SPIN 7 (1) (2025) 29-39

SPIN

JURNAL KIMIA & PENDIDIKAN KIMIA

https://journal.uinmataram.ac.id/index.php/spin

THE RELATIONSHIP BETWEEN STUDENTS' CONCEPTIONS OF CHEMISTRY AND LABORATORY PERFORMANCE: AN ANALYSIS OF SCIENCE PROCESS SKILLS

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DOI: 10.20414/spin.v7i1.12831

History Article
Accepted:
Jan 25, 2025
Reviewed:
May 17, 2025
Published:
July 10, 2025

Kata Kunci:
keterampilan berpikir tingkat tinggi, keterampilan proses sains, kinerja laboratorium, pemahaman konsep

Keywords:
conceptual understanding, higher-order thinking skills, laboratory performance, science process skills

ABSTRAK

Penelitian ini menyelidiki hubungan antara pemahaman konsep kimia mahasiswa dan kinerja mereka dalam eksperimen laboratorium, dengan fokus pada keterampilan berpikir tingkat tinggi (HOTS) seperti analisis, evaluasi, dan kreasi. Penguasaan konsep diukur melalui lima soal esai dengan skala rubrik, dan validitas butir tes diperiksa menggunakan *Corrected Item-Total Correlation*, di mana semua butir dinyatakan valid. Analisis data menggunakan korelasi Pearson menunjukkan korelasi positif yang cukup kuat (r = 0,612, p = 0,005) antara pemahaman konsep dan kinerja laboratorium. Penelitian ini juga mengungkap bahwa pemahaman konsep meningkatkan keterampilan proses sains seperti pengamatan, interpretasi data, klasifikasi, komunikasi, dan perumusan hipotesis. Temuan ini menyarankan bahwa pembelajaran berbasis konsep dan interaktif dapat meningkatkan kinerja laboratorium mahasiswa, dengan implikasi pedagogis bagi pendidik untuk memprioritaskan integrasi teori dan praktik dalam pengajaran kimia.

ABSTRACT

This study examines the relationship between students' understanding of chemical concepts and their performance in laboratory experiments, with a focus on higher-order thinking skills (HOTS), including analysis, evaluation, and creation. Concept mastery was assessed through five essay questions using a rubric scale, and the validity of the test items was examined using the Corrected Item-Total Correlation, with all items deemed valid. Data analysis using Pearson correlation revealed a moderately strong positive correlation (r = 0.612, p = 0.005) between concept understanding and laboratory performance. The study also found that concept mastery enhances students' integrated science process skills, such as observation, data interpretation, classification, communication, and hypothesis formulation. These findings suggest that concept-based and interactive learning can improve students' laboratory performance, with pedagogical implications for educators to prioritize the integration of theory and practice in chemistry instruction.

How to Cite

Pamenang, F. D. N., & Ratri, M. C. (2025). The Relationship Between Students' Conceptions of Chemistry and Laboratory Performance: An Analysis of Science Process Skills. *SPIN-Jurnal Kimia & Pendidikan Kimia*. 7(1). 29-39.

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p-ISSN: 2580-2623
e-ISSN: 2745-6854

INTRODUCTION

The learning of chemistry involves two important aspects: mastering theoretical concepts and applying them through laboratory practicum activities. These two aspects complement each other and cannot be separated in the process of building a comprehensive understanding of the science of chemistry (Shadle et al., 2012). Achieving conceptual mastery in a scientific field involves a combination of acquiring knowledge specific to that field of study, as well as developing cognitive abilities across various dimensions. These include understanding factual information, grasping conceptual principles, and comprehending procedural applications (Anderson & Krathwohl, 2001; Wells, 2008; Safarati & Zuhra, 2023). According to this perspective, an individual cannot be considered to have truly mastered a concept by merely memorizing facts and concepts covered (Abdullah & Shariff, 2008). True conceptual mastery is demonstrated when an individual can synthesize the acquired knowledge through higher-order thinking processes (Anderson et al., 2012; Krathwohl, 2002).

However, chemistry is also an empirical and experimental science. Laboratory practicum activities provide students with direct experiences to observe, measure, and manipulate chemical phenomena tangibly. This helps students visualize the concepts they have learned theoretically and understand their applications in real-life situations (Yao, 2023). Through practicum activities, students can apply the chemical concepts they have learned theoretically to actual practice (Boutonnet, 2021). Without understanding these concepts, students will experience difficulties in comprehending the reasoning behind each step in the practicum procedure and the purpose of each stage in the practicum. For example, students can practice how to perform titrations, observe color changes in chemical reactions, or analyze data from experiments. Data obtained from chemistry practicum, whether in the form of observational results, measurements, or calculations, must be analyzed and interpreted correctly. Adequate mastery of chemical concepts helps students connect data with related concepts, make predictions, and draw valid conclusions from the practicum.

