula. The percentages for each aspect are grouped by range and category, as presented in Table 3. To provide a clearer picture of students' meaningful learning outcomes, the results are first presented in terms of the distribution across performance categories, followed by an analysis of average scores.

Table 3. Distribution of Students' Meaningful Learning Levels Across Affective, Cognitive, and Affective–Cognitive Aspects (N_C = 51, N_B = 75)

Percentage Range (%)	Affective		Cognitive		Affective-Cognitive		Category
	C	B	C	B	C	B	
<20	-	-	-	-	-	-	Very poor
21-40	-	-	-	-	-	-	Poor
41-60	-	-	-	-	-	-	Fair
61-80	7	36	3	8	7	14	Good
81-100	44	39	48	67	44	61	Very good

Note: C is for Chemistry Education Students, while B is for Biology Education Students

As shown in Table 3, the majority of both Chemistry Education (C) and Biology Education (B) students are in the "very good" category (81–100%) across affective, cognitive, and affective–cognitive aspects. Specifically, 48 Chemistry students and 67 Biology students achieved this level in the cognitive aspect. A smaller proportion were classified in the "good" category (61–80%), and none were placed in the "fair," "poor," or "very poor" categories. This distribution indicates that the laboratory consistently supported meaningful learning at a high level. The absence of low-category results reflects that the laboratory design effectively engaged students across both cognitive and affective domains (Ausubel, 1963; Novak, 2010).

This strong concentration in the "very good" category further suggests that the laboratory experience was not merely procedural but actively facilitated deeper conceptual connections and positive attitudes. The fact that no students were categorized as "fair," "poor," or "very poor" demonstrates a uniform impact across the cohort, minimizing disparities in learning outcomes. Such consistency is important because meaningful learning often varies depending on students' prior knowledge, motivation, and learning strategies (Taber, 2013; Talanquer, 2018). In this case, the structured design of the laboratory appeared to mitigate those variations, creating an equitable environment where both Chemistry and Biology students could engage productively. This finding strengthens the argument that well-designed laboratory instruction can act as a leveling mechanism, ensuring that all learners, regardless of background, can achieve meaningful engagement and understanding.

Table 4. Average Percentages of Affective, Cognitive, and Affective–Cognitive Aspects for Chemistry and Biology Education Students (N_C = 51, N_B = 75)

Class	Aspects Type Affective (%)	Cognitive (%)	Affective-Cognitive (%)	Average (%)	Category
C	91	93	91	92	Very good
B	85	89	89	88	Very good

To further synthesize the findings, the average percentage scores for each aspect were calculated. As presented in Table 4, Chemistry Education students obtained mean scores of 91% (affective), 93% (cognitive), and 91% (affective–cognitive), yielding an overall average of 92%. Biology Education students scored slightly lower, with averages of 85%, 89%, and 89%, producing an overall mean of 88%. Although both groups are in the “very good” category, Chemistry students demonstrated higher scores, especially in the cognitive dimension. This suggests that their disciplinary background provided stronger conceptual alignment with the laboratory content, enabling deeper assimilation of knowledge (Johnstone, 1991; Talanquer, 2015). At the same time, the high results of Biology students show that the laboratory framework was sufficiently general to foster meaningful learning even for those outside the chemistry discipline.

The consistently high averages reported in Table 4 highlight the robustness of the laboratory framework in fostering meaningful learning (Davis, 1993). The Chemistry Education students’ slightly higher outcomes, particularly in the cognitive aspect, suggest that their disciplinary background enabled them to anchor new information more effectively onto existing knowledge structures. However, the Biology Education students’ achievement of “very good” scores across all aspects underscores the accessibility of the laboratory tasks for students outside the core discipline. This suggests that laboratory activities were designed with sufficient scaffolding to support diverse learners, a critical consideration in higher education where student cohorts often have mixed backgrounds (Galloway & Bretz, 2015; Seery, 2015).

To complement the tabular data, graphical comparisons were made to highlight trends more clearly. The affective aspect, which reflects motivation, confidence, and emotional engagement, is presented in Figure 1. Chemistry Education students scored slightly higher than Biology students, suggesting that their subject familiarity enhanced emotional involvement. This result supports the idea that affective engagement contributes significantly to meaningful learning outcomes (Bretz, 2019; Pekrun, 2021).

The affective outcomes shown in Figure 1 underscore the importance of emotional engagement in laboratory learning. Chemistry Education students’ slightly higher affective scores likely stem from stronger interest and confidence derived from their disciplinary alignment. However, Biology Education students also demonstrated strong affective engagement, suggesting that the laboratory context itself fostered motivation and positive attitudes regardless of program affiliation. Since affective factors are known to influence persistence, self-efficacy, and long-term retention of knowledge (Bretz, 2019; Pekrun, 2021), these results highlight that well-designed laboratories not only build conceptual understanding but also cultivate a supportive emotional climate conducive to learning.

