JPPIPA 11(6) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Preliminary Analysis for Developing Digital Assessment of Science Process Skills in Occupational Health and Safety for University Chemistry Laboratory

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Received: December 10, 2024
Revised: May 20, 2025
Accepted: June 25, 2025
Published: June 30, 2025

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DOI: 10.29303/jppipa.v11i6.11430

Abstract: This study represents the initial phase in the development of a digital assessment instrument targeting science process skills (SPS) contextualized within occupational health and safety (OHS) practices in university chemistry laboratories. The objective was to identify field-based needs and formulate relevant SPS indicators through a needs analysis framework. The research adopted the Analysis phase of the ADDIE model, collecting data via field observations, student pre-assessment, semi-structured interviews with laboratory personnel, and literature and regulation reviews. Results showed that although 95.7% of students considered OHS important, only 14.9% had prior training, and most struggled with basic procedures such as proper use of personal protective equipment and chemical hazard identification. Interviews confirmed the absence of valid assessment tools integrating both SPS and safety procedures. These findings underscore the urgency of developing an interactive digital assessment aligned with educational goals and national safety regulations.

Keywords: ADDIE method; Digital assessment; Laboratory safety; Occupational health and safety; Science process skills

Introduction

Practical work in university-level chemistry laboratories plays a pivotal role in developing students' scientific competencies, particularly their science process skills (SPS)—which include observation, inference, experimentation, and scientific communication. These skills are best cultivated through authentic and structured laboratory experiences. However, chemistry laboratories are not merely learning environments; they also pose significant health and safety risks. Many first-year students enter laboratories without adequate knowledge of chemical hazards, safe equipment handling, or the proper use of personal protective equipment (PPE). This lack of preparedness not only increases the risk of accidents but also undermines the integrity of the learning environment.

Despite the critical importance of occupational health and safety (OHS) in laboratory practice, it is often underemphasized in early university curricula. Studies such as Bai et al. (2022) in China show that university students demonstrate limited understanding of hazard labels and emergency protocols, which significantly heightens their vulnerability to laboratory-related incidents. Wahab et al. (2021) also emphasize the absence of systematic safety assessment as a key factor contributing to weak safety culture in educational laboratories. Similarly, Syakbania & Wahyuningsih (2017) emphasized that chemistry laboratory safety programs in Indonesia are often procedural and lack integration into learning systems, resulting in minimal

How to Cite:
Kusuma, M. B., Nahadi, & Anwar, B. Preliminary Analysis for Developing Digital Assessment of Science Process Skills in Occupational Health and Safety for University Chemistry Laboratory. *Jurnal Penelitian Pendidikan IPA*, *11*(6), 7-15. https://doi.org/10.29303/jppipa.v11i6.11430

student awareness of occupational risks and prevention strategies. Laboratory safety guidelines are frequently treated as static regulations rather than integrated into daily learning processes and student assessment. This condition reinforces the need for holistic safety programs that are pedagogically structured and supported with relevant educational assessments.

While these findings highlight a widespread issue, existing efforts to address it have not sufficiently considered the integration of SPS into safety training. Students need not only be informed about safety protocols but also be given the opportunity to practice scientific thinking in real safety-related contexts. In this regard, SPS—such as making observations, analyzing variables, and drawing conclusions—can serve as vital tools for students to identify potential hazards, evaluate laboratory conditions, and respond effectively to unsafe situations. Moreover, numerous studies have confirmed that students' academic performance is positively influenced by the development of scientific process skills, especially when these skills are embedded in authentic and inquiry-driven science instruction (Dolapcioglu & Subası, 2022). Diana et al. (2020) further support this by showing that the integration of SPS in learning activities significantly improves students' understanding and academic outcomes, especially when practiced through structured laboratory-based inquiry.

