International Journal of Innovative Research and Scientific Studies, 8(5) 2025, pages: 556-565

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

Development and implementation of CHEMIDIA: A digital support system for distance chemistry practicum in high schools

Nani Rahmah[1*], Ucu Cahyana[2], Ivan Hanafi[3]

[1]*Department of Education Management, Postgraduate Program, Jakarta State University, Indonesia.*
[2]*Department of Chemistry Education, Faculty of Mathematic and Science, Jakarta State University, Indonesia.*
[3]*Department of Technology and Vocational Education, Faculty of Technology, Jakarta State University, Indonesia.*

Corresponding author: Nani Rahmah (*Email: nanirahmah_9911921025@mhs.unj.ac.id*)

Abstract

This study aimed to develop and implement Chemidia, a web-based application designed to support remote and blended chemistry practicums in high school settings. It focused on the application's features, its impact on student preparedness, and student perceptions of its effectiveness. Using a Design-Based Research (DBR) approach, Chemidia was developed through iterative phases: needs analysis, design, testing, and implementation. The platform includes four core features: Chemical Inventory Management, Safety Protocol Access, Chemistry Experiment Modules, and Self-Directed Learning Tasks. Implementation involved 89 students in a blended learning environment, with data collected through surveys, interviews, and observations. Survey results showed significant improvements in students' practicum preparedness (mean increased from 3.1 to 4.2), understanding of safety protocols (3.3 to 4.4), and confidence in conducting experiments (2.9 to 4.1). Over 82% of students strongly agreed that Chemidia improved their understanding. TAM-based evaluations indicated high perceived usefulness and ease of use. Qualitative feedback reinforced these findings, highlighting enhanced student autonomy, clarity, and engagement. Chemidia effectively supports chemistry practicum learning in hybrid environments by improving student readiness, self-efficacy, and instructional continuity. This study presents Chemidia as a scalable model for integrating digital tools into science education. It offers practical insights for educators and developers aiming to enhance laboratory learning through blended or remote delivery formats.

Keywords: Digital practicum tools, Educational innovation, Learning technologies, Remote laboratory, Science instruction, Technology-enhanced learning.

DOI: 10.53894/ijirss.v8i5.8766
Funding: This study received no specific financial support.
History: Received: 22 May 2025 / **Revised:** 27 June 2025 / **Accepted:** 1 July 2025 / **Published:** 22 July 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Publisher: Innovative Research Publishing

1. Introduction

The advancement of digital technologies has significantly transformed various facets of education, notably the delivery of practical science learning. In chemistry education, laboratory practicums are essential for cultivating students' conceptual understanding and experimental skills [1, 2]. However, the recent shift towards remote and blended learning modalities, accelerated by global events such as the COVID-19 pandemic, has posed substantial challenges in maintaining the quality and continuity of laboratory experiences [3].

Traditional laboratory activities heavily depend on physical presence and hands-on manipulation of chemicals and instruments, aspects that are challenging to replicate fully in online or hybrid settings. To address these challenges, educators and researchers have explored digital solutions that support the management and delivery of chemistry practicums remotely while fostering students' independent learning and safety awareness [4, 5].

Virtual laboratories have emerged as a viable alternative, offering interactive simulations that allow students to conduct experiments in a controlled, digital environment [6]. Studies have shown that virtual chemistry laboratory software can be as effective as real laboratories in facilitating constructivist learning environments, enabling students to conduct experiments safely and relate them to real-life contexts [7-9]. These virtual labs not only bridge the gap between theoretical knowledge and practical application but also enhance students' engagement and understanding of complex chemical concepts [10].

Furthermore, the integration of virtual laboratories into blended learning environments has been found to improve students' laboratory educational awareness and skills. By providing dynamic, interactive learning opportunities, virtual labs cater to various educational needs and contexts, thereby enriching the overall learning experience [11, 12].

In addition to virtual laboratories, digital laboratory management systems have been developed to assist in the efficient management of chemicals and laboratory equipment [13]. These systems facilitate inventory management, access to safety protocols, and the organization of online experiment modules, thereby streamlining laboratory operations and ensuring safety compliance [14].

The development of students' self-directed learning skills is also a crucial focus in chemistry practicum education. Research indicates that integrating online learning modules that support students' practical skills can enhance their readiness and confidence in conducting chemistry experiments [15, 16]. For example, online modules that provide experiment instructions, safety guidelines, and self-practice exercises have been shown to improve students' understanding and practical skills in conducting chemistry practicums [17, 18].

Despite the availability of various digital solutions, there remains a need for an integrated support system for chemistry practicums that not only provides experiment simulations but also includes chemical inventory management, safety training, and the development of students' self-directed skills within a single, easily accessible platform [19]. Chemidia, short for Chemistry Information and Digital Integrated Application, is designed to meet this need by offering features that effectively and efficiently support the implementation of online and blended chemistry practicums.