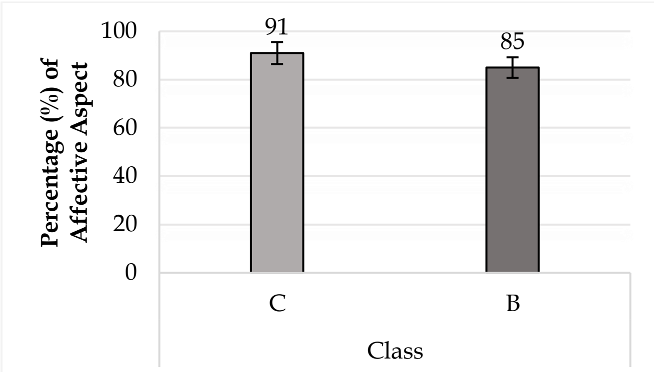

Figure 1. Affective aspect scores of Chemistry and Biology Education students (N_C = 51, N_B = 75)

The cognitive aspect, which reflects knowledge and thinking skills (Ridani & Arianingrum, 2024), are displayed in Figure 2. Chemistry Education students achieved near-perfect scores, while Biology students also performed strongly in the “very good” category. This pattern is consistent with expectations that Chemistry majors, who have stronger prior knowledge, would assimilate laboratory concepts more effectively. Nonetheless, the high cognitive scores of Biology students indicate that meaningful learning can still be achieved across disciplines when laboratory tasks are well designed (Taber, 2013; Talanquer, 2018).

The cognitive results in Figure 2 reveal the central role of prior knowledge in shaping meaningful learning. Chemistry Education students’ near-perfect outcomes point to the synergy between laboratory experiences and disciplinary preparation, while the strong performance of Biology students shows that thoughtfully structured tasks can support cognitive gains even when prior knowledge is less extensive. This finding aligns with Taber’s (2013) view that effective teaching bridges gaps in students’ understanding by situating abstract concepts within tangible contexts. Thus, the laboratory design not only reinforced existing conceptual frameworks for Chemistry majors but also expanded the knowledge base of Biology students in a way that promoted genuine understanding rather than rote memorization.

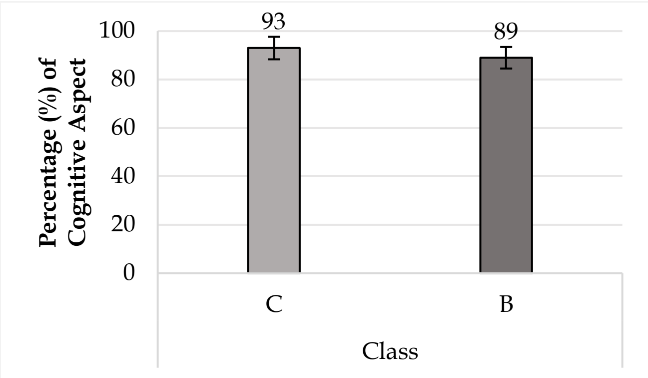

Figure 2. Cognitive aspect scores of chemistry and biology education students (N_C = 51, N_B = 75)

The integration of affective and cognitive dimensions is reflected in Figure 3. Both groups performed similarly well, with only minor differences, suggesting that the laboratory environment supported the simultaneous development of emotional engagement and conceptual understanding. This finding echoes Novak's (2010) assertion that meaningful learning requires the interplay of cognitive and affective processes.

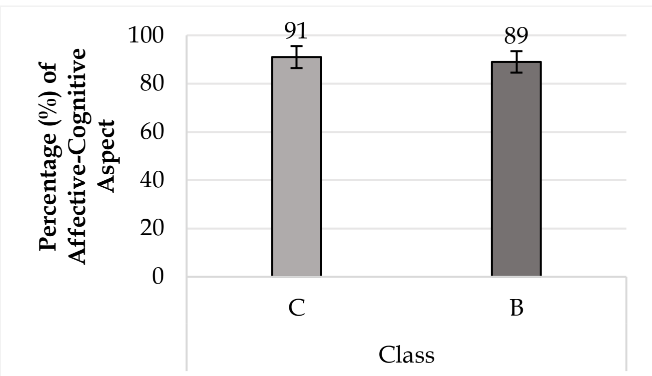

Figure 3. Affective–cognitive aspect scores of chemistry and biology education students (N_C = 51, N_B = 75)

The convergence of affective–cognitive results in Figure 3 demonstrates the integrative nature of meaningful learning, where both emotional and intellectual engagement must occur simultaneously. The minimal gap between Chemistry and Biology students indicates that the laboratory effectively supported the dual processes of emotional involvement and cognitive assimilation. Lestari et al. (2025) state that the integration of cognitive abilities and students' emotional responses can achieve meaningful learning in the laboratory. This dual engagement fosters holistic, durable learning, allowing students to internalize knowledge in personally meaningful ways. Jeppesen et al. (2017) argue that when learners can relate academic content to personal goals and values, the learning becomes more impactful and transferable. Novak (2010) emphasizes that meaningful learning emerges when learners find value in what they are doing and can link it to their existing frameworks. These findings confirm that the laboratory not only promoted understanding but also nurtured students' willingness to engage actively with the material, bridging the often-separate domains of motivation and knowledge.

