IJCER
p-ISSN 2549-9947 | e-ISSN 2614-1426
doi: 10.20885/ijcer.vol9.iss1.art6
p-ISSN 2549-9947
e-ISSN 2614-1426

Analyzing the Competence of Pre-Service Chemistry Teachers in Designing Psychomotor Assessment Instruments for Basic Chemistry Laboratory Practices

Munawwarah [a], Sakinah Zubair [b,*]

[a,b]*Chemistry Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar, Makassar, Indonesia*

** Corresponding author: sakinah.zubair@unm.ac.id*

Received: January 24, 2025; Accepted: March 12, 2025; Published: April 30, 2025

ABSTRACT: This study investigates the competence of pre-service chemistry teachers at Universitas Negeri Makassar in designing psychomotor assessment instruments for basic chemistry laboratory practices. Employing a descriptive quantitative approach, the study aimed to evaluate the alignment of these instruments with laboratory procedural guidelines and identify challenges faced by pre-service teachers. A sample of 30 students, selected through random sampling, participated in project-based tasks to develop psychomotor instruments corresponding to six basic chemistry laboratory activities. Data were collected through skill tests and questionnaires, analyzed descriptively to determine the alignment and effectiveness of the instruments. The findings reveal that most instruments demonstrated strong alignment with procedural steps, particularly in the cases of Solution Preparation and Separation Techniques, which received high scores for clarity, well-structured rubrics, and ease of implementation. However, challenges were noted in integrating explicit safety protocols and balancing the level of difficulty in instruments such as Redox Reactions and Functional Group Identification, which exhibited minor discrepancies. The study underscores the importance of aligning assessment instruments with laboratory standards and enhancing training programs to address both cognitive and psychomotor dimensions effectively.

Keywords: Pre-service chemistry teachers, psychomotor assessment instruments, basic chemistry laboratory, procedural alignment, safety protocols, training programs.

INTRODUCTION

Chemistry education, particularly in the laboratory context, plays a crucial role in shaping students' understanding of chemical concepts and the practical skills necessary for the field. Laboratories serve not only as venues for applying theoretical knowledge but also as arenas where students can develop practical skills and critical thinking essential for becoming scientists. Research indicates that effective laboratory experiences can enhance students' comprehension of chemistry content and prepare them for real-world challenges [1, 2]. In this context, it is vital to evaluate how pre-service chemistry teachers are prepared to design effective assessment instruments. Psychomotor assessment, which focuses on practical skills, is a critical component of chemistry education. This includes students' abilities to conduct experiments, observe results, and draw conclusions based on the data obtained. Studies suggest that many pre-service chemistry teachers may not be fully equipped to design assessments that reflect these practical skills, potentially negatively impacting student learning in the laboratory [3, 4].

With the advancement of technology and new teaching methods, such as project-based learning and online education, pre-service chemistry teachers need to adapt their approaches to designing assessment instruments. For instance, the use of virtual laboratories has been shown to enhance

learning effectiveness and student interest in STEM subjects, including chemistry [5, 6]. Therefore, it is essential to explore how pre-service teachers can leverage these technologies to create more relevant and effective assessments that meet current student needs.

Previous studies have investigated various aspects of pre-service teachers' competencies and the design of assessment instruments in chemistry education. For example, Galloway and Bretz developed an assessment tool aimed at measuring students' meaningful learning in undergraduate chemistry laboratories, emphasizing the integration of cognitive, affective, and psychomotor domains in laboratory experiences [7] Similarly, Hosbein and Walker assessed scientific practice proficiency and content understanding following an inquiry-based laboratory course, highlighting the importance of scaffolding assessment questions to enhance student engagement and proficiency in scientific practices [8]. An and Holme evaluated the use of augmented reality applications in instrumentation education, finding that students' attitudes toward using laboratory instruments significantly influenced their learning experiences [9]. Furthermore, Arjoon et al. examined the psychometric evidence in chemistry education research, advocating for the use of robust measurement tools to assess student competencies effectively [10]. Lastly, Hernández et al. explored the impact of COVID-19 on curriculum changes in forensic science chemistry laboratories, utilizing various assessment instruments to analyze laboratory experiences from different perspectives [11]. Collectively, these studies underscore the critical need for effective assessment design in chemistry education, particularly in preparing pre-service teachers to develop psychomotor assessment instruments for laboratory practices.