Chemidia is a web-based application specifically developed to assist high school students in conducting chemistry practicums within a blended learning framework. The application integrates key features such as:

- Digital Inventory Management: Allows students and educators to track and manage chemical inventories efficiently.
- Access to Safety Protocols: Provides comprehensive safety guidelines to ensure safe conduct during experiments.
- Chemistry Experiment Modules: Offers interactive modules that simulate real-life chemistry experiments, enabling students to engage in practical activities remotely.
- Self-Directed Learning Tasks: Includes assignments and exercises aimed at developing students' independent practical skills.

Unlike conventional laboratory information systems that primarily focus on laboratory management by staff, Chemidia centers on student engagement and readiness. It provides structured guidance and resources to facilitate effective practicum activities outside the traditional lab environment.

Based on the background and identified needs, this study focuses on the development and implementation of the Chemidia web application as a support system for distance chemistry practicum. This study aims to design, develop, and evaluate the Chemidia web application as an innovative digital platform to support chemistry education in high schools. The research questions posed are as follows:

1. How can the Chemidia web application be designed and developed to include features such as chemical inventory management, safety protocols, chemistry experiment modules, and the development of students' self-directed skills?
2. How does the implementation of the Chemidia application in the context of blended chemistry learning in high schools enhance students' preparedness for conducting online chemistry practicums?
3. What are students' perceptions of the effectiveness of the Chemidia application in supporting distance chemistry practicum learning, particularly in terms of engagement, understanding, and the development of practical skills?

The study aims to contribute to the advancement of digital educational tools tailored for chemistry laboratory management and learning, promoting safer, more accessible, and skill-oriented chemistry education in high schools.

2. Materials and Methods

2.1. Research Design

This study employs a Design-Based Research (DBR) approach, which involves iterative cycles of design, development, testing, and refinement. DBR is well-suited for educational technology research, as it allows for the development of practical solutions while simultaneously contributing to theoretical understanding [20].

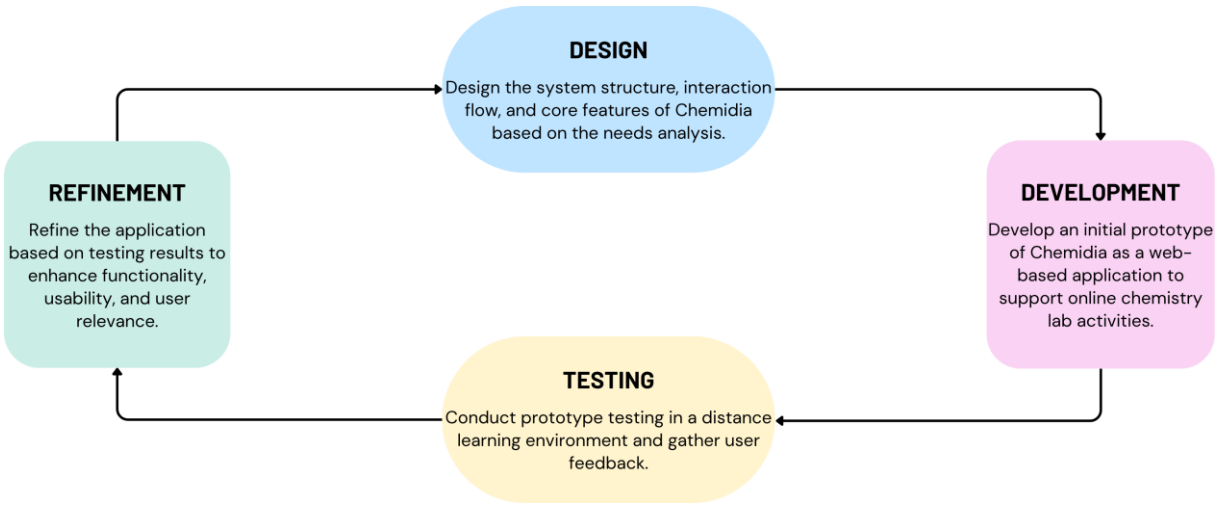

Figure 1.
The four phases of design-based research are experienced in an iterative cycle.

2.2. Research Subjects and Location

The study's participants consist of 11th-grade students from three senior high schools in Jakarta that have implemented blended learning models. These schools were selected based on the availability of digital infrastructure and the readiness of teachers to integrate technology into chemistry practicum instruction. Blended learning, which combines traditional face-to-face instruction with online learning components, has been shown to enhance student engagement and learning outcomes when effectively implemented.

2.3. Data Collection and Analysis

Data were collected through questionnaires, interviews, and observations.

- Questionnaires: Administered to students to assess their perceptions of the Chemidia application's features and its impact on their preparedness for practicums.
- Interviews: Conducted with chemistry teachers and laboratory technicians to gather feedback on the implementation process and the application's effectiveness.
- Observations: Performed during both online and face-to-face practicum sessions to monitor the usage of the application and its integration into the learning process.

Quantitative data from the questionnaires were analyzed using descriptive statistics to calculate the percentage of positive responses regarding the application's features. Qualitative data from interviews and observations were analyzed thematically to identify key themes related to the application's effectiveness and the challenges encountered during its implementation.

