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# The Impact of Cognitive Knowledge on Laboratory Skills Development in Chemistry Students: A Correlational Study

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**Abstract:** The aim of this study is to examine the relationship between students' cognitive abilities and their laboratory skills. The research was conducted using a quantitative approach with a correlational study design. The subjects of the study were 32 students from the Chemistry Education program. The laboratory skills assessed were related to activities in the Basic Chemistry laboratory, as this course integrates both classroom learning and laboratory practice. Cognitive ability data were obtained from quizzes, midterm exams, and final exams, while laboratory skills data were collected from assessments of pre-laboratory activities (assistance and response), laboratory experiment performance, practical reports, and a final exam conducted after all practical units were completed. The data analysis revealed a strong positive correlation between cognitive abilities and laboratory skills, with a correlation coefficient of 0.65.

**Keywords:** Chemistry; Cognitive abilities; Correlation; Laboratory Skills

## Introduction

The development of laboratory skills in chemistry education is deeply intertwined with cognitive abilities, yet understanding how these mental processes specifically influence practical skill acquisition remains a crucial but underexplored area. Existing research highlights the importance of cognitive functions-such as memory, reasoning, and problem-solving-in facilitating students' comprehension of complex chemistry concepts and their application in laboratory settings (Kovarik et al., 2022; Panergayo, 2023). However, the gap in understanding how these cognitive capabilities translate into hands-on proficiency is particularly pronounced among first-year university students, who often encounter significant challenges transitioning to the rigors of university-level chemistry. These students frequently lack both the foundational cognitive knowledge and the practical experience necessary to excel in laboratory tasks, making this area of study critically important for improving educational outcomes.

Laboratory work has long been regarded as a cornerstone of chemistry education, with hands-on experiments providing students with essential opportunities to apply theoretical knowledge in a controlled, practical environment. However, recent pedagogical innovations, such as Chemistry Laboratory Alternative Work (CLAW) and virtual laboratories, have highlighted the evolving nature of laboratory instruction, where cognitive skills are increasingly recognized as essential for mastering practical tasks (Antrakusuma et al., 2021; Panergayo, 2023). Despite these advancements, few studies have investigated the direct link between cognitive development and laboratory proficiency, especially in the critical early stages of university education, where students are first introduced to foundational laboratory techniques. Addressing this gap is not only timely but necessary, as the ability to integrate cognitive learning with practical execution is fundamental to success in both academic and professional chemistry settings.

Furthermore, the role of self-efficacy and metacognition in this process cannot be understated.

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Research suggests that students with higher self-efficacy are more likely to engage deeply with laboratory tasks, displaying greater resilience and problem-solving abilities when faced with challenges (Graham et al., 2019; Harris et al., 2020). Yet, this area has been insufficiently studied in first-year chemistry students, who may face additional psychological barriers-such as low confidence or inadequate prior knowledge—that impede their ability to fully develop laboratory skills. By focusing on the intersection of cognitive development, self-efficacy, and laboratory performance, this study aims to provide a clearer understanding of how educators can tailor their teaching strategies to better support novice learners.

One significant factor influencing this relationship is the prior knowledge that students bring to their chemistry courses. Students entering university with low foundational knowledge in chemistry often struggle to keep pace with the curriculum, which can hinder their ability to develop necessary laboratory skills (Eitemüller & Habig, 2020). This challenge is compounded by the complexity of laboratory tasks that require not only cognitive engagement but also practical skills, such as the ability to conduct experiments, analyze data, and draw conclusions (Bretz, 2019; Stoodley et al., 2023). Consequently, bridging courses or preparatory programs that enhance students' foundational knowledge can be beneficial in fostering both cognitive abilities and laboratory skills. Moreover, the role of self-efficacy in shaping students' performance in chemistry cannot be overlooked. Studies have shown that students with low self-efficacy often experience declines in motivation and performance, particularly in challenging subjects like chemistry (Harris et al., 2020).

This is particularly concerning for underrepresented minority students, who may face additional barriers that affect their confidence and academic success (Harris et al., 2020). Therefore, fostering a supportive learning environment that enhances students' self-efficacy is crucial for improving their cognitive engagement and laboratory performance. The integration of innovative teaching methodologies, such as inquiry-based learning and competency-based assessments, has also been shown to enhance students' cognitive abilities and laboratory skills (Pullen et al., 2018; Reynders et al., 2019). These approaches encourage active learning and critical thinking, allowing students to engage more deeply with the material and develop essential skills that are transferable to real-world applications (Blumling et al., 2022).