The novelty of this research lies in its effort to uncover and prepare pre-service chemistry teachers, particularly at Universitas Negeri Makassar, to become educators capable of conducting effective assessment processes. This study focuses on developing the ability of pre-service teachers to construct assessment instruments that encompass not only the cognitive aspects of students but also the psychomotor aspects, such as laboratory skills. This is crucial because comprehensive assessments provide a more accurate picture of students' capabilities in laboratory practices, which are integral to chemistry education [12, 13].

Additionally, the integration of green chemistry principles into the laboratory curriculum is of significant concern. Green chemistry not only teaches students about safe and sustainable laboratory practices but also encourages them to think critically about the environmental impact of the experiments they conduct [14, 15]. Therefore, pre-service chemistry teachers must be trained to design assessment instruments that measure not only practical skills but also students' environmental awareness. The importance of adequate training for pre-service chemistry teachers in designing psychomotor assessment instruments cannot be overstated. Research shows that teachers who are well-trained in curriculum design and assessment tend to be more successful in improving student learning outcomes [16, 17]. Consequently, teacher training programs should include a strong component on assessment design, focusing on practical skills and the application of chemistry concepts in laboratory contexts. A study by Sarwar et al [18] introduced a social constructivism flipped-classroom model to foster conceptual understanding of photocatalysis for sustainable development, emphasizing the role of active engagement and interactive learning in chemistry education. This model aligns with the need for improved pedagogical approaches in laboratory-based instruction, where students not only engage with theoretical concepts but also develop hands-on competencies. The integration of innovative teaching strategies, such as flipped-classroom models, highlights the importance of structured instructional designs that enhance both cognitive and psychomotor learning outcomes.

In examining the integration of interactive learning media within chemistry education, notable gaps persist in existing research, particularly regarding the assessment of psychomotor skills among students. While numerous studies highlight the potential of interactive technologies in enhancing student engagement and conceptual understanding [19], there is a deficiency in empirical evidence on how these tools effectively measure and assess practical laboratory skills, which are crucial in the chemistry discipline. Recent research has predominantly focused on enhancing cognitive aspects of learning through interactive media but does not sufficiently address the design of assessments that incorporate psychomotor competencies, leading to significant shortcomings in evaluating students' practical skills. Additionally, while teacher competencies in utilizing digital tools are acknowledged [20], the training of pre-service chemistry teachers in developing comprehensive assessment instruments

that address both cognitive and psychomotor dimensions remains underexplored. This lack is critical as effective pedagogical approaches that align with modern educational demands are needed, especially concerning the evolving emphasis on green chemistry principles. The role of environmental awareness in chemistry education is increasingly recognized, highlighting a gap in literature that connects these sustainable practices with assessment strategies. For instance, while the necessity of applying green chemistry principles in laboratory teaching is discussed [21], there is insufficient empirical research exploring how pre-service teachers can integrate these principles into their pedagogical approaches and assessment designs. Therefore, addressing these gaps is imperative in preparing educators for the challenges of teaching chemistry in an environmentally conscious manner while ensuring robust evaluations of student competencies [22].

In the context of this research, several research questions need to be addressed to achieve the established objectives. The primary research question to be explored is: "What is the competence of pre-service chemistry teachers at Universitas Negeri Makassar in designing psychomotor assessment instruments for basic chemistry laboratory practices?" Additionally, other relevant questions include: "What challenges do pre-service teachers face in developing assessment instruments that encompass both cognitive and psychomotor aspects?" and "How can the training provided enhance the ability of pre-service teachers to design effective assessment instruments?" The aim of this research is to uncover and analyze the competence of pre-service chemistry teachers in designing psychomotor assessment instruments, as well as to provide recommendations that can assist in the development of more effective training programs. By understanding the existing competencies and the challenges faced, this research aims to prepare pre-service chemistry teachers to conduct assessment processes effectively, which includes not only the cognitive aspects of students but also the laboratory skills that are an integral part of chemistry education. This research is expected to make a significant contribution to the development of the chemistry teacher education curriculum at Universitas Negeri Makassar and to improve the overall quality of education in the field of chemistry.