3. Findings

This study aimed to develop and implement Chemidia, a web-based application designed to support remote and blended chemistry practicums in high school settings. The research focused on three key questions: the design and development of Chemidia's features, its impact on students' preparedness for online chemistry practicums, and students' perceptions of its effectiveness. The findings are organized to address each of these questions, providing insights into the application's functionality, its educational impact, user feedback, and areas for improvement.

3.1. Design and Development of the Chemidia Web Application

The Chemidia web application was developed using a Design-Based Research (DBR) approach, which involves iterative cycles of design, implementation, analysis, and refinement to create practical educational solutions. This methodology ensures that the application is grounded in both theory and practice, allowing for continuous improvement based on user feedback and observed outcomes. The Chemidia web application was designed and developed as an integrated digital platform to support high school chemistry practicums in blended learning environments. As illustrated in the feature framework in Figure 2, Chemidia incorporates four main functional components: chemical inventory management, safety protocol access, chemistry experiment modules, and self-directed learning tasks.

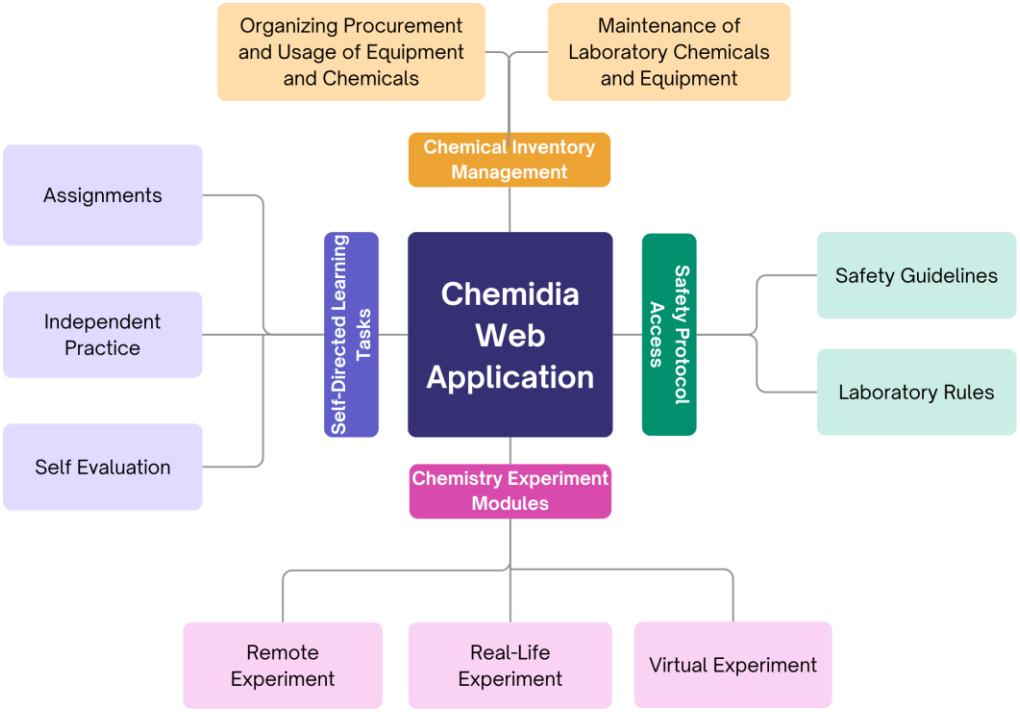

Figure 2.
Feature framework diagram of Chemidia.

The Chemical Inventory Management feature allows users to organize the procurement, usage, and maintenance of laboratory equipment and chemicals, ensuring up-to-date inventory records and supporting practical readiness. The Safety Protocol Access feature provides students with easy access to laboratory safety guidelines and rules, which are essential for promoting safe laboratory practices, particularly in remote settings. To support practical engagement, Chemidia includes Chemistry Experiment Modules that cover three types of experiment delivery modes: remote experiments, real-life (hands-on) experiments, and virtual simulations. This flexible structure enables students to participate in various practicum activities depending on available resources and learning conditions. Additionally, the platform promotes independent learning through the Self-Directed Learning Tasks feature, which consists of structured assignments, independent practice, and self-evaluation components. These tasks are designed to foster student autonomy, enhance skill mastery, and support continuous reflection throughout the practicum process. Together, these features make Chemidia a comprehensive and student-centered tool that addresses both logistical and pedagogical challenges in conducting chemistry practicums remotely.

The results of the design and development phase are visually represented in the user interface of Chemidia (see Figure 3). The main landing page emphasizes the system's role as a modern laboratory platform that offers an effective management solution for progressive learning, reflecting its educational purpose. The login interface provides secure access to the system, reinforcing the platform's professional and school-based orientation. These visuals confirm that Chemidia was not only technically functional but also pedagogically aligned and user-friendly for both students and educators in a school setting.

