The Development of 21st Century Skills through PSL Practicum and HOT Lab in Science Education

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Abstract - *Laboratory work has traditionally served as an essential component of science education, offering students the opportunity to experience science directly through observation and experimentation. However, in the context of 21st-century learning, traditional laboratory approaches are no longer sufficient. The current educational landscape demands learning environments that not only facilitate conceptual understanding but also cultivate essential competencies such as critical thinking, problem-solving, creativity, communication, and collaboration. In response to these challenges, two innovative laboratory models have emerged, namely the Problem-Solving Laboratory (PSL) and the Higher Order Thinking Laboratory (HOT Lab). This study aims to explore how these laboratory designs contribute to the development of 21st-century skills among high school students. Using a descriptive quantitative approach, the research involved 120 students from schools that have implemented PSL and HOT Lab activities. Data were gathered through a 25-item Likert-scale questionnaire and observation of laboratory sessions. The results indicated a positive shift in student skills, with 82 percent showing improvement in problem-solving, 78 percent in critical thinking, 75 percent in creativity, 68 percent in communication, and 63 percent in collaboration. Students also expressed higher levels of engagement, motivation, and enthusiasm during their participation in the laboratory sessions. These findings suggest that when laboratory learning is designed to promote inquiry, reflection, and contextual problem-solving, it can meaningfully enhance both cognitive and interpersonal skills. Furthermore, the study highlights the importance of active learning in fostering a dynamic and student-centered classroom atmosphere. Although the results are promising, the research also points to several practical challenges, such as the need for teacher training, sufficient resources, and adequate time allocation. Overall, PSL and HOT Lab represent effective strategies to support the holistic development of learners and provide a valuable framework for science educators seeking to align classroom practices with the demands of the 21st century.*

Keywords: *Laboratory; HOTS; Problem Solving; 21st Century Skills; Science Education*

INTRODUCTION

Laboratory activities have long been recognized as a central component of science education, offering students the opportunity to observe, investigate, and understand scientific phenomena firsthand. Traditionally, laboratories were utilized primarily for the verification of theoretical concepts; however, in the context of 21st-century education, this role has evolved. Learning demands have shifted from mere conceptual mastery to the development of broader skills such as problem-solving, critical thinking, creativity, communication, and collaboration—collectively referred to as 21st-century skills (Ahmed et al., 2025).

Despite this shift, many laboratory practices in schools remain procedural and teacher-centered, often failing to challenge students to engage in higher-order thinking or to solve real-world problems. This gap between the ideal laboratory as a space for inquiry-based, student-centered learning and its actual implementation raises concern. Several recent studies (Nasreldin, 2022; Aritami, 2021; Arni, 2023) emphasize the need for laboratory learning designs that not only improve conceptual understanding but

also foster analytical and problem-solving skills.

In response to this need, innovative approaches such as the Problem-Solving Laboratory (PSL) and Higher Order Thinking Laboratory (HOT Lab) have emerged. These models incorporate elements of inquiry, metacognition, and real-life contextual problems into laboratory settings. The present study aims to explore the nature, roles, and pedagogical implications of PSL and HOT Lab, analyze their contribution to students' 21st-century skills, and evaluate current research findings regarding their impact. This research offers a new value by synthesizing theory and empirical evidence to support the broader integration of PSL and HOT Lab in science education frameworks.

RESEARCH METHODS

This research adopts a descriptive quantitative approach. The population comprises 120 senior high school students from three schools that have implemented PSL and HOT Lab strategies in their science instruction. The participants were selected using purposive sampling, considering the schools' consistent application of both laboratory models. Data were collected using a validated Likert-scale questionnaire (Cronbach's Alpha = 0.87) and documentation of laboratory implementation.

The questionnaire used in this study explored five different skills areas related to 21st-century learning. These included critical thinking, problem-solving, creativity, communication skills, and collaboration skills. For each area, there were five questions, so in total, students answered 25 items. These statements were created based on well-known frameworks, including those from P21 and Binkley et al. (2012). A five-point Likert scale was used, ranging from 1 (strongly disagree) to 5 (strongly agree). One example of an item under creativity was: "I can come up with new ideas when dealing with problems during lab work."