Finally, to provide a holistic perspective, Figure 4 consolidates overall scores across affective, cognitive, and affective–cognitive aspects for all participants (N = 126). The figure confirms that both groups reached the "very good" category overall, with Chemistry students slightly outperforming Biology students across most aspects. These results demonstrate that the laboratory promoted not just procedural learning but a balanced integration of conceptual depth and affective engagement (Ausubel, 1963; Bretz, 2019).

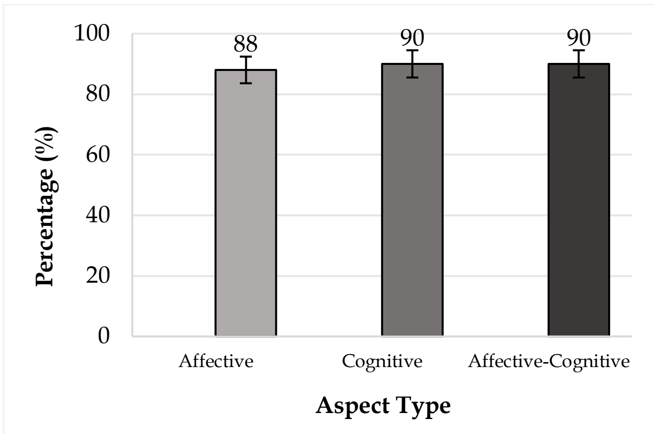

Figure 4. Overall scores across affective, cognitive, and affective–cognitive aspects for all students (N_{total} = 126)

The holistic results in Figure 4 show that the affective aspect received the lowest percentage score compared to the cognitive and affective-cognitive aspects. This finding is in line with previous studies that also found the lowest percentage in the affective aspect, because many students feel anxious and worried and lack confidence in their abilities when conducting practical work in the laboratory (Amat et al., 2024; Cahyani et al., 2024; Lestari et al., 2025). Bretz et al. (2013) stated that the affective aspect is often neglected in practical activities. The affective aspect in laboratory activities is often limited to group work and its relevance in practical activities (Bretz et al., 2013). Therefore, it is important to emphasize and pay attention to the affective aspect in laboratory learning, considering that meaningful learning requires the integration of feelings (affective) and actions (psychomotor) with thinking (cognitive) (Novak, 2010).

Overall, the holistic results in Figure 4 affirm the success of the laboratory program, as all students achieved "very good" outcomes across dimensions. This finding reinforces previous research stating that learning in laboratories provides a more meaningful learning experience for students, namely in terms of a more in-depth learning experience that is relevant to their daily lives (Apriani et al., 2020; Mundy & Nokeri, 2024; Williams et al., 2022). The slight advantage of Chemistry Education students reflects disciplinary familiarity, yet the consistently high performance of both groups indicates that the laboratory was effective in creating equitable learning opportunities. This balance between cognitive and affective success is crucial in preparing students for future professional and academic contexts, where understanding must be paired with motivation and confidence (Ausubel 1963; Bretz, 2019). By demonstrating high levels of meaningful learning across a mixed cohort, the laboratory model employed here can be viewed as a promising framework for wider implementation in science education.

Taken together, these findings demonstrate that laboratory activities provide a fertile ground for fostering meaningful learning, encompassing both conceptual mastery and affective engagement. They corroborate previous research asserting that the laboratory is not merely a site for skill acquisition but a critical learning environment where students can experience holistic and enduring understanding (Bretz, 2019; Galloway & Bretz, 2015; Mundy & Nokeri, 2024). The results of this study thus affirm the central role of laboratory work in shaping meaningful learning experiences in science education.

Conclusion

This study shows that the general chemistry laboratory can be a powerful space for fostering meaningful learning among both Chemistry and Biology Education students. Most students consistently performed at a "very good" level across cognitive, affective, and integrated domains. While Chemistry Education students scored slightly higher due to stronger disciplinary alignment, the strong results achieved by Biology Education students demonstrate that the laboratory design was inclusive and accessible to learners from different backgrounds. More importantly, the findings make it clear that meaningful learning in the laboratory goes beyond mastering concepts. Students' motivation, confidence, and engagement emerged as equally vital in shaping the quality of their experiences. This suggests that educators need to strike a balance between cognitive understanding and affective growth. While a solid grasp of concepts remains essential, cultivating emotional involvement makes laboratory learning more relevant, impactful, and closely connected to students' academic progress as well as their future professional pathways. Future research could extend these findings by examining how laboratory learning impacts long-term retention, problem-solving skills, and professional readiness across different educational contexts, as well as by exploring how digital or virtual laboratory environments might further support both cognitive and affective dimensions of learning.

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Author Contributions

Conceptualization, E and MU; methodology, E, MU, and EM; validation and formal analysis E, MU, EM; data collection and investigation E and EM; data analysis MU and EM; data curation, E, MU, and EM; writing the original draft preparation, E and MU; writing-review editing, E, MU, EM; visualization EM and M. All authors have read and approved the final version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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