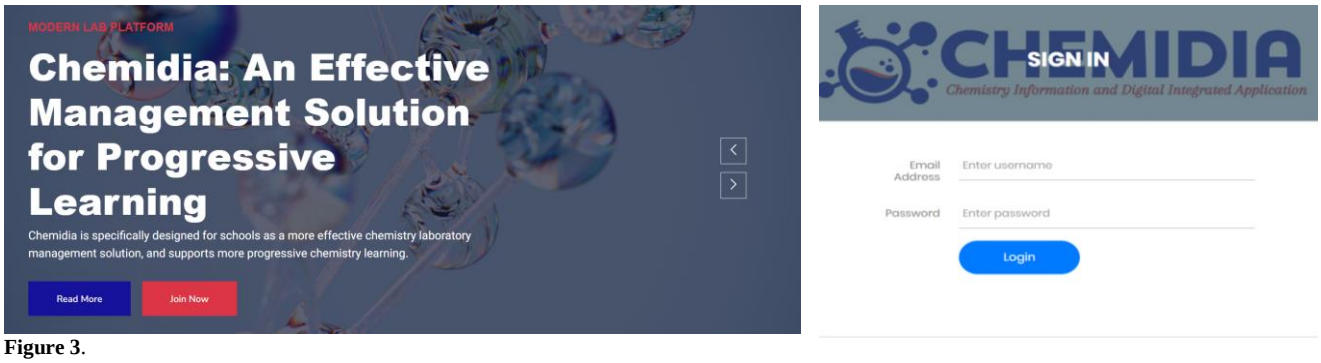

Figure 3.
The main landing page and the user login page.

Chemidia was developed to address various needs in the management of school chemistry laboratories, focusing on three categories of users: laboratory managers, chemistry teachers, and students. Laboratory manager accounts are primarily responsible for organizing and managing the inventory of laboratory equipment and chemicals, making them the dominant users of the *Chemical Inventory Management* feature on the Chemidia platform. Meanwhile, chemistry teachers have access to all available features but have different roles and responsibilities compared to laboratory managers.

Chemistry teachers mainly utilize the *Safety Protocol Access* and *Chemistry Experiment Modules* features. Students, on the other hand, are directed to use the *Chemistry Experiment Modules* and *Self-Directed Learning Tasks* features as part of the learning process. This paper focuses on discussing the benefits of the *Safety Protocol Access*, *Chemistry Experiment Modules*, and *Self-Directed Learning Tasks* features in supporting students' distance learning.

3.2. Implementation of Chemidia in Blended Chemistry Learning

The implementation of the Chemidia web application in a blended learning setting showed significant promise in enhancing students' preparedness for conducting online chemistry practicums. The integration of Chemidia with conventional classroom instruction enabled a more seamless transition between physical and digital lab environments. Through its structured digital features, including experiment modules, safety protocol access, and inventory visualization, Chemidia helped students engage in practicum activities with greater independence and clarity. The blended learning environment, which combines face-to-face instruction with digital resources, allowed students to revisit materials and instructions at their own pace, enhancing both flexibility and comprehension.

Quantitative data collected from a pre- and post-implementation survey (n = 89 students) support these outcomes. The results showed measurable improvements across several key indicators. As shown in Table 1, the mean score for students' preparedness for practicum increased from 3.1 to 4.2 on a 5-point Likert scale. Understanding of safety protocols improved from 3.3 to 4.4, indicating enhanced awareness after using the platform. Confidence in conducting experiments, either virtually or in person, rose from 2.9 to 4.1, reflecting a significant gain in students' self-efficacy. Additionally, more than 82% of students strongly agreed that Chemidia helped them better understand experimental procedures.

Table 1.
Pre-Post Implementation Survey.

Indicators	Pre	Post	Interpretation
Preparedness for Practicum	3.1	4.2	Significant improvement in students' readiness
Understanding of Safety Protocols	3.3	4.4	Increased awareness of lab safety procedures
Confidence in Conducting Experiments	2.9	4.1	Higher self-efficacy in carrying out practical tasks
Agreement that Chemidia Enhances Understanding	-	82% Strongly Agree	Strong positive student perception of learning support

Qualitative data collected through interviews and classroom observations further support these results. Students expressed that Chemidia helped them better understand what was expected during experiments and increased their confidence in following procedures. A student noted, *"Before, I was always unsure about how to prepare for the lab. But now, I just open Chemidia and everything is there, from steps to safety tips."*

Teachers echoed this sentiment, emphasizing how the platform streamlined lesson planning and ensured students came to class with prior exposure to the experimental objectives. One chemistry teacher explained, *"Chemidia doesn't just store resources; it prepares students mentally. They walk into the lab already familiar with what they need to do."*

Classroom observations confirmed that students frequently referred to the platform during experiments, followed safety protocols more diligently, and required less direct guidance from the teacher. This indicated increased autonomy and preparedness.

The alignment between the numerical survey data and narrative feedback from interviews and observations reveals the holistic impact of Chemidia. While quantitative results point to improvements in preparedness, understanding, and engagement, qualitative data illustrate how these improvements manifest in real classroom behavior and teaching dynamics. Chemidia not only equips students with digital content but also cultivates confidence, self-direction, and safety-mindedness, which are core competencies for effective science learning in blended environments.