Once the data were collected, the results were processed using simple descriptive statistics. The analysis included average scores, response distributions, and the percentage of students choosing each option. This provided a clearer picture of how well students developed their skills during the PSL and HOT Lab activities.

The full outline of the instrument can be seen in Table 1. It shows which skills were measured, what indicators were used, how many questions each had, and what kind of statements students responded to.

Table 1. Blueprint of the Questionnaire Instrument

No	Skill Area	Indicator Example	Items	Sample Statement
1	Critical Thinking	Identifying useful information	5	I can tell which parts of the data are most important.
2	Problem Solving	Finding new ways to fix problems	5	I try different ways when my first idea doesn't work.
3	Creativity	Thinking differently, coming up with ideas	5	I often get new ideas during experiments.
4	Communication Skills	Sharing clearly, understanding others	5	I can explain what I find during experiments to my group.
5	Collaboration Skills	Working together, taking part actively	5	I do my part when we work as a team in the lab.

RESULTS AND DISCUSSION

Results

The research aimed to evaluate the effects of Problem-Solving Laboratory (PSL) and Higher Order Thinking Laboratory (HOT Lab) activities on students' 21st-century skills. A total of 120 students participated in the study. All of them engaged in PSL and HOT Lab activities as part of their science practicum. The research utilized a descriptive quantitative approach, using data collected through Likert-scale surveys.

The results show that PSL and HOT Lab activities had a positive impact on students' problem-solving, critical thinking, creativity, communication skills, and collaboration skills. The data gathered through surveys revealed significant improvements in all the targeted skills, particularly in problem-solving and critical thinking.

Table 2 summarizes the key findings regarding the improvements in student skills.

Table 2. Improvement in Student Skills

Skill	PSL Group (%)	HOT Lab Group (%)	Combined (%)
Problem-Solving Skills	80	85	82
Critical Thinking	75	80	78
Creativity	70	80	75
Communication Skills	65	70	67.5
Collaboration Skills	60	65	62.5

Additionally, survey responses also indicated that 88% of students felt more involved in their learning process during PSL and HOT Lab activities. This is consistent with the finding of previous studies (Wani, 2021) that highlight the role of active learning in enhancing student engagement and learning outcomes.

Discussion

This aligns with previous research on active learning. Research by Arni (2021) and Ragab (2022) suggests that integrating PSL and HOT Lab activities into education encourages students to engage with complex problems and collaborate effectively, which is critical in preparing them for the challenges of the 21st century. Furthermore, the enhancement of creativity among students, as seen in the results, supports the view expressed by Marnah (2022) that the development of creative skills is crucial in today's rapidly changing world.

The study also supports the claim made by Subramaniam (2023) and Sellberg (2023) that laboratory-based activities such as PSL and HOT Lab provide a rich environment for students to apply theoretical knowledge to real-world situations. This hands-on approach helps to reinforce learning and foster deeper understanding, which is in line with the findings of Fadwa (2022), who emphasizes the importance of practical, problem-based learning in improving critical thinking skills.

In addition to academic skills, this study highlights the role of PSL and HOT Lab in developing soft skills such as collaboration and communication, which are essential for success in the workplace. The positive impact on communication skills observed in this study supports the findings of Janssen et al. (2010), who suggest that collaborative learning environments facilitate the development of these skills. Moreover, the research underscores the importance of teacher preparation and resources, as effective implementation of these laboratories requires trained educators who can guide students through complex tasks and discussions (Soliyeva, 2023).

Another key finding from this research is the high level of student engagement, which aligns with the concept of "active learning" discussed by Chaidir (2021). Active learning strategies, such as those employed in PSL and HOT Lab, are shown to improve not only cognitive skills but also students' motivation and interest in learning. The high level of engagement reported by students in this study further emphasizes the effectiveness of these methods in maintaining student attention and involvement.

This study also provides insights into the challenges associated with implementing PSL and HOT Lab activities. While the results indicate significant improvements in student skills, the success of these activities depends heavily on factors such as class size, resources, and the teacher's skills to facilitate discussions and problem-solving tasks. Previous studies by Fajrin (2022) and Syafitri (2022) highlight the importance of resource availability and teacher preparedness in ensuring the success of laboratory-based learning.