Laboratory or practicum activities provide opportunities for students to engage all types of intelligence they possess. Multiple studies showed that practical work gives many advantages, including developing laboratory skills and scientific knowledge, as well as understanding science concepts and theories (Oliveira & Bonito, 2023; Schwichow et al., 2016). According to Shana & Abulibdeh (2020), laboratory activities aim to teach students process skills and help them understand chemical concepts through hands-on practice. Chemistry is a subject intricately linked to laboratory work. Irwanto et al. (2017) describe experiments as a teaching method where students perform an experiment, observe the process, record the results, compile a report, present it to the class, and receive an evaluation from the instructor. Therefore, laboratory skills are essential for students to meet the profile of a chemistry graduate, one of which is becoming a skilled and professional chemical analyst.

Chemistry practicum activities provide invaluable learning experiences for students to develop important scientific process skills in building scientific knowledge. Through the practicum, students can practice skills such as carefully observing chemical phenomena, accurately measuring quantities, classifying data and observational results, predicting experimental outcomes based on learned concepts, and effectively communicating findings and conclusions.

Students develop laboratory skills through practicum activities, such as physical chemistry experiments, which support their abilities in the laboratory. One of the skills well-suited for physical chemistry labs is science process skills (SPS). According to

Gizaw & Sota (2023) state that SPS refers to the physical and mental skills related to the basic abilities possessed, mastered, and applied in scientific activities, enabling scientists to make new discoveries. Sukarno et al. (2013) argue that by developing SPS, students can discover and develop their own facts and concepts, as well as foster and develop the necessary attitudes and values. SPS are categorized into basic SPS and integrated SPS.

According to Utami et al. (2021), basic SPS indicators include observation, measurement, prediction, classification, and communication. Meanwhile, integrated process skills, such as identifying variables, interpreting data, planning experiments, and formulating hypotheses, develop gradually and reach a high level of sophistication when performed in meaningful contexts (Roth & Roychoudhury, 1993) .

Previous studies have shown that there is a significant relationship between mastery of chemical concepts and students' practical performance. Students who have good mastery of chemical concepts tend to have better practical performance compared to students who have less mastery of chemical concepts. Prior knowledge provides a foundation for understanding new material, while cognitive skills such as language comprehension help bridge gaps in knowledge. Pedagogical experiences that emphasize understanding over rote procedures, mastery learning approaches, and the use of concept maps as study tools can all contribute to better practical performance. Additionally, a positive self-concept in chemistry is important for developing a meaningful understanding of scientific concepts (Seery, 2009; Pyburn, Pazicni, Benassi, & Tappin, 2013). However, these studies have not considered the factor of science process skills as a variable that can influence the relationship between mastery of chemical concepts and student practical performance. Given the importance of chemistry learning involving theoretical and practical aspects, as well as the role of scientific process skills in building scientific knowledge, research examining the correlation between chemical concept knowledge, practicum performance, and scientific process skills becomes highly relevant in the current context of chemistry education.

Therefore, this study aims to determine the correlation between knowledge of chemical concepts and students practical performance in terms of science process skills. By knowing this correlation, it is hoped that it can provide useful information for chemistry educators in designing and implementing learning that can integrate mastery of chemical concepts, science process skills, and practical skills better so that it can improve the overall quality of chemistry learning.

METHODS

The current study employed a correlational research methodology. The population consisted of all chemistry education students at Sanata Dharma University. The research sample included 40 students. This study was conducted during the 2023/2024 academic semester. An experimental study preceded the correlational analysis.

Following the experiment, a correlational analysis was carried out to investigate the relationship between students' conceptual mastery and laboratory performance in relation to their science process skills. The procedures of the correlational study involved: (1) identifying the research variables, X for conceptual mastery and Y for laboratory performance; (2) determining indicators for each variable; (3) selecting instruments to measure the indicators; (4) developing a blueprint for the instruments; (5) formulating questions for each variable and the corresponding answers; (6) establishing criteria for alternative answers; (7) validating the instruments; (8) collecting the data; (9) calculating the correlation between X and Y.

The research instruments were divided into two categories: (1) a questionnaire and observation sheets to assess students' science process skills; and (2) a test and interview sheets to evaluate students' conceptual mastery. Both instruments underwent expert and empirical validation, as well as reliability testing. The validation results indicated that the instruments were reliable for data collection. Data analysis was performed using descriptive and inferential statistics.