Table 2.
Student Perceptions of Chemidia's Effectiveness Based on TAM Constructs.

TAM Construct	Survey Item	Mean Score	% Agree
Perceived Usefulness (PU)	Chemidia helps me understand chemistry experiments better.	4.2	83%
	Chemidia increases my interest and engagement in practical chemistry.	4.3	85%
Perceived Ease of Use (PEOU)	Chemidia is easy to navigate and use.	4.4	88%
	I can access the experiment modules and safety information without trouble.	4.3	86%
Attitude Toward Use	I would like to use Chemidia again in future practicums.	4.5	89%

3.3. Student Perception of Chemidia's Effectiveness

To evaluate student perceptions of Chemidia's effectiveness, this study employed constructs from the Technology Acceptance Model (TAM), which include Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) as predictors of technology adoption and user satisfaction [21]. These constructs were integrated into the post-implementation survey and used to guide qualitative interview protocols. The findings in Table 2 suggest that students find Chemidia both useful and easy to use, which in turn supports a positive attitude toward continued use of the platform. Interviews and classroom observations also reinforced TAM constructs. Students described Chemidia as a helpful tool that reduced cognitive load and increased learning autonomy.

Chemidia provides clear instructions and visuals:

When I was doing the virtual practicum, I felt more independent. The step-by-step instructions and visuals were very clear, so I didn't have to constantly ask the teacher what to do. It made me more confident to try things on my own. – Student 23, from School A.

Chemidia helps students become more prepared:

It is very helpful to review the modules at home before the actual lab; it makes me feel prepared. I usually feel nervous before lab activities, but with Chemidia, I could review the material in advance. The modules helped me understand what to expect during the lab. When the actual lab arrived, I already knew what to do, which made me feel more prepared and less anxious – Student 45, from School B.

Chemidia makes the experiments easier to understand:

Compared to printed handouts, this is much easier to follow and more engaging. I find printed instructions boring and sometimes confusing. Chemidia made the experiments easier to understand with interactive features. It was actually fun to use, so I paid more attention and remembered the steps better. – Student 77, from School C.

Teachers also observed that students arrived at class better prepared and were more confident during experiments. These observations align with students' self-reported perceptions of ease and usefulness. Measured through the TAM framework, the findings suggest that Chemidia demonstrates strong perceived usefulness and ease of use, which are key predictors of user satisfaction and sustained adoption. The alignment between survey data and qualitative insights indicates that Chemidia meets students' learning needs in both digital and physical lab environments. The model helps explain why students were not only willing to use the platform but also felt empowered and more autonomous in their learning processes.

4. Discussion

The Chemidia Web Application significantly enhances the effectiveness of blended chemistry learning by providing flexible and accessible learning opportunities beyond the traditional classroom setting. Through its online platform, students and teachers can access educational resources, safety protocols, and laboratory management tools anytime and anywhere, supporting self-paced study and preparation prior to hands-on, virtual, and/or remote laboratory sessions. Chemidia incorporates interactive multimedia elements such as videos, animations, and simulations, which make complex chemistry concepts more tangible and engaging, thereby improving students' conceptual understanding and motivation [18]. In addition to facilitating theoretical learning, Chemidia supports efficient laboratory management by enabling inventory tracking and safety compliance, ensuring a safer and more organized environment for practical activities [22]. The application promotes personalized learning through online assessments and progress tracking, allowing students to focus on areas needing improvement while enabling teachers to monitor individual progress effectively [23]. Communication and collaboration tools within Chemidia further enrich the learning experience by encouraging peer interaction and teacher support beyond classroom hours, which are critical for maintaining engagement in blended learning environments [24]. By integrating theory with practice on one platform, Chemidia bridges the gap between conceptual knowledge and laboratory application, reinforcing learning in a meaningful way [25].

Moreover, Chemidia supported independent and self-directed learning by offering accessible resources and assessment tools that students could use at their own pace. In a hybrid setting, where face-to-face contact is partially replaced or supplemented with online learning, this autonomy is essential. Students could revisit complex concepts through multimedia content and practice quizzes, enabling reinforcement of knowledge without depending solely on teacher-led instruction [26, 27]. This fosters deeper conceptual understanding and promotes lifelong learning habits.

Self-directed learning (SDL) refers to a process in which learners take the initiative, with or without the assistance of others, to diagnose their learning needs, set learning goals, identify resources, choose and implement appropriate learning strategies, and evaluate learning outcomes [28]. In SDL, learners assume responsibility for their own learning, making it a crucial component of 21st-century education that fosters autonomy, critical thinking, problem-solving, and lifelong learning skills.