Given the increasing importance of STEM disciplines in today's knowledge-based economy, fostering the cognitive and practical skills of chemistry students is of utmost importance. As more universities adopt competency-based and inquiry-driven laboratory curricula, understanding the cognitive processes that underlie laboratory skill acquisition becomes essential for optimizing instructional design. This study addresses the need for empirical evidence linking cognitive abilities with laboratory skills in novice learners, offering insights that can inform curriculum development and pedagogical strategies aimed at enhancing student success in chemistry. By shedding light on these critical connections, this research seeks to contribute to a more comprehensive understanding of how students can be better prepared for the demands of both academia and the professional world, ultimately supporting the broader goals of STEM education.

The relationship between cognitive abilities and laboratory skills among first-semester university students in basic chemistry is a critical area of investigation that has implications for educational practices and student success in STEM fields. Cognitive abilities, which encompass various mental processes such as reasoning, problem-solving, and memory, are essential for understanding complex chemical concepts and executing laboratory tasks effectively (Eitemüller & Habig, 2020; Reynders et al., 2019). Research indicates that students with higher cognitive abilities tend to perform better in both theoretical and practical aspects of chemistry, suggesting a strong correlation between cognitive skills and laboratory competencies (Hootegem, 2023; Reynders et al., 2019).

Additionally, the implementation of small-scale laboratory experiments has been found to improve cognitive outcomes by providing students with hands-on experiences that reinforce theoretical knowledge (Syaadah et al., 2021). In conclusion, while previous research has explored various dimensions of chemistry education, the specific relationship between cognitive development and laboratory skill acquisition among first-semester students remains under-researched. This study seeks to fill that gap by examining how cognitive abilities—when properly nurtured—can accelerate the mastery of laboratory skills, thereby equipping students with the tools they need to succeed both in the classroom and beyond.

## Method

This study aims to measure the relationship between two variables: the independent variable, which is students' cognitive knowledge, and the dependent variable, which is students' laboratory skills. Therefore, the research method employed is a quantitative approach with a correlational study design. This method allows the researcher to explore and analyze the relationship between the two variables, namely cognitive knowledge and laboratory skills in chemistry students. Previous studies have shown that a deep understanding of chemical concepts significantly contributes to practical laboratory skills (Enneking et al., 2019).