The advancement of educational technology has opened new opportunities to address this challenge. Technology-enhanced assessment has shown promise in bridging the gap between theory and practice, allowing for more interactive, context-based learning. Blundell (2021) highlights that digital assessments increase both engagement and validity. In a comparative study, Withers et al. (2012) found that computer-based safety training formats resulted in higher student retention of chemical safety knowledge compared to traditional classroom instruction, suggesting that digital formats may be more effective for long-term learning of essential laboratory practices. Similarly, Ismawati et al. (2023) and Sari et al. (2023) emphasize the effectiveness of virtual laboratories and interactive tools in supporting chemistry instruction. Ekici & Erdem (2020) demonstrated that mobile-supported scientific inquiry significantly enhances students' mastery of science process skills by promoting authentic, inquiry-based learning activities that mirror real-world scientific practices. Mako & Levine (2019) demonstrated that inquiry-based laboratory activities—such as designing and evaluating paper-based devices—enhance students' ability to apply process skills in complex laboratory contexts, suggesting the need for complementary assessment tools that reflect the complexity of real laboratory practices. Hassan et al. (2024) also found that when technology is carefully integrated into authentic assessment design, it provides meaningful opportunities for students to apply knowledge in solving real-world problems, and enhances their engagement, critical thinking, and reflection. Hilmiyati et al. (2024) adds that the use of cognitive technology in assessments enables personalized feedback and better identification of student learning needs, thus contributing to more efficient and equitable learning environments.

Meanwhile, safety concerns in chemistry laboratories remain persistent. Kaban et al. (2024) emphasized that the lack of systematic risk management practices and proper understanding of chemical hazards in laboratories contributes significantly to incidents, and urged that continuous safety training, SOPs, and use of protective equipment must be institutionalized. A case-series study by Fatemi et al. (2022) also highlighted that structured implementation of chemical health, safety, and environmental risk assessment in laboratories leads to significant improvements in hazard control and staff compliance. Their findings reinforce the need for practical risk assessment tools that support safety planning and decision-making, particularly in resource-constrained academic settings. In a similar vein, Özbakır (2023) examined OHS risk assessment and mitigation in university chemistry laboratories and emphasized that regular risk assessments, hazard identification, and mitigation strategies are vital to preventing chemical accidents and fostering a safety-conscious academic environment. This case study further illustrates the value of structured OHS frameworks and assessment tools tailored to laboratory education contexts. Additionally, Marendaz et al. (2011) introduced the MICE (Management, Information, Control, and Emergency) program as a comprehensive safety management system specifically designed for academic laboratories. Their framework integrates hazard identification, chemical classification (ACHiL), and real-time emergency preparedness into daily laboratory operations. This structured approach reinforces the argument for integrating educational tools that simultaneously promote scientific process skills and laboratory safety awareness among students.

Supporting this, a recent study Wu et al. (2025) applied a quantitative risk assessment model to chemical laboratories in educational institutions, illustrating the pressing need for structured risk evaluation frameworks to ensure safe laboratory operations and provide empirical data to inform educational safety policies and assessment tools. Similarly, Arfiana & Fanika (2023) revealed that many students still lack consistent awareness of laboratory safety protocols, and that structured OHS education must target both behavioral and environmental factors.

In addition, Kuselman et al. (2025) emphasized that the risk of false decisions in chemical laboratory testing—resulting from inadequate analytical procedures or uncertainty quantification—poses serious threats to laboratory reliability and safety. This underscores the importance of developing assessment tools that help students understand the implications of uncertainty and decision-making errors, particularly within the high-stakes context of laboratory safety management.

Furthermore, Ozdemir et al. (2017) conducted a case study applying fuzzy logic-based risk assessment in a university chemistry laboratory and revealed that integrating uncertainty modelling into safety evaluations allows for more accurate identification of occupational hazards. Their findings suggest that nuanced risk assessment models are essential for capturing the complexity of laboratory environments, and they reinforce the need for digital tools that incorporate both scientific process skills and structured safety evaluation criteria. Astriawati et al. (2023) highlight that learning attitudes, knowledge, and motivation play an important role in the application of OHS practices, indicating the need for a holistic learning approach to laboratory safety. Cahyaningrum (2020) also supports this by showing that most educational laboratories underestimate safety programs, focusing mainly on fire response, while neglecting broader risk mitigation strategies. The study underscores the importance of institutional OHS policies, staff training, and SOP implementation to prevent incidents such as chemical spills, burns, and equipment failures. Additionally, Fracaroli & Caminos (2021) illustrate how a structured program like "Safety Watch"—designed for academic laboratories with limited resources—can significantly foster a safety culture through practical and inclusive steps. Their findings provide a valuable reference for integrating safety education and participatory practices into science learning environments.