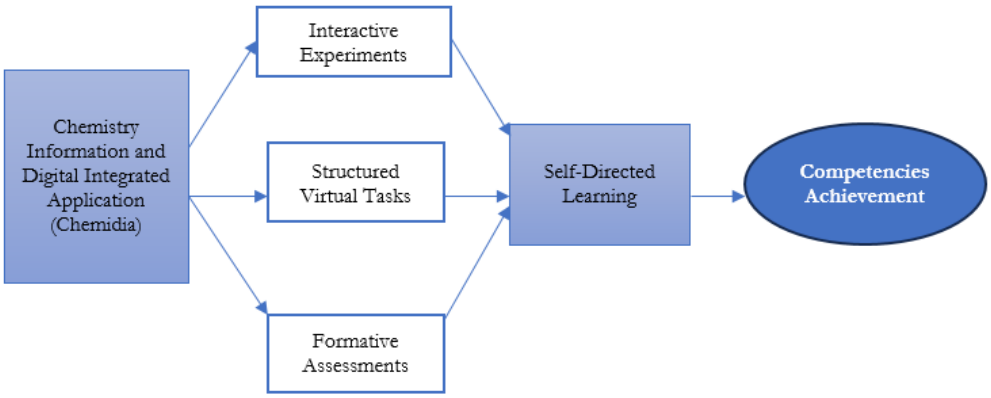

Figure 4.
Chemidia-Integrated Framework for Competency-Oriented Experimental Learning.

In the context of science education, particularly chemistry, self-directed learning empowers students to explore scientific phenomena, engage with experimental procedures, and construct conceptual understanding at their own pace. However, effective implementation of SDL in laboratory-based subjects often requires structured digital environments that provide both guidance and flexibility [29].

Chemidia, a web-based digital chemistry laboratory system, is designed to facilitate self-directed learning by integrating key features that support competency achievement (Figure 4). The platform includes interactive experiments, structured virtual tasks, and formative assessments that guide students through the learning process without limiting their independence. For example, in the *self-directed learning task* interface, students are provided with a series of guided activities, including pretests, virtual experiments, and posttests, allowing them to monitor their own progress and deepen their understanding of chemical concepts such as acidity and basicity. Moreover, Chemidia offers flexible access to practicum materials, quizzes, and literacy tasks, enabling learners to revisit content, reflect on results, and engage in exploratory learning outside of formal classroom hours. The inclusion of features such as experiment simulations and contextual problem-solving activities fosters inquiry-based learning, which is central to SDL. Teachers also benefit from the platform's management tools that allow them to assign tasks, monitor student performance, and provide timely feedback, further promoting learner agency and self-regulation. By bridging the gap between teacher guidance and student autonomy, Chemidia exemplifies how digital tools can transform traditional laboratory education into an environment that nurtures self-directed, active, and reflective learners.

Despite its advantages, implementing Chemidia within blended chemistry learning presents challenges that must be addressed to maximize its effectiveness. First, digital literacy varies among students and teachers, which can limit the effective use of the platform [30, 31]. Adequate training and ongoing technical support are necessary to ensure all users can navigate and utilize Chemidia's features effectively. Additionally, unequal internet access or connectivity issues, especially in rural or under-resourced areas, may hinder the seamless use of the web application [32-34]. Infrastructure improvements and offline-accessible resources can help mitigate this barrier. Third, some users may resist adopting new technology due to comfort with traditional methods or fear of increased workload [35, 36]. Therefore, building user awareness of the benefits, providing clear guidelines, and integrating Chemidia gradually into existing curricula are recommended strategies. Finally, continuous evaluation and feedback mechanisms should be established to refine Chemidia's functionalities based on user experiences and educational outcomes. By addressing these challenges with targeted recommendations, Chemidia can fulfill its potential as an effective tool for blended chemistry education.

5. Conclusion

The development and implementation of CHEMIDIA as a digital support system for distance and blended chemistry practicums in high schools has demonstrated significant potential in improving both the quality and accessibility of chemistry learning. By integrating theoretical content, interactive experiment modules, safety protocols, inventory management tools, and self-directed learning features into a single web-based platform, CHEMIDIA fosters a more flexible, student-centered approach to laboratory instruction in hybrid settings. Students benefit from increased autonomy, clearer procedural guidance, and opportunities for repeated practice, while teachers are supported through streamlined oversight and enhanced monitoring of student progress. These results confirm that digital practicum tools can meaningfully enhance the delivery of science education beyond traditional lab environments.

5.1 Implications

The findings suggest that CHEMIDIA can serve as a scalable and adaptive model for integrating laboratory experiences into remote and blended learning curricula. It provides practical benefits for schools seeking to modernize science instruction, particularly in contexts where physical lab access is limited. The platform also contributes to pedagogical innovation by promoting self-directed learning, safety awareness, and digital competence among students. For educators and school administrators, CHEMIDIA offers a structured solution for improving practicum readiness and instructional continuity.

5.2 Limitations

Despite its strengths, several limitations were identified during the study. Variability in students' digital literacy, differences in internet access, and teachers' readiness to adopt new digital tools affected the consistency of implementation across schools. Additionally, the evaluation was limited to a specific regional context and focused mainly on students' perspectives, leaving out a deeper analysis of long-term learning outcomes.