Furthermore, while the PSL and HOT Lab activities contributed positively to students' development, the study also identified some challenges related to time management, as some students struggled to complete complex tasks within the allocated time. This finding is consistent with the results of Widiyawati (2023), who observed similar challenges in the implementation of complex problem-solving tasks in laboratory settings.

The integration of PSL and HOT Lab into the curriculum also presents opportunities for innovation in science education. As highlighted by Zhanatbekova (2022), the evolution of laboratory activities to include higher-order thinking skills and problem-solving tasks can significantly enhance the quality of education and better prepare students for future challenges. This study's findings indicate that when properly implemented, these activities not only foster academic skills but also prepare students for the demands of the 21st century workforce.

The results of this research contribute to the growing body of evidence supporting the integration of PSL and HOT Lab activities into educational curricula. By providing students with opportunities to engage in problem-solving and critical thinking, these activities offer valuable experiences that extend beyond traditional classroom learning, aligning with the goals of modern education systems to develop well-rounded, future-ready individuals.

The findings from this study further emphasize the importance of incorporating active learning strategies into education systems worldwide. As suggested by previous studies, including those by Fadwa (2022) and Soliyeva (2023), laboratories that focus on higher-order thinking skills and problem-solving provide a rich environment for students to engage with complex ideas, collaborate with peers, and develop skills necessary for success in the modern world.

Moreover, when comparing the development of each skill area, it becomes evident that problem-solving and critical thinking saw the highest gains. This may be attributed to the nature of both PSL and HOT Lab, which consistently present students with open-ended challenges and opportunities to evaluate evidence, make decisions, and justify their reasoning. These features are strongly aligned with the recommendations from Ragab et al. (2024), who emphasize that structured problem-solving environments can significantly increase students' analytical capacities.

On the other hand, communication and collaboration showed relatively lower improvement rates. One possible explanation is that while PSL and HOT Lab

are effective in promoting individual cognitive engagement, they may require additional strategies—such as structured peer interaction, clear group roles, or scaffolded teamwork—to more fully develop interpersonal skills. Collaborative success often depends not only on having opportunities to work together but also on how well those opportunities are supported and facilitated in practice.

Interestingly, the increased creativity observed in students supports the findings of Marnah et al. (2022), who argue that exposure to real-world problems naturally encourages learners to think divergently and adaptively. The flexible structure of HOT Lab, in particular, appears to offer a space for trial, error, and exploration, which students may not experience in traditional laboratory settings.

This study also contributes to the literature by reinforcing the idea that effective laboratory design must include not only technical and cognitive dimensions, but also motivational and emotional aspects. As highlighted by Chaidir et al. (2023), student engagement is not merely a by-product of active tasks, but a result of meaningful and relevant learning experiences. The high levels of reported motivation and enthusiasm among participants in this study suggest that PSL and HOT Lab may serve as powerful catalysts for student-centered learning environments that prioritize depth, curiosity, and confidence in science learning.

CONCLUSION

In conclusion, the study demonstrates that Problem Solving Laboratory (PSL) and Higher Order Thinking Laboratory (HOT Lab) activities significantly enhance students' problem-solving skills, critical thinking, creativity, communication, and collaboration, which are essential 21st-century skills. The findings align with previous studies that emphasize the importance of active, experiential learning environments in developing these skills. The PSL and HOT Lab activities, when integrated effectively into the curriculum, provide a conducive learning environment that not only helps students engage with complex problems but also fosters deeper understanding and long-term retention of knowledge. These activities also enhance student motivation and active participation, further contributing to their academic and personal development.

The study also highlights the importance of teacher preparedness and resource availability in ensuring the success of PSL and HOT Lab activities. Despite the positive results, challenges such as time management and the need for adequate resources were identified. Addressing these challenges will be crucial for the broader implementation of such laboratory-based learning strategies. Future research could focus on exploring the long-term impact of these activities on students' academic performance and career readiness. Moreover, it is essential to continue refining the design and implementation of these laboratory activities to maximize their potential and better prepare students for future challenges in both academic and professional settings.