Various national studies have underscored the importance of developing robust, contextually relevant SPS assessments. Ovilia et al. (2024) emphasized that although the implementation of SPS assessment in chemistry learning in Indonesia is aligned with its intended goals, the assessment indicators used often lack completeness and contextual integration. Sembiring & Nasution (2023) similarly found that contextual-based authentic assessment instruments, especially in microbiology courses, significantly improve students' ability to connect scientific processes with real-world applications. Pratama et al. (2024) also pointed out that science process skills, scientific habits of mind, and chemical literacy of chemistry education students remain underdeveloped, and must be strengthened through empirically grounded learning models and assessments. Mandalia et al. (2025) reinforced this by showing that the use of articulate storyline-based virtual media significantly increases SPS acquisition among junior high school students, suggesting broader applicability to science education contexts. Eliaumra et al. (2024) also demonstrated that assessments based on digital literacy within project-based learning models are effective in enhancing creative thinking and digital competencies, which are closely related to students' ability to conduct scientific inquiry. Likewise, Yulia et al. (2023) validated that interactive multimedia developed through the ADDIE model successfully addresses learning gaps in technical and science-related fields, highlighting the model's adaptability and relevance.

In parallel, research by Mayuri et al. (2022) shows the effectiveness of digital-based assessment development using iSpring Quizmaker in improving students' conceptual understanding. Their study demonstrates that technology-enhanced tools can simplify the evaluation process, improve assessment accuracy, and support interactive engagement in science learning. The validation from media, content, construction, and linguistic aspects further confirms its practicality and effectiveness. This aligns with the need for digital instruments that not only assess scientific knowledge but also engage students in authentic, contextually rich tasks aligned with laboratory practice. Similarly, Puspita (2019) found that the implementation of project-based digital worksheets designed with a scientific approach significantly improves students' scientific literacy and process skills, highlighting that digital worksheets can be effectively used to support science learning when aligned with inquiry-based frameworks and structured activities.

Pakaya et al. (2023) further note that many SPS components—such as classification, interpretation, and experimental planning—are often neglected in instructional design and rarely assessed in contextually meaningful ways. Hassan et al. (2024) argue for authentic learning strategies that not only develop scientific understanding but also embed real-world issues like laboratory safety into assessment practices. Digital platforms thus present an opportunity to create assessments that reflect real laboratory situations while strengthening students' scientific reasoning and safety awareness.

Nevertheless, current assessment tools remain fragmented. Existing digital instruments may target either general SPS or basic lab safety, but rarely both. There is a clear research gap in the development of reliable, contextually grounded assessment instruments that evaluate science process skills within the specific domain of occupational health and safety in chemistry laboratories. Such tools are essential for improving not only students' laboratory readiness, but also the quality of science education as a whole.

Therefore, this study aims to develop a digital-based assessment instrument for science process skills (SPS) contextualized within occupational health and safety (OHS) in university-level chemistry laboratories. Using a modified ADDIE development model, this research focuses on the initial analysis stage to identify field needs and formulate assessment indicators that are relevant, practical, and aligned with real laboratory conditions.

Method

This study employed a research and development (R&D) approach by adopting the ADDIE instructional design model, which consists of five sequential stages: Analysis, Design, Development, Implementation, and Evaluation, as outlined by Branch (2009). The ADDIE model was selected for its systematic and structured framework, which supports the step-by-step development of educational instruments or instructional materials based on empirical needs identified in the field. It allows researchers to align the development process with clear objectives and continuous evaluation.

In this study, the development process focuses solely on the Analysis phase, which serves as the foundation for subsequent stages. The aim of this phase is to explore field-based needs and determine the essential indicators required for assessing science process skills (SPS) in the context of occupational health and safety (OHS) within university chemistry laboratories. This approach is consistent with Yulia et al. (2023), who emphasize the importance of initial analysis to validate instructional products and align content with practical competence requirements. Similarly, Asnur et al. (2025) highlight the relevance of analyzing both content needs and media system requirements to ensure the appropriateness of interactive learning materials. Mandalia et al. (2025) also demonstrate that a well-executed analysis phase in ADDIE significantly enhances the feasibility and effectiveness of science learning media designed to improve SPS.

To support the analysis, data were collected through several techniques, including direct observation of laboratory practicum activities, a pretest to assess students' baseline understanding of OHS principles, semi-structured interviews with laboratory instructors and technicians, and a document review of safety regulations and related academic literature. The instruments used in this study consisted of observation sheets, pretest questions, and an interview guide.

The collected data were analyzed using a qualitative thematic analysis approach, which involved coding, theme identification, and interpretation to uncover patterns and categories that could inform the formulation of relevant SPS assessment indicators. The analysis was conducted inductively, ensuring that the resulting indicators were grounded in field data and reflective of actual laboratory conditions.