RESEARCH METHODS

This study employed a descriptive quantitative approach to analyze the competencies of pre-service chemistry teachers in designing psychomotor assessment instruments for basic chemistry laboratory practices. The research focused on collecting and analyzing numerical data to describe the current state of competency without intervention or experimentation.

Participants and Sampling

The study involved pre-service chemistry teachers from Universitas Negeri Makassar who were in their fifth semester and had completed the Chemistry Learning Assessment course. A total of 30 students were selected through random sampling from this population, as they were expected to possess foundational knowledge in designing psychomotor assessment instruments.

Data Collection Instruments

The primary data collection instrument consisted of project-based tasks designed to measure students' ability to create psychomotor assessment instruments for laboratory practices. These tasks required students to design assessment tools for six key chemistry laboratory activities. The assessment instruments they developed were evaluated using a structured questionnaire, which measured their accuracy and alignment with laboratory procedural guidelines.

Data Analysis

The collected data were analyzed descriptively to determine the effectiveness and alignment of the instruments. Questionnaire responses were processed using frequency distribution to assess the proportion of responses in each category. Additionally, skill test results were evaluated based on predefined criteria, including clarity of objectives, alignment with laboratory procedures, and the appropriateness of evaluation rubrics.

RESULT AND DISCUSSION

This study began by providing students with an understanding of the concepts and methods for developing psychomotor instruments. The researcher presented an example of instrument construction designed to assess psychomotor skills in basic chemistry laboratory activities. Students were tasked with developing these instruments as a group project. They were divided into six groups corresponding to the number of experimental units conducted in the basic chemistry laboratory practicals. The instruments they developed served as a reference for evaluating students' abilities to construct psychomotor instruments, particularly in assessing basic chemistry laboratory activities. Table 1 presents the evaluation results of the psychomotor instruments designed by the students based on various criteria.

TABLE 1. Results of Evaluation of Psychomotor Instruments

Instrument	Clarity of Objectives	Procedure Alignment	Assessment Criteria	Evaluation Rubric	Level of Difficulty	Ease of Use	Instrument Design	Standard Alignment	Average
Separation Techniques	4	4	3	4	4	4	4	4	3.88
Reaksi Redoks	3	3	4	4	3	4	3	3	3.38
Solution Preparation	4	4	3	4	4	4	4	4	3.88
Thermochemistry	3	3	4	4	3	4	4	4	3.63
Functional Group Identification	3	4	3	4	4	4	3	3	3.50
Redox Reactions	4	3	4	4	3	4	4	4	3.75

Table 1 shows the evaluation results of the six psychomotor instruments indicate an overall satisfactory performance, with average scores ranging from 3.38 to 3.88. Criteria such as Clarity of Objectives, Assessment Rubric, and Ease of Use consistently received high scores (4), reflecting the effectiveness and user-friendly design of the instruments. For instance, the Separation Techniques and Solution Preparation instruments achieved the highest scores (3.88) due to their ability to integrate clear practical objectives, measurable rubrics, and ease of implementation, which facilitate the assessment of students' skills in the laboratory.

However, several aspects warrant further attention. Criteria such as Instrument Design and Standard Suitability exhibited score variations in certain instruments, such as Thermochemistry and Functional Group Identification, which only attained a score of 3. This suggests that there are design elements that are suboptimal or not fully aligned with the applicable laboratory standards. Previous research indicates that misalignment between instrument design and laboratory standards can hinder the effectiveness of learning [23, 24]. Additionally, the Level of Difficulty in some instruments, such as Redox Reactions, reflects practical challenges that students may encounter, indicating the need for a reevaluation to balance complexity and students' capabilities [25, 26].

Based on the average score graph of the instruments in Figure 1, it is evident that all instruments demonstrate good performance, with average scores above 3.5. Solution Preparation and Separation Techniques received the highest average scores, indicating clarity and appropriateness of the assessment criteria in evaluating students' psychomotor skills. Meanwhile, instruments such as Functional Group Identification have lower average scores compared to others, suggesting areas that require improvement, such as standard suitability or instrument design. Overall, this graph reflects that each instrument has been well-designed; however, there are opportunities for refinement in some instruments to achieve more optimal performance. To support this analysis, Plummer et al. [27] emphasize the importance of feedback in the learning process, particularly in psychomotor skills development, suggesting

that effective assessment criteria can significantly enhance learning outcomes. Additionally, Suparno et al. [28] highlight the effectiveness of interactive technologies in improving psychomotor skills and self-efficacy among students, which aligns with the findings that certain instruments excel in clarity and assessment criteria.