Conceptual mastery refers to the capacity to integrate newly acquired knowledge with prior understanding, serving as the foundation for personal growth in employing diverse methodologies to formulate ideas, generate innovative and valuable concepts, provide explanations, refine existing notions, conduct analyses, and critically evaluate one's ideas (Krathwol, 2002). In the context of this research, the assessment of conceptual mastery focuses on the higher-order cognitive levels of C4-C6, encompassing analysis (C4), evaluation (C5), and creation (C6), as these levels align with higher-order thinking skills (HOTS). The concept mastery assessment consists of 5 essay-type questions. The scoring process for conceptual mastery employs a rubric-based scale ranging from 1 to 5.

RESULT AND DISCUSSION

This study involved 20 students enrolled in the Thermodynamics and Chemical Equilibrium course during the Fall 2023/2024 semester and the Chemical Reaction Kinetics course during the Spring 2023/2024 semester at the Chemistry Education Program, Sanata Dharma University. Three data collection methods were employed in this study: observation, interviews, and concept mastery tests. Observations were conducted to assess students' laboratory performance and scientific attitudes. The integrated science process skills (SPS) were observed during the practical sessions.

One skill particularly suited for the chemistry lab is science process skills (SPS). According to Gizaw & Sota (2023), SPS refers to the physical and mental abilities related to fundamental skills that are acquired, mastered, and applied in scientific activities, enabling scientists to make new discoveries. Sukarno et al. (2013) argue that by developing SPS, students can discover and develop their own facts and concepts, while also cultivating the attitudes and values necessary for scientific work. SPS are categorized into basic SPS and integrated SPS. According to Utami et al. (2021), basic SPS indicators include observation, measurement, prediction, classification, and communication. Meanwhile, integrated process skills, such as identifying variables, interpreting data, planning experiments, and formulating hypotheses, evolve gradually and reach a high level of sophistication when performed in meaningful contexts (Roth & Roychoudhury, 1993). Table 1 displays the indicators of integrated science process skills.

Table 1. The Integrated Science Process Skills Criteria

Integrated Science Process Skills	Indicators
Controlling variables	Recognizing the factors that can influence the results of an experiment, holding the most constant while altering only the independent variable.
Defining operationally	Specifying how to measure a variable in an experimental setup.
Formulating hypotheses	Predicting the anticipated outcome of an experiment.
Interpreting data	Arranging data and deriving conclusions from it.
Experimenting	Possessing the ability to experiment, including formulating an appropriate question, proposing a hypothesis, identifying and controlling variables, providing operational definitions, designing an unbiased experiment, performing the experiment, and interpreting the experimental results.
Formulating models	Developing a conceptual or physical representation of a process.

The observation results of students' laboratory performance in this study covered various aspects of science process skills. Most students (80%) demonstrated strong abilities in following instructions and preparing the experimental tools and materials. This skill reflects a procedural understanding that facilitates smooth practical implementation. According to Utami et al. (2023), the ability to accurately follow instructions depends on prior mastery of fundamental concepts. Students who understand the relevant chemical concepts are more likely to interpret and apply lab instructions effectively. Most students carefully prepared the equipment and materials, though some experienced delays or inadequacies in preparing materials before starting the experiment.

Overall, students were attentive to safety measures, such as using personal protective equipment (PPE), though some were less meticulous in maintaining cleanliness in the work area during and after the lab sessions. Most (75%) adhered to safety protocols and maintained cleanliness throughout the experiment. Rahmantiyoko et al. (2019) suggest that awareness of lab safety is a fundamental science process skill closely linked to mastery of experimental procedures and understanding potentially hazardous chemical reactions.

Data analysis by the students revealed that 70% were able to correctly interpret experimental results. They successfully connected the data to theoretical concepts learned, enabling them to draw relevant conclusions. This demonstrates that conceptual understanding is crucial not only for observation but also for processing and analyzing data scientifically (Lestari et al., 2024). Mastery of these skills shows that students can apply theory to real-world contexts and understand the causal relationships in observed phenomena.

Around 75% of students were able to communicate effectively within their teams, both in explaining experimental steps and discussing the results. Effective collaboration indicates a combination of social skills and scientific communication abilities. Good communication within teams is a key factor in problem-solving and reaching consensus during scientific experiments.