Participants and Setting

This study was conducted in the Chemistry Laboratory of the Chemistry Education Study Program at a public teacher-training university in Indonesia. The participants consisted of 47 undergraduate students from the 2024 cohort enrolled in an introductory chemistry laboratory course. In addition, three lecturers and one laboratory technician were involved as key informants during the interview sessions.

The importance of the analysis phase in ADDIE is emphasized in several relevant studies. Nadiyah & Faaizah (2015) demonstrated that developing instructional models such as Online Project-Based Collaborative Learning (OPBCL) using ADDIE leads to more structured design outputs and supports iterative refinement through validation stages. Likewise, Ramly et al. (2022) affirmed the critical role of analysis in identifying learners' needs in the development of STEM-based innovation modules. Furthermore, Asnur et al. (2025) highlighted that analysis must include media requirements and learning behavior patterns, while Mandalia et al. (2025) and Yulia et al. (2023) reinforced that valid instructional media rooted in initial field analysis improves both instructional impact and practical feasibility.

By integrating these frameworks and findings, this study ensures a strong empirical and theoretical foundation for the development of a context-specific, SPS-based digital assessment aligned with OHS competencies.

Result and Discussion

Field Observation Findings

Observations conducted during chemistry laboratory sessions revealed that many students were unable to explain the rationale behind the use of specific equipment and had limited understanding of the chemical substances involved, including their hazards. Furthermore, there was a noticeable lack of awareness regarding accident prevention procedures, including the proper use of personal protective equipment (PPE) and emergency protocols.

These findings indicate that occupational health and safety (OHS) principles have not been fully implemented by students in laboratory practices. This aligns with studies by Al-Zyoud et al. (2019) and Walters et al. (2017), which emphasize the need for in-depth, practice-based safety training. Arfiana & Fanika (2023) also highlight that OHS implementation in educational laboratories depends on both human (attitude, discipline) and environmental (facilities, rules) factors. In this context, science process skills (SPS) such as observation, risk classification, and decision-making are crucial competencies that should be assessed through well-designed and contextualized instruments. Simulation-based assessments can enhance students' awareness and ability to apply OHS principles correctly in laboratory settings.

This photo serves as visual documentation of real-time laboratory practices conducted by chemistry education students. While students appear well-organized and compliant with standard attire (lab coats), closer observation during the session revealed several areas for improvement regarding OHS implementation.

Thus, this image provides supportive evidence for qualitative findings suggesting that compliance in appearance does not equate to full procedural safety competence. It reinforces the need for an assessment model that goes beyond checklists and includes performance-based observation of science process skills (SPS), particularly in safety-critical environments.

Figure 1. Practical laboratory activity of chemistry education students

Pre-Assessment Results

A total of 47 students from the 2024 cohort of the Chemistry Education Study Program participated in the initial assessment, which aimed to measure their baseline understanding of OHS in laboratory settings. The results showed that 95.7% of the students considered OHS to be "very important" (Likert scale score of 5), as illustrated in Figure 1. However, only seven students (14.9%) had previously received training or taken a course related to OHS.

Despite a high level of perceived importance, the students' procedural knowledge remained limited. Many were unaware of correct procedures for handling hazardous chemical waste, locating emergency equipment, and selecting appropriate PPE. In several cases, responses about PPE use were incomplete, reflecting a gap between theoretical knowledge and practical application.

Despite the perceived importance, students demonstrated limited procedural understanding. Many could not identify proper waste disposal methods or PPE usage. These findings are consistent with Al-Zyoud et al. (2019) and supported by Pratama et al. (2024), who observed that SPS mastery remains low despite awareness levels. Sembiring & Nasution (2023) also confirmed the value of contextual-based assessments in evaluating real student competencies.

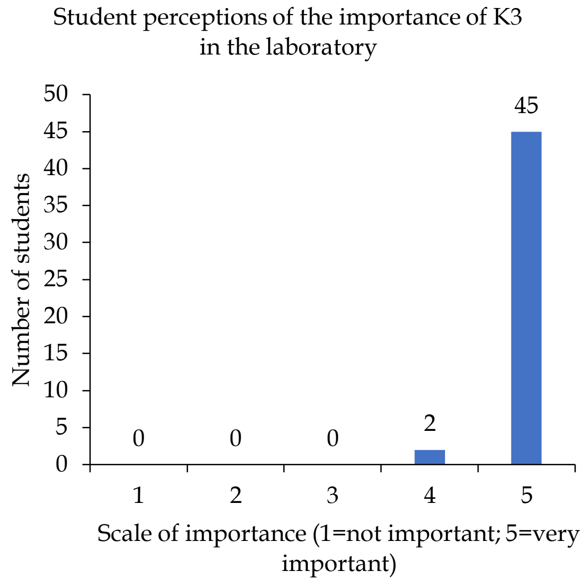

Figure 2. The distribution of students' ratings regarding the importance of occupational health and safety (OHS) in laboratory practice