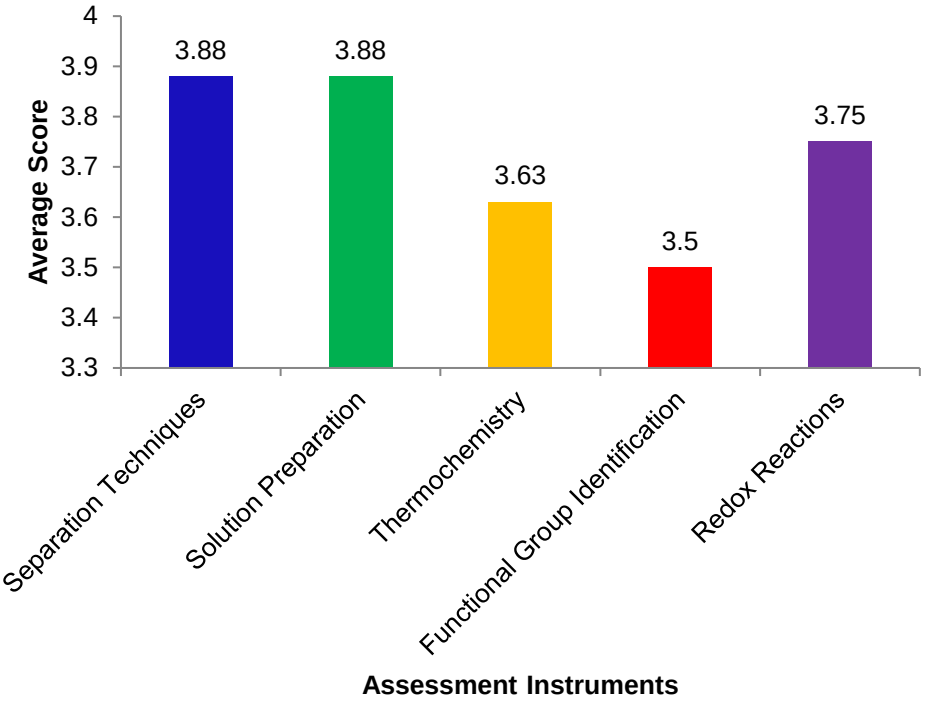

FIGURE 1. Instrument average score chart

Overall, the assessed instruments demonstrate strengths in consistent rubrics, procedures that generally align with standards, and the ability to encompass relevant psychomotor skills. Nevertheless, improvements can be focused on the suitability of procedures and standards to ensure that all instruments meet optimal criteria within the context of laboratory education. Research has shown that enhancements in instrument design and balancing difficulty can provide more accurate evaluations and support effective learning processes in the laboratory [29, 30]. By refining the design and balancing the difficulty levels, these instruments can yield more accurate assessments and foster effective learning experiences in laboratory settings [23, 24].

In addition to the evaluations conducted previously, the researcher also reviewed the alignment of the instruments developed by the students with the experimental procedures outlined in the basic chemistry laboratory manual. This review aimed to ensure that the instruments were specifically tailored to the procedures applicable to each unit. This aspect is considered crucial because generalized instruments cannot effectively measure students' laboratory skills in a specific manner. Based on the analysis of the six instruments developed by the students, the majority were found to align well with the experimental procedures. However, three instruments showed minor discrepancies. The results of these alignment analyses are presented in Table 2, 3, and 4.

The psychomotor instrument for redox reactions demonstrates good alignment with the procedures outlined in the Basic Chemistry Laboratory Manual. All essential steps, such as the use of dropper pipettes, solution filling, and heating, are adequately covered within the instrument criteria. Precision in

filling and measuring solution volumes, as well as observing color changes during the reaction, is also consistent with the procedural steps. This indicates that the instrument effectively evaluates students' psychomotor skills in a comprehensive manner. However, the use of personal protective equipment (PPE) is mentioned only as an instrument criterion without explicit emphasis in the manual's procedures. Nonetheless, this aspect remains critical for enhancing safety during laboratory activities. Therefore, it is recommended that the manual be updated to explicitly include the use of PPE, ensuring greater consistency with the instrument and adherence to laboratory safety standards.