5.3 Future Research

Future studies should explore the longitudinal effects of using CHEMIDIA on students' conceptual understanding, laboratory competence, and academic achievement. Further research could also examine teacher experiences, institutional adoption processes, and cross-school comparisons to assess the model's adaptability in diverse educational environments. Expanding the application to include collaborative experiment design, AI-supported feedback, or mobile accessibility may also enhance its impact and usability in broader contexts.

References

[1] B. Nainggolan, W. Hutabarat, M. Situmorang, and M. Sitorus, "Developing innovative chemistry laboratory workbook integrated with project-based learning and character-based chemistry," *International Journal of Instruction*, vol. 13, no. 3, pp. 895-908, 2020.

[2] G. Moutsakis, K. Paschalidou, and K. Salta, "Chemistry laboratory experiments focusing on students' engagement in scientific practices and central ideas of chemical practices," *Chemistry Teacher International*, vol. 7, no. 1, pp. 173-182, 2025. https://doi.org/10.1515/cti-2024-0070

[3] M. r. Babinčáková and P. Bernard, "Online experimentation during COVID-19 secondary school closures: Teaching methods and student perceptions," *Journal of Chemical Education*, vol. 97, no. 9, pp. 3295-3300, 2020. https://doi.org/10.1021/acs.jchemed.0c00748

[4] R. D. Link and M. Gallardo-Williams, "We should keep developing digital laboratory resources in the postpandemic era," *Journal of Chemical Education*, vol. 99, no. 2, pp. 519-520, 2022. https://doi.org/10.1021/acs.jchemed.1c01197

[5] S. Tisoglu, K. Cagiltay, and E. Kursun, "Adoption of online multimedia resources in a general chemistry laboratory course context: A case study," *E-Learning and Digital Media*, vol. 18, no. 2, pp. 185-208, 2021.

[6] R. Wolski and P. Jagodziński, "Virtual laboratory—Using a hand movement recognition system to improve the quality of chemical education," *British Journal of Educational Technology*, vol. 50, no. 1, pp. 218-231, 2019. https://doi.org/10.1111/bjet.12563

[7] S. M. Reeves, K. J. Crippen, and E. D. McCray, "The varied experience of undergraduate students learning chemistry in virtual reality laboratories," *Computers & Education*, vol. 175, p. 104320, 2021. https://doi.org/10.1016/j.compedu.2021.104320

[8] C. Byukusenge, F. Nsanganwimana, and A. P. Tarmo, "Effectiveness of virtual laboratories in teaching and learning biology: a review of literature," *International Journal of Learning, Teaching and Educational Research*, vol. 21, no. 6, pp. 1-17, 2022.

[9] R. Abdelmoneim, E. Hassounah, and E. Radwan, "Effectiveness of virtual laboratories on developing expert thinking and decision-making skills among female school students in Palestine," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 18, no. 12, p. em2199, 2022. https://doi.org/10.29333/ejmste/12708

[10] R. J. Petillion and W. S. McNeil, "Student experiences of emergency remote teaching: Impacts of instructor practice on student learning, engagement, and well-being," *Journal of Chemical Education*, vol. 97, no. 9, pp. 2486-2493, 2020. https://doi.org/10.1021/acs.jchemed.0c00733

[11] J. L. Davenport, A. N. Rafferty, and D. J. Yaron, "Whether and how authentic contexts using a virtual chemistry lab support learning," *Journal of Chemical Education*, vol. 95, no. 8, pp. 1250-1259, 2018. https://doi.org/10.1021/acs.jchemed.8b00048

[12] M. Bima, H. Saputro, and A. Efendy, "Virtual laboratory to support a practical learning of micro power generation in Indonesian vocational high schools," *Open Engineering*, vol. 11, no. 1, pp. 508-518, 2021.

[13] R. Zhang and A. O. Reha, "RFID-based logistics technology of laboratory equipments in university," *Open Electrical and Electronic Engineering Journal*, vol. 8, no. 1, pp. 615-619, 2014.

[14] M. Elzagheid, *Chemical technicians: Good laboratory practice and laboratory information management systems. Chemical Engineering Department, Jubail Industrial College, Jubail Industrial City, Jubail, 31961*. Saudi Arabia: De Gruyter, 2023.

[15] A. S. Stender, R. Newell, E. Villarreal, D. F. Swearer, E. Bianco, and E. Ringe, "Communicating science concepts to individuals with visual impairments using short learning modules," *Journal of Chemical Education*, vol. 93, no. 12, pp. 2052-2057, 2016. https://doi.org/10.1021/acs.jchemed.6b00461

[16] F. A. Müller and T. Wulf, "Blended learning environments that work: An evidence-based instructional design for the delivery of qualitative management modules," *The International Journal of Management Education*, vol. 19, no. 3, p. 100530, 2021. https://doi.org/10.1016/j.ijme.2021.100530

[17] N. Zezekwa and N. Nkopodi, "Physics teachers' views and practices on the assessment of students' practical work skills," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 16, no. 8, p. em1868 2020.