In addition to observations, interviews were conducted with the students to gain insights into their perceptions of the relationship between science process skills, chemical knowledge, and laboratory practice. Some students shared interesting observations from their chemistry lab sessions, one of which involved the color change of a solution when a particular reagent was added. For example, in the reaction between $FeCl_3$ and KSCN solutions, a red $FeSCN^{2+}$ complex is formed, according to the reaction equation:

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq) \qquad \text{(Petrucci, 1985)}$$

They noted that the reaction occurred quickly, and the color change from clear to deep red was one of the most memorable aspects. To document changes or patterns, most students used written notes, carefully recording each step, including the time required for each change to occur. The majority of students recorded the experimental data in tables or written notes, with many preferring tables for ease of tracking and to better observe patterns. Some students also used graphs to help visualize more complex data, especially when multiple variables were involved. When asked if they could conclude the data collected, many students felt confident in identifying patterns, such as temperature increases or color changes that correlated with chemical concentration. They explained their experimental results by attempting to connect the data with theoretical concepts they had previously learned. The students mentioned that these experiments often helped reinforce their understanding of the chemistry material being studied.

When encountering problems or difficulties during the lab, some students shared experiences where equipment malfunctioned or materials did not react as expected. In such situations, they typically discussed the issue with their group members or sought guidance from lab assistants and lecturers. If the experimental results did not meet expectations, they would usually review the steps taken or repeat the experiment to ensure accuracy.

Some students raised new questions during the lab or even proposed alternative experiments, especially when the results seemed inconsistent with the theory. They believed alternative solutions could be found by taking a different approach, such as modifying variables or adjusting the testing method. In terms of group work, the students generally reported contributing well, dividing tasks based on individual strengths. One student added that visualizations and the use of models were often helpful in explaining complex concepts, particularly when results required deeper interpretation. Overall, the students felt that the lab sessions enriched their learning experience, allowing them to better understand the material through hands-on experimentation and group collaboration.

Mastery of concepts refers to the ability to integrate newly acquired knowledge with previous understanding, serving as a foundation for personal growth in applying various methodologies to formulate ideas, generate innovative and valuable concepts, provide explanations, refine existing ideas, analyze, and critically evaluate concepts (Krathwol, 2002). In this study, concept mastery assessment focuses on higher cognitive levels, specifically from C4 to C6, which include analysis (C4), evaluation (C5), and creation (C6). These levels correspond to higher-order thinking skills (HOTS). The assessment comprises five essay questions, evaluated using a rubric-based scale ranging from 1 to 5.

Table 2. Correlation Analysis Results

		Mastery concept	Laboratory performance
Mastery concept	Pearson Correlation	1	0,612**
	Sig. (2-tailed)		0,005
	N	19	19
Laboratory performance	Pearson Correlation	0,612**	1
	Sig. (2-tailed)	0,005	
	N	19	19

**. Correlation is significant at the 0,01 level (2-tailed).

The concept mastery test questions were validated before being tested. The item validity test results showed that all instrument items were declared valid based on the Corrected Item-Total Correlation results. To determine item validity, the calculated r value from each item's correlation with the total score is compared to the table r value. In this case, the table r_{value} at $d_f = 17$ and a 5% significance level were 0.389. If the calculated r_{value} is greater than the table r_{value}, the item is considered valid. Based on the results, all items had a calculated r value greater than 0.389, indicating that the entire instrument was valid. This means each item is strongly related to the total measurement and can accurately assess the expected aspects.

According to Sugiyono (2013), instrument validity is crucial to ensure that the instrument truly measures what it is supposed to, making the results reliable. A valid instrument will produce data consistent with the concept or variable being measured. Additionally, Arikunto (2016) emphasized the importance of item validity in research, stating that a calculated r value greater than the table r value indicates that the item has a significant correlation with the variable being measured, thus considered valid.

The concept mastery test results were then analyzed using Pearson correlation statistics to evaluate the relationship between concept mastery and other variables in this study. The results, shown in Table 2, indicate a significant positive correlation between students' chemistry concept understanding and their laboratory performance. The calculated r value was 0.612, which is greater than the table r value of 0.369 at a significance level of 0.05. This shows a significant correlation between chemistry concept understanding and students' lab performance. The correlation value of

0.612 indicates a moderately strong relationship between the two variables, meaning that the better a student's understanding of chemistry concepts, the better their performance in chemistry lab work.

A correlation value of 0.612 can be interpreted as a fairly strong relationship. This suggests that students with a strong conceptual understanding are more likely to apply learned chemistry theories more efficiently and accurately in laboratory experiments (Theresia et al., 2023). For example, students who understand basic chemical reaction concepts and thermodynamic laws tend to perform experiments more precisely, as seen in their accuracy in making observations, recording experimental results, and drawing conclusions aligned with the theories they have studied.