The instrument for the acid-base neutralization practical is deemed highly aligned with the procedural steps outlined in the laboratory manual. Key activities, such as filling the burette, using a volumetric pipette, and performing the titration technique, are comprehensively covered within the instrument. The precision in observing changes in the indicator's color and recording titration results also reflects the procedures described in the manual. This demonstrates that the instrument effectively evaluates students' psychomotor skills with accuracy. However, similar to the redox reaction instrument, safety aspects such as the use of personal protective equipment (PPE) require further attention. While the instrument evaluates compliance with safety protocols, the laboratory manual provides limited explicit guidance on this matter. Including detailed explanations regarding the use of PPE in the manual would enhance consistency with the instrument and reinforce the importance of safety during laboratory activities.

TABLE 2. The Results of the Evaluation of the Alignment Between Instruments of Redox Reactions Developed by Students and the Experimental Procedures in the Basic Chemistry Laboratory Manual

Procedure Aspect	Procedure in the Manual	Instrument Criteria	Alignment	Commentary
Use of Personal Protective Equipment (PPE)	Not explicitly mentioned in the manual.	The instrument mandates the use of PPE as a primary criterion.	Partial	PPE is an essential aspect of safety not explicitly stated in the manual but highly relevant for inclusion.
Preparation of Tools and Materials	Tools: test tubes, dropper pipette, measuring cylinder. Materials: $KMnO_4$, $FeSO_4$, H_2SO_4, $Na_2S_2O_3$, $H_2C_2O_4$.	Preparation and cleaning of tools and materials are included in the evaluation criteria.	Aligned	The preparation of tools and materials aligns with the instrument.
Use of Dropper Pipette	Used to collect solutions such as $KMnO_4$ and H_2SO_4.	Evaluation includes accuracy and precision in using the dropper pipette.	Aligned	The use of the dropper pipette as a primary tool in the experiment aligns with the instrument.
Filling and Measurement	Solutions ($KMnO_4$, H_2SO_4) are measured with a measuring cylinder and dropper pipette.	Precision in filling and measuring is included in the instrument criteria.	Aligned	The instrument covers essential aspects such as precision and accuracy in measuring solution volumes.
Heating the Solution	Heating is performed after adding $H_2C_2O_4$ to observe changes.	Evaluation includes heating techniques as required for the solution.	Aligned	Heating techniques are clearly instructed in the procedure and reflected in the instrument.

Procedure Aspect	Procedure in the Manual	Instrument Criteria	Alignment	Commentary
Observation of Reaction	Observe color changes during the reaction (e.g., $KMnO_4$ solution fades upon reaction with $FeSO_4$ or $Na_2S_2O_3$).	Accuracy in observing results (color) is included in the instrument criteria.	Aligned	Focus on observing results such as color changes aligns with the manual procedures.

TABLE 3. The Results of the Evaluation of the Alignment Between Instruments of Acid-Base Neutralization Developed by Students and the Experimental Procedures in the Basic Chemistry Laboratory Manual

Procedure Aspect	Procedure in the Manual	Instrument Criteria	Alignment	Commentary
Filling the Burette	The burette is filled with NaOH solution, ensuring no air bubbles.	The technique includes filling above the zero line and removing air bubbles.	Aligned	The manual procedure aligns with the instrument's criteria for careful burette filling.
Filling the Volumetric Pipette	The pipette is used to transfer HCl solution into an Erlenmeyer flask.	Evaluation includes accuracy and careful handling when using the volumetric pipette.	Aligned	The procedure supports the use of the pipette, as assessed by the instrument.
Titration Technique	NaOH is carefully added to HCl until a color change from colorless to light pink occurs.	The instrument evaluates the skill of observing indicator color changes during titration.	Aligned	The evaluation of titration techniques aligns well with the procedural steps outlined in the manual.
Use of Laboratory Equipment	The use of burette, pipette, and Erlenmeyer flask is described in detail.	Skillful and precise use of equipment is included in the criteria.	Aligned	The use of laboratory equipment fully aligns with the procedural steps in the manual.
Safety Measures	Emphasis on using PPE (lab coat, gloves) and exercising caution with chemicals in the laboratory.	Safety is evaluated based on adherence to procedures, including PPE use.	Partial	The instrument adds safety aspects not explicitly described in the manual, though they are relevant and important.
Observation of Results	Titration results are observed and recorded, including solution volume and pH changes.	Final experimental results are evaluated for accuracy and documentation.	Aligned	The instrument supports the detailed recording of results as required by the procedure.