[18] M. T. Ali, A. Lykknes, and D. T. Tiruneh, "Examining the effects of supervised laboratory instruction on students' motivation and their understanding of chemistry," *Education Sciences*, vol. 13, no. 8, p. 798, 2023. https://doi.org/10.3390/educsci13080798

[19] V. Camel, M.-N. Maillard, N. Descharles, E. Le Roux, M. Cladière, and I. Billault, "Open digital educational resources for self-training chemistry lab safety rules," *Journal of Chemical Education*, vol. 98, no. 1, pp. 208–217, 2020. https://doi.org/10.1021/acs.jchemed.0c00094

[20] J. Moss, *Keeping connected: the design and overview of the research. In J. Moss (Ed.), Making Difficult Life Decisions: From Womb to Tomb*. London, UK: Routledge, 2012.

[21] C. Antonietti, A. Cattaneo, and F. Amenduni, "Can teachers' digital competence influence technology acceptance in vocational education?," *Computers in Human Behavior*, vol. 132, p. 107266, 2022. https://doi.org/10.1016/j.chb.2022.107266

[22] A. A. Adekunle, B. L. Abolore, G. Mutiu, and A. M. Olalekan, "Design and implementation of a web-based laboratory management system for efficient resource tracking," *Asian Journal of Electrical Sciences*, vol. 13, no. 2, pp. 19-24, 2024.

[23] O. Egambaram *et al.*, "The future of laboratory chemistry learning and teaching must be accessible," *Journal of Chemical Education*, vol. 99, no. 12, pp. 3814-3821, 2022. https://doi.org/10.1021/acs.jchemed.2c00328

[24] R. Scherer and T. Teo, "Unpacking teachers' intentions to integrate technology: A meta-analysis," *Educational Research Review*, vol. 27, pp. 90-109, 2019. https://doi.org/10.1016/j.edurev.2019.03.001

[25] C. Mahanani, S. Wening, M. Susanto, and A. Sudirman, "The effect of laboratory knowledge, teaching practice experience, and work motivation on laboratory management," presented at the Journal of Physics: Conference Series, IOP Publishing, 2020.

[26] K. M. Enneking, G. R. Breitenstein, A. F. Coleman, J. H. Reeves, Y. Wang, and N. P. Grove, "The evaluation of a hybrid, general chemistry laboratory curriculum: Impact on students' cognitive, affective, and psychomotor learning," *Journal of Chemical Education*, vol. 96, no. 6, pp. 1058-1067, 2019.

[27] S. Hadisaputra, G. Gunawan, and M. Yustiqvar, "Effects of green chemistry based interactive multimedia on the students' learning outcomes and scientific literacy," *Journal of Advanced Research in Dynamical and Control Systems*, vol. 11, no. 7, pp. 664-674, 2019.

[28] S. Laine, I. Hakala, and M. Myllymäki, "Self-directed learning in distance education," presented at the 2022 IEEE Frontiers in Education Conference, 2022.

[29] M. Camargo, R. Bary, N. Skiba, V. Boly, and R. Smith, "Studying the implications and impact of smartphones on self-directed learning under a Living Lab approach," *International Journal of Product Development*, vol. 17, no. 1-2, pp. 119-138, 2012. https://doi.org/10.1504/IJPD.2012.051151

[30] C. Dewi, P. Pahriah, and A. Purmadi, "The urgency of digital literacy for generation Z students in chemistry learning," *International Journal of Emerging Technologies in Learning*, vol. 16, no. 11, pp. 88-103, 2021.

[31] E. F. Rusydiyah, E. Purwati, and A. Prabowo, "How to use digital literacy as a learning resource for teacher candidates in Indonesia," *Cakrawala Pendidikan*, vol. 39, no. 2, pp. 305-318, 2020.

[32] L. Liu, C. Cao, and W. Song, "Bibliometric analysis in the field of rural revitalization: Current status, progress, and prospects," *International Journal of Environmental Research and Public Health*, vol. 20, no. 1, p. 823, 2023. https://doi.org/10.3390/ijerph20010823

[33] F. A. Senese, C. Bender, and J. Kile, "The internet chemistry set: Web-based remote laboratories for distance education in chemistry," *Interactive Multimedia Electronic Journal of Computer-Enhanced Learning*, vol. 2, no. 1, 2000.

[34] E. W. Kelley, "Reflections on three different high school chemistry lab formats during COVID-19 remote learning," *Journal of Chemical Education*, vol. 97, no. 9, pp. 2606-2616, 2020.

[35] J. Loonam, S. Eaves, V. Kumar, and G. Parry, "Towards digital transformation: Lessons learned from traditional organizations," *Strategic Change*, vol. 27, no. 2, pp. 101-109, 2018.

[36] C. G. Flint *et al.*, "Promoting wellness in Alaskan villages: Integrating traditional knowledge and science of wild berries," *EcoHealth*, vol. 8, pp. 199-209, 2011. https://doi.org/10.1007/s10393-011-0707-9