The significance value from this analysis was 0.005, which is less than 0.05, indicating that the correlation between chemistry concept understanding and lab performance is statistically significant at a 95% confidence level. This result confirms that there is a significant relationship between students' chemistry concept understanding and their lab performance. This significance suggests that the variable of chemistry concept understanding contributes significantly to students' lab performance. In other words, a solid theoretical understanding of chemistry plays a key role in students' success in lab work, whether in understanding experiment instructions, making observations, or analyzing and concluding experimental results. This also implies that if students have a strong grasp of concepts, their chances of success in laboratory experiments increase significantly.

These findings have several important implications. A strong understanding of chemistry concepts forms a crucial foundation for students' lab performance. Therefore, enhancing concept understanding through effective teaching and the use of interactive learning methods is essential to improving students' laboratory outcomes (Azmi, et al., 2024). To improve lab results, lecturers can emphasize the importance of theoretical understanding before students conduct experiments. Problem-based or project-based learning approaches can help students connect theory with laboratory practice. Students' laboratory skills appear to be closely related to their ability to understand and apply chemistry concepts, highlighting the importance of developing lab programs that focus not only on lab procedures but also on integrating theory with practice. Overall, this correlation supports the hypothesis that chemistry concept understanding plays a significant role in students' lab performance, and strengthening theoretical understanding can improve lab outcomes in the future.

In this study, in addition to the quantitative analysis using Pearson correlation, a qualitative analysis of students' integrated science process skills was also conducted. These skills are crucial in developing scientific thinking and applying it in practical lab work. Based on the correlation results showing a significant positive relationship between concept understanding and lab performance, it can be concluded that students with good chemistry concept understanding are also more effective observers. Students who understand basic theory tend to be more accurate in observing phenomena or changes during experiments, as seen in the accuracy of the data they record and their ability to recognize indicators of chemical reactions, such as color changes, gas formation, or temperature changes.

Students with strong conceptual understanding are better at interpreting their observations accurately. The significant positive correlation between concept understanding and lab performance suggests that theoretical understanding helps students understand why certain changes occur during experiments. They can connect their observations with relevant chemical theories, such as reaction laws or thermodynamics, allowing them to provide accurate interpretations of the data obtained. Students' ability to classify data or observations is also influenced by their conceptual understanding. Students with a better understanding of chemistry concepts tend to systematically categorize experimental results based on specific variables. For example, they can distinguish between independent and dependent variables or classify types of reactions based on the reaction mechanisms. This helps in more structured lab data processing.

Students' communication skills, whether in presenting experimental results orally or in writing, are closely related to their conceptual understanding. Students with better concept understanding tend to be more organized and clear in explaining their results. They can present findings using proper scientific terminology and link experimental results to relevant chemistry theories. In group lab work, students with good concept understanding are also more effective in communicating with other group members, contributing to discussions, and providing constructive suggestions.

Hypothesis formulation skills, or the ability to make predictions based on prior knowledge, also depend on concept understanding. The positive correlation between concept understanding and lab performance shows that students with better chemistry concept understanding are more capable of formulating logical hypotheses before conducting experiments. They use previously learned theories to predict what will happen during the experiment, enabling them to validate or revise their hypotheses after the experiment is completed.

The significant positive correlation between chemistry concept understanding and lab performance demonstrates that integrated science process skills are closely related to students' conceptual understanding. Concept understanding plays a key role in all aspects of science process skills, including observation, interpretation, classification, communication, and hypothesis formulation. Students who master chemistry theory well are better able to apply that theory in practice, as reflected in their lab performance.

Pedagogical experiences that emphasize understanding rather than rote memorization, mastery-oriented learning approaches, and the use of concept maps as learning tools can all contribute to improved lab performance. Additionally, a positive self-concept in chemistry is important for developing meaningful scientific concept understanding (Seery, 2009; Pyburn et al., 2013). Overall, the qualitative analysis of integrated science process skills reinforces the quantitative correlation results, showing that good chemistry concept understanding significantly contributes to the development of students' practical skills and science process skills in a laboratory context.

CONCLUSION

There is a significant positive correlation between students' conceptual understanding of chemistry and their performance in laboratory experiments. Students with stronger conceptual mastery demonstrated better performance in experiments, particularly in their abilities to observe, interpret data, classify, communicate, and formulate hypotheses. These findings highlight the importance of concept-based learning in supporting students' ability to apply chemical theory in laboratory practice. Therefore, strengthening conceptual understanding through interactive and problem-based learning methods can enhance students' laboratory skills and overall learning outcomes.

ACKNOWLEDGMENT

The author would like to express sincere gratitude to the Research and Community Service Institutions of Universitas Sanata Dharma, Yogyakarta, Indonesia, for their generous financial support, which made this research possible. Your commitment to advancing academic research and fostering scientific development is greatly appreciated.

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