The psychomotor instrument for solution preparation demonstrates full alignment with the procedural steps outlined in the laboratory manual. Key activities, such as the preparation of tools and materials, weighing solid substances, filling volumetric pipettes, and mixing solutions until homogeneous, are fully reflected in the instrument's evaluation criteria. Additionally, the detailed assessment of recorded results, including the mass of materials, solution volumes, and concentrations, aligns closely with the procedural steps in the manual. While the aspect of workplace safety is included in the instrument, it is

not well-integrated into the procedures in the manual. Incorporating more explicit safety guidelines would enhance the consistency between the manual and the instrument. With these adjustments, the instrument will be even more effective in supporting the learning objectives of basic chemistry laboratory practices.

TABLE 4. The Results of the Evaluation of the Alignment Between Instruments of Solution Preparation Developed by Students and the Experimental Procedures in the Basic Chemistry Laboratory Manual

Procedure Aspect	Procedure in the Manual	Instrument Criteria	Alignment	Commentary
Preparation of Tools and Materials	Tools: volumetric flask, beaker, pipette. Materials: solid NaOH and HCl solution.	Preparation of tools and materials is part of the instrument criteria.	Aligned	The procedure emphasizes clean tools and complete materials, aligning with the instrument.
Weighing Solid Materials	Weigh NaOH in a beaker with accuracy, then dissolve it in distilled water until fully dissolved.	Evaluation includes accurate weighing and precise measurement techniques.	Aligned	Weighing techniques and solution preparation are well covered in the instrument.
Use of Pipette	Measure solutions with a pipette up to the calibration mark with accuracy.	The use of the pipette with technical skill is a primary assessment aspect.	Aligned	The instrument evaluates pipette usage techniques, aligning with the manual procedure.
Mixing and Stirring	Stir the solution until homogeneous before transferring to a volumetric flask and filling up to the calibration mark.	Mixing and stirring skills are part of the assessment criteria.	Aligned	The procedure for mixing aligns with the steps outlined in the instrument.
Recording Results	Document results such as NaOH mass, solution volume, and concentration.	Documentation is evaluated based on clarity and completeness.	Aligned	Recording experimental results is a significant part of the instrument and aligns with procedural requirements.
Safety Measures	Use tools carefully and ensure the workspace is safe.	Safety is included in the instrument assessment criteria.	Partial	Safety procedures need to be emphasized more explicitly in the manual, although they are included in the instrument.

CONCLUSION

The study finds that pre-service chemistry teachers at Universitas Negeri Makassar are capable of designing psychomotor assessment instruments for basic chemistry labs, with most following procedural guidelines. Instruments like Solution Preparation and Separation Techniques scored well due to clear objectives, strong rubrics, and easy implementation. However, some, such as Redox Reactions and Functional Group Identification, need better safety measures and difficulty balance. This highlights the need for better training to improve safety standards and assessment design. The study is limited to one university, so the results may not apply to others with different curricula. It also does not explore external factors like training time and facility support, which could affect the assessment

design. Future research should involve multiple universities and develop better instruments that integrate safety, cognitive, and psychomotor aspects for more effective lab assessments.

REFERENCES

[1] J. H. Carmel, D. G. Herrington, L. A. Posey, J. S. Ward, A. M. Pollock, and M. M. Cooper, "Helping Students to 'Do Science': Characterizing Scientific Practices in General Chemistry Laboratory Curricula," *J. Chem. Educ,* vol. 96, no. 3, pp. 423–434, 2019. doi: 10.1021/acs.jchemed.8b00912.

[2] M. K. Seery, "Establishing the Laboratory as the Place to Learn How to Do Chemistry," 2020. doi: 10.1021/acs.jchemed.9b00764.