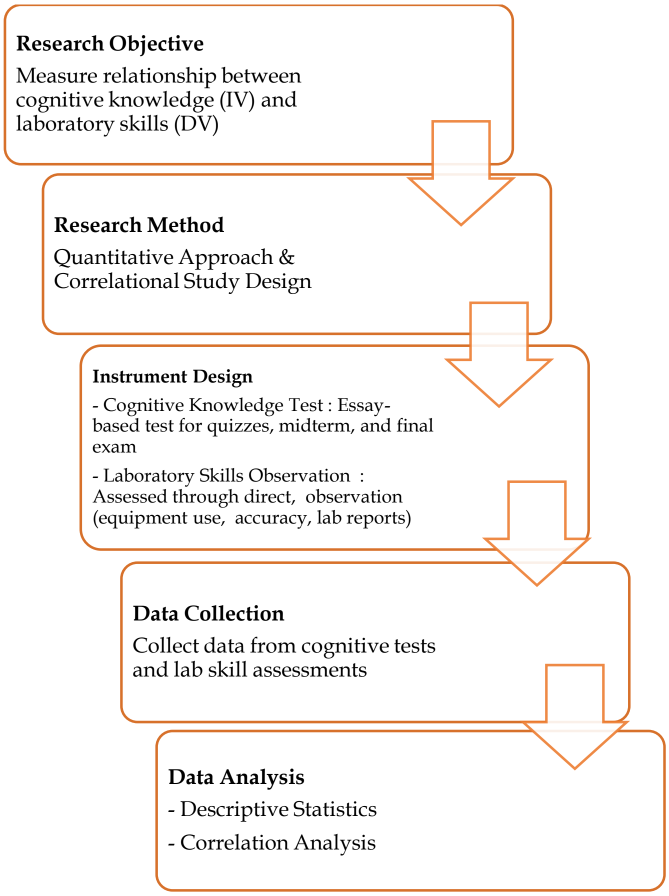


**Figure 1.** The research flow illustrates the process undertaken in this study

The subjects of this study were 32 first-year students from the Chemistry Education program enrolled in the Basic Chemistry course. This course is one of the subjects that integrates classroom learning with laboratory activities. The instrument used to assess students' cognitive abilities was an essay test administered at various evaluation stages, including quizzes, midterm exams, and final exams. Meanwhile, laboratory skills were assessed through direct observation of students' knowledge in conducting practical experiments accurately, from using equipment and materials properly to evaluating the laboratory reports produced by the students (Reynders et al., 2019) (Seung et al., 2016;).

The data collected were analyzed using descriptive statistics to describe the gathered information. This was followed by a correlation analysis to determine the strength and direction of the relationship between cognitive knowledge and laboratory skills. Figure 1 presents the stages of the research conducted.

**Table 1.** The level of correlation and the strength of the relationship (Siregar, 2015)

| Level of Correlation | The Strength of the relationship |
|---|---|
| 0.00 – 0.1999 | Very Weak |
| 0.20 – 0.399 | Weak |
| 0.40 – 0.599 | Moderate |
| 0.60 – 0.799 | Strong |
| 0.80 – 0.100 | Very Strong |

## Result and Discussion

The data on students' cognitive knowledge or abilities in this study were obtained from the results of exams, including quizzes, midterm exams, and final exams in the Basic Chemistry course. The tests administered were aligned with the learning outcomes of the course, as outlined in the semester learning plan. Open-ended essay tests were used to analyze students' ability to respond to the questions given. Additionally, essay tests provide information on the depth of students' understanding of the material and their ability to connect it with related concepts. Open-ended questions allow for a more in-depth evaluation of students' understanding. This approach also demonstrates that using questions requiring students to apply higher-order cognitive skills enables them to show a better grasp of the concepts taught (Roels, 2019).

Information regarding students' practical skills is assessed from several aspects, including their ability to conduct experiments accurately, starting from the selection of tools and materials, measurement precision, discipline, and weekly reports for each experiment conducted. The final grade for laboratory skills is the integration of all scores from pre-laboratory activities, in-laboratory performance, practical reports, and the final exam, with each aspect assigned a specific weight. Table 2 presents the average scores obtained by students in both cognitive abilities and laboratory skills.

**Table 2.** The Average Scores of Students' Cognitive Abilities and Laboratory Skills

| Variable | Average |
|---|---|
| Cognitive abilities | 78 |
| Laboratory skills | 60 |

Table 2 shows the difference in average scores between the two aspects being compared, namely students' cognitive abilities and laboratory skills in the Basic Chemistry course. The data indicate that, based on the average scores of both aspects, students' cognitive abilities have a higher average than their laboratory skills. However, this does not necessarily imply that students' laboratory skills are very low. The data reveal that the difference in average scores between the two aspects is not significant, with a relatively small range. Therefore, to determine the correlation between these two aspects, further analysis was conducted, and the results can be seen in Table 3.

There are eight main topics covered in the classroom learning process. Meanwhile, six units in the Basic Chemistry laboratory serve as the basis for assessing students' laboratory skills. With a greater number of core concepts taught during classroom instruction, it is expected to provide support and a positive impact on students' performance in the laboratory. This is evidenced by the results of the correlation analysis between cognitive abilities and laboratory skills.

**Table 3.** displays the magnitude of the correlation between students' cognitive abilities and laboratory skills.

| Parameters | Cognitive Abilities | Laboratory Skills |
|---|---|---|
| Cognitive Abilities | 1 | |
| Laboratory Skills | 0.65 | 1 |

Table 3 indicates a positive correlation between students' cognitive abilities and laboratory skills, with a "strong" level of relationship. This finding suggests that students with higher cognitive abilities tend to exhibit better laboratory skills, which are crucial for success in science education, particularly in chemistry. For instance, research by Harsono shows that cognitive skills are directly related to learning outcomes, where students with strong cognitive skills also demonstrate superior laboratory skills (Harsono et al., 2023). Additionally, the study by Aini et al. (2022) emphasizes that good cognitive abilities can facilitate a better understanding of laboratory procedures and experimental techniques, thereby enhancing students' practical skills. Other research has also demonstrated that critical thinking skills, which are part of cognitive abilities, significantly contribute to laboratory skills, with students trained in critical thinking performing better in designing experiments and analyzing data (Hayati, 2019).