Literature and Policy Review

The literature supports the importance of science process skills (SPS) in science education, particularly in laboratory contexts. According to Puslitjak Kemendikbud (2019), SPS include observing, classifying, interpreting data, and making evidence-based decisions.

From a regulatory standpoint, the Ministry of Research and Technology Regulation No. 3 of 2020 on the National Standards for Higher Education emphasizes learning outcomes that include attitudes and competencies related to workplace safety. Furthermore, the Ministry of Manpower Regulation No. 5 of 2018 mandates that all laboratory activities adhere to safety standards, with relevant assessments for both lecturers and students. This regulatory framework underscores the necessity of developing digital assessment tools based on SPS in the context of OHS to align with both educational and occupational policies.

Interview Findings with Lecturers and Technicians

Interviews with lecturers and laboratory technicians revealed strong support for developing a digital assessment focused on OHS. One key issue raised was the lack of basic safety education at the high school level, which leaves students ill-prepared for laboratory environments at the university level.

Lecturers noted that while students may understand basic OHS principles, they often struggle to apply them in practice. This suggests that assessments should not only measure knowledge but also thinking skills relevant to safety. Laboratory technicians emphasized the need for assessments that evaluate not just memorization, but students' ability to think and make decisions under emergency conditions. Therefore, case-based or simulation-based assessments are critical in building a strong safety culture while also promoting science process skills.

These findings are reinforced by Stuart & McEwen (2016), who stated that integrating laboratory skills and OHS awareness fosters deeper understanding. However, many students continue to memorize safety protocols without understanding the scientific rationale behind them. Hassan et al. (2024) emphasized that technology-integrated assessments foster deeper engagement and real-world readiness. Similarly, Hilmiyati et al. (2024) confirmed that AI-driven cognitive tech can improve assessment accuracy and personalized feedback in higher education.

Limitations of the Study

This study is limited to the initial phase of the ADDIE model, focusing solely on the analysis stage. As such, the development, implementation, and evaluation phases of the digital assessment instrument were not covered within the scope of this research. Additionally, the study's sample was restricted to a single cohort of undergraduate students from one institution, which may limit the generalizability of the findings. Future research should consider expanding the participant pool and implementing the full development cycle to validate the effectiveness and applicability of the designed instrument across diverse educational settings.

Conclusion

Findings from field observations, pre-assessments, interviews, and literature reviews reveal a substantial gap between students' theoretical understanding and the practical application of Occupational Health and Safety (OHS) principles in university chemistry laboratories. This gap manifests in their limited ability to implement safety procedures related to equipment usage, hazardous material handling, and emergency response, despite recognizing the importance of OHS. The lack of prior exposure to OHS concepts during secondary education, as noted by instructors and laboratory staff during interviews, is one contributing factor. Therefore, the development of a digital, SPS-based assessment instrument is both timely and strategic. Such tools are essential not only for measuring cognitive understanding but also for assessing students' procedural competencies and preparedness for real-life laboratory situations. A contextual and interactive approach to SPS assessment will significantly contribute to strengthening safety culture in higher education science environments.

Acknowledgments

With great gratitude, we express our deepest gratitude to all parties who have contributed and set aside time to support the implementation of this research. Every assistance and support provided has an important role in ensuring the smooth running of the research process and the achievement of optimal results.

Author Contributions

Conceptualization, methodology, investigation, resources, data curation, visualization, M.B.K. and N.; validation, N. and B.A.; formal analysis, original draft writing and editing, M.B.K.; review, N. and B.A. All authors have read and approved the published version of the manuscript.

Funding

This research was funded by the education chemistry department Study Program, faculty of mathematics and natural sciences education, Universitas Pendidikan Indonesia.

Conflicts of Interest

This research was conducted on the mandate of the institution to improve the competence and capacity of lecturers. It is expected that the findings of this study can provide a significant positive impact on the development of human resources, especially in the academic environment, as well as support the creation of innovation and progress in the world of education.

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