[3] M. Feszterová, "The Education of Pre-Service Chemistry Teachers, the Content of Innovation, Methods and Forms During COVID-19," *R&E-SOURCE*, no. S24, Jul. 2022, doi: 10.53349/resource.2022.is24.a1104.

[4] GG. Yuliani, H. S. Halimatul, S. Aisyah, and T. Widhiyanti, "The profile of teachers' performance in designing practical chemistry laboratory works," in *Proc. 4th Asian Education Symp. (AES 2019)*, Atlantis Press, May 2020, pp. 275–278, doi: 10.2991/assehr.k.200513.062.

[5] M. C. Manyilizu, "Effectiveness of virtual laboratory vs. paper-based experiences to the hands-on chemistry practical in Tanzanian secondary schools," *Educ. Inf. Technol.*, vol. 28, pp. 4831–4848, 2023, doi: 10.1007/s10639-022-11327-7.

[6] N. Garner, A. Siol, and I. Eilks, "The Potential of Non-Formal Laboratory Environments for Innovating the Chemistry Curriculum and Promoting Secondary School Level Students Education for Sustainability," *Sustainability*, vol. *7, no.* 2, pp. 1798-1818, 2015, doi: 10.3390/su7021798.

[7] K. R. Galloway and S. L. Bretz, "Development of an Assessment Tool to Measure Students' Meaningful Learning in the Undergraduate Chemistry Laboratory," 2015. doi: 10.1021/ed500881y.

[8] K. N. Hosbein and J. P. Walker, "Assessment of Scientific Practice Proficiency and Content Understanding Following an Inquiry-Based Laboratory Course," *J. Chem. Educ,* vol. 92, no. 7, pp. 1149–1158, 2022, doi: 10.1021/acs.jchemed.2c00578.

[9] J. An and T. A. Holme, "Evaluation of Augmented Reality Application Usage and Measuring Students' Attitudes Toward Instrumentation," *J. Chem. Educ,* vol. 98, no. 4, pp. 1458–1464, 2021, doi: 10.1021/acs.jchemed.0c01268.

[10] J. A. Arjoon, X. Xu, and J. E. Lewis, "Understanding the State of the Art for Measurement in Chemistry Education Research: Examining the Psychometric Evidence," *J. Chem. Educ,* vol. 90, no. 5, pp. 536–545, 2013. doi: 10.1021/ed3002013.

[11] L. A. Hernández, L. A. E. Escobar, A. M. S. Reyes, J. Zepeda, and L. A. V Queijeiro, "Covid-19 School Disruptions as Drivers of Curriculum Change in the Forensic Science Chemistry Laboratory," 2020. doi: 10.22201/fq.18708404e.2020.5.76857.

[12] W. Ang, "Integrating Green Chemistry Into Teaching Laboratories: Aqueous Suzuki–Miyaura Cross-Coupling Reaction Using a Recyclable Fluorous Precatalyst," *J. Chem. Educ*, vol 98, no. 1, 2020. doi: 10.1021/acs.jchemed.0c00072.

[13] K. B. Aubrecht, M. Bourgeois, E. Brush, J. MacKellar, and J. E. Wissinger, "Integrating Green Chemistry in the Curriculum: Building Student Skills in Systems Thinking, Safety, and Sustainability," *J. Chem. Educ*, vol. 96, no. 12, 2019. doi: 10.1021/acs.jchemed.9b00354.

[14] L. B. Bruck, M. H. Towns, and S. L. Bretz, "Faculty Perspectives of Undergraduate Chemistry Laboratory: Goals and Obstacles to Success," *J. Chem. Educ*, vol. 87, no. 12, 2010. doi: 10.1021/ed900002d.

[15] R. Stoodley, K. J. Knox, and E. A. Gillis, "Application of a Cognitive Task Framework to Characterize Opportunities for Student Preparation for Research in the Undergraduate Chemistry Laboratory," *J Chem Educ*, vo. 100, no. 5, 2023, doi: 10.1021/acs.jchemed.2c00948.

[16] T. Armstrong, *Multiple Intelligences in The Class Room*, 4th ed. Alexandria Virginia USA: ASCD, 2018.