The assessment of laboratory skills is weighted more heavily on laboratory activities compared to the weight assigned to the final exam. This approach is taken because a series of pre-laboratory activities leading up to the preparation of reports provide a more comprehensive reflection of students' laboratory skills and their understanding in presenting information acquired during practical activities.

Comprehensive observation of students' laboratory work is crucial in higher education, particularly in enhancing motivation and learning outcomes. Research indicates that positive laboratory experiences can improve students' conceptual understanding and practical skills, as well as facilitate more effective active learning (Moozeh et al., 2019; Sharmila et al., 2022). While studies have shown that virtual laboratories can increase learning motivation, direct experiences in physical laboratories are still considered more effective in developing practical skills and deep conceptual understanding (Faris & Dwikoranto, 2021; Gamage et al., 2020; Hendratmoko et al., 2023). Furthermore, interaction between students and instructors in the laboratory context significantly contributes to the learning experience, where direct guidance can assist students in overcoming technical difficulties and reinforce their understanding of the material (Horrigan, 2021). Therefore, it is essential for educational institutions to thoroughly observe and evaluate students' laboratory experiences to enhance the quality of teaching and learning outcomes in the future.

**Figure 2.** Student Activities in Laboratory

Students' cognitive knowledge is assessed through a series of tests, including both formative and summative assessments. The administration of these tests is preceded by various learning activities that are relevant to students' needs and aligned with the material being taught. Instructors employ a variety of teaching models, including case studies, inquiry-based learning, cooperative learning, flipped classrooms, and direct instruction through traditional lectures. The choice of teaching model used in the instructional process significantly impacts students' achievement in understanding the concepts presented in the curriculum.

Research indicates that the use of appropriate teaching models, such as modeling and inquiry-based learning, can significantly enhance students' conceptual understanding. For instance, the modeling instruction approach has been shown to be effective in improving the understanding of oscillation concepts, with a very high effect size (Trisnawati et al., 2021). Furthermore, the

ECIRR model (Elicit, Confront, Identify, Resolve, Reinforce) has been successfully employed to address students' misconceptions in the topic of chemical bonding, demonstrating that a structured approach can assist students in grasping difficult concepts (Warsito et al., 2021). Other studies also indicate that the implementation of guided inquiry models integrated with virtual laboratories can improve students' conceptual understanding and metacognitive skills, which are crucial in chemistry education (Muhali et al., 2021). Additionally, STEM-based learning models (Science, Technology, Engineering, and Mathematics) have shown positive impacts on students' understanding of salt hydrolysis concepts, highlighting that the integration of various disciplines can enrich the learning experience (Laliyo, 2021). Therefore, the selection of the appropriate teaching model is essential for fostering a deep and comprehensive understanding of chemical concepts.

## Conclusion

This study provides important insights into the relationship between cognitive abilities and laboratory skills among first-year chemistry students. The findings demonstrate a strong positive correlation between students' cognitive abilities and their laboratory performance, with students who exhibit higher cognitive capabilities tending to perform better in practical laboratory tasks. The data analysis revealed a strong positive correlation between cognitive abilities and laboratory skills, with a correlation coefficient of 0.65. The results emphasize that both theoretical understanding and hands-on skills are critical for success in chemistry education. Cognitive abilities, such as problem-solving and critical thinking, are shown to directly influence the students' ability to navigate complex laboratory experiments, analyze data, and apply learned concepts in practical settings.

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**Author Contributions**
S.S., M.: Conceptualization and methodology. M.A..; validation and revision. Z.A.,: formal analysis, and resources. M. A.A.,: writing—original draft preparation, visualization and revision All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest**
The researchers affirm that there are no conflicts of interest associated with this study. It was carried out independently, without any external financial, professional, or personal influences that could have impacted the results or the integrity of the research. The findings and conclusions are entirely based on the authors' own analysis and work.

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