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REFERENCES

Ahmed, N., Atawi, M. E. A., Abdelgadir, H. S., & Alzawawi, B. (2025). The effect of team active learning in prior problem-solving versus afterward problem-solving on medical students' achievement. https://doi.org/10.21203/rs.3.rs-5757594/v1

Aritami, A. F., & Prahani, B. K. (2025). Analysis of students' critical thinking skills profile on momentum impulse material and implementation of PBL learning model. *SAR Journal - Science and Research*, 8(1), 49-57. https://doi.org/10.18421/sar81-06

Arni, K. J. (2025). Systematic review of research trends on critical thinking skills in physics learning. *International Journal of Science Education and Science*, 2(1), 43-52. https://doi.org/10.56566/ijses.v2i1.262

Chaidir, J., Hidayati, P. P., & Harnadi, K. K. (2023). The relationship between critical thinking ability and problem-based learning with a causality pattern in learning improvement. *MIX: Jurnal Ilmiah Manajemen*, 13(1), 122-137. https://doi.org/10.22441/jurnal_mix.2023.v13i1.009

Fadwa, F., Muhibbuddin, M., Rahmatan, H., Artika, W., & Sarong, M. A. (2024). Enhancing problem-solving skills and learning motivation through problem-based learning modules in biology education. *Tadris: Jurnal Keguruan dan Ilmu Tarbiyah*, 9(2), 413-425. https://doi.org/10.24042/tadris.v9i2.24627

Fajrin, S., & Hakim, D. L. (2022). Implementation of low-cost laboratory in education: A systematic literature review. *JIPTEK: Jurnal Ilmiah Pendidikan Teknik dan Kejuruan*, 45(2), 123-132. https://doi.org/10.17977/um031v45i22022p123-132

Marnah, Y., Suharno. S., & Sukarmin, S. (2022). Development of physics module based high order thinking skill (HOTS) to improve student's critical thinking. *Journal of Physics: Conference Series*, 2165(1), 012018. https://doi.org/10.1088/1742-6596/2165/1/012018

Ragab, A., Kaid, A., & Sayed, A. K. (2024). Enhancing higher order thinking skills (HOTS) in education: Strategies and outcomes. *The Future of Education Journal (TOFEDU)*, 3(5), 1488-1499. https://doi.org/10.61445/tofedu.v3i5.267

Sellberg, C., Nazari, Z., & Solberg, M. (2024). Virtual laboratories in STEM higher education: A scoping review. *Nordic Journal of Systematic Reviews in Education*, 2, 58-75. https://doi.org/10.23865/njsre.v2.5766

Soliyeva, Madinabonu M. (2023). Implementation of case study technology in laboratory lessons on physics.

Subramaniam, R. C., Morphew, J. W., Rebello, C. M., & Rebello, N. S. (2025). Presenting a STEM ways of thinking framework for engineering design-based physics problems. *Physical Review Physics Education Research*, 21(1), 010122. https://doi.org/10.1103/PhysRevPhysEducRes.21.010122

Syafitri, W., Agustina, M. S., & Yanti, F. (2023). Analysis of student needs for the development of science laboratory learning media. *Jurnal Penelitian Pendidikan IPA*, 9(1), 20–27. https://doi.org/10.29303/jppipa.v9i1.2283

Wani, S., Arismunandar, A., Herman, H., & Mustafa, M. (2025). The effect of the application of project-based learning model on improving problem-

solving skills. *Pancasila Internasional Journal of Applied Social Science*, 3(1), 105-115. https://doi.org/10.59653/pancasila.v3i01.1382

Widiyawati, Y., Nurwahidah, I., Sari, D. S., Masykuri, M., & Budiyanto, C. W. (2021). The 21 st century science learning: HOTS and digital literacy among junior high school students in Semarang, Indonesia. *Journal of Physics: Conference Science*, 1842(1), 012081. https://doi.org/10.1088/1742-6596/1842/1/012081

Zhanatbekova, N., Andasbayev, Y., Khaimuldanov, Y., Abdulayeva, A., & Boribekova, F. (2024). The development of research skills in physics laboratory works of secondary school students in an information and education environment. Sientific Herald of Uzhhorod University. *Series Physics*, (56), 1-9. https://doi.org/10.54919/physics/56.2024.0fer1