[17] S. Kennedy, "Design of a Dynamic Undergraduate Green Chemistry Course," *J Chem Educ*, vo. 93, no. 4, 2015. doi: 10.1021/acs.jchemed.5b00432.

[18] M. N. Sarwar *et al.*, "Fostering Conceptual Understanding of Photocatalysis for Sustainable Development: A Social Constructivism Flipped-Classroom Model," *Sustainability*, vol. 16, no. 23, p. 10324, Nov. 2024, doi: 10.3390/su162310324.

[19] S. C. Nwafor, F. N. Ibe, and N. M. Muoneke, "Optimizing information and communication technology applications in chemistry learning," *Journal of Research in Instructional*, vol. 2, no. 2, pp. 151–162, Nov. 2022, doi: 10.30862/jri.v2i2.92.

[20] A. Shemshack and J. M. Spector, "A systematic literature review of personalized learning terms," *Smart Learning Environments*, vol. 7, no. 1, p. 33, Dec. 2020, doi: 10.1186/s40561-020-00140-9.

[21] P. P. Nechypurenko, S. O. Semerikov, and O. Yu. Pokhliestova, "Cloud technologies of augmented reality as a means of supporting educational and research activities in chemistry for 11th grade students," *Educational Technology Quarterly*, vol. 2023, no. 1, pp. 69–91, Jan. 2023, doi: 10.55056/etq.44.

[22] E. A. Alasadi and C. R. Baiz, "Multimodal Generative Artificial Intelligence Tackles Visual Problems in Chemistry," *J Chem Educ*, vol. 101, no. 7, pp. 2716–2729, Jul. 2024, doi: 10.1021/acs.jchemed.4c00138.

[23] G. Wu, Y. Yang, and C. Xu, "Determination of University Students' Laboratory Safety Awareness: A Cross-Sectional Study," *J. Chem. Educ,* vol. 100, no. 9, pp. 3402–34092023, 2023, doi: 10.1021/acs.jchemed.3c00305.

[24] S. L. Sonawane, V. J. Patil, and R. A. Tigaa, "Evaluating and Promoting Chemical Safety Awareness in the Chemical Sciences," *J. Chem. Educ*, vol. 100, no. 2, pp. 469–478, 2022, doi: 10.1021/acs.jchemed.2c00102.

[25] M. A. Rashidi, S. Khazaei, K. Samimi, S. Khodakarim, A. Khatabakhsh, and M. Pouyakian, "Application of Social Media in Chemical Safety Training: A Case Study of Training GHS Standards to Students and Laboratory Staff at a University," *J. Chem. Educ,* vol. 100, no. 2, pp. 517–5272023, 2023, doi: 10.1021/acs.jchemed.2c00593.

[26] S. Zhou, Y. Wang, and C. Zhang, "Pre-service science teachers' PCK: Inconsistency of pre-service teachers' predictions and student learning difficulties in newton's third law," *EURASIA J Math Sci Tech Ed*, vol. 12, no. 3, pp. 373–385, 2016, doi: 10.12973/eurasia.2016.1203a.

[27] L. Plummer, L. Smith, E. Cornforth, and S. Gore, "Teaching Psychomotor Skills in a Virtual Environment: An Educational Case Study," *Educ. Sci,* vol. 11, no. 9, pp. 537, doi: 10.3390/educsci11090537.

[28] Suparno, Sukardiyono, T. K. Ardiyati, and B. E. Dasilva, "The Effectiveness of Android-Based Interactive Physics Mobile Learning Media to Improve Students' Psychomotor and Self-Efficacy," in *Proceedings of the International Conference on Educational Research and Innovation (ICERI 2019)*, Paris, France: Atlantis Press, 2020. doi: 10.2991/assehr.k.200204.005.

[29] U. Gaikwad *et al.*, "Educational Intervention to Foster Best Infection Control Practices Among Nursing Staff," *Int J Infect*, vol. 5, no. 3, 2018. doi: 10.5812/iji.81531.

[30] A. Y. Zhao, N. E. DeSousa, H. C. Henriksen, A. M. May, X. Tan, and D. S. Lawrence, "An Assessment of Laboratory Safety Training in Undergraduate Education," *J. Chem. Educ,* vol. 101, no. 4, pp. 1626–1634, 2024. doi: 10.1021/acs.jchemed.3c01299.