JPPIPA 11(3) (2025)

Jurnal Penelitian Pendidikan IPA

*Journal of Research in Science Education*

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

# Chemvilative: Enhancing Conceptual Understanding in Chemistry Through an Android-Based Virtual Laboratory

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Received: December 03, 2024
Revised: February 12, 2025
Accepted: March 25, 2025
Published: March 31, 2025

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DOI: 10.29303/jppipa.v11i3.9885



**Abstract:** Chemistry education often faces challenges due to limited access to laboratory facilities, particularly in abstract topics like buffer solutions, where hands-on experimentation is critical for conceptual understanding. This research aims to develop and evaluate the effectiveness of Chemvilative, an Android-based interactive virtual laboratory designed to address these challenges by providing accessible, engaging, and hypothesis-driven simulations for teaching buffer solutions in high school chemistry. The study addresses challenges related to limited laboratory facilities and the need for more accessible and engaging learning tools. The study used a Research and Development (R&D) methodology based on the ADDIE model, which guided the process from analysis, design, development, implementation, and evaluation. Chemvilative was validated by chemistry experts, teachers, and students. Feasibility was assessed via a 4-point Likert scale questionnaire (material and media), while effectiveness was measured through pre-test/post-test comparisons (N = 120 students). Results showed that Chemvilative significantly improved students' conceptual understanding compared to traditional teaching methods. There was a 15% increase in post-test scores. The virtual laboratory was rated as highly feasible. It provides clear visualizations and interactive simulations that enhance both learning motivation and comprehension. These findings suggest that Chemvilative is a practical and effective alternative for chemistry learning, especially in environments with limited laboratory resources. Future research should expand Chemvilative to other chemistry topics and evaluate its scalability across diverse student populations.

**Keywords:** Chemistry; Conceptual understanding; Interactive learning; Virtual laboratory

## Introduction

Chemical concepts understanding is a fundamental element in learning chemistry at the high school (SMA) and college levels. Chemistry education extends beyond theoretical knowledge, requiring students to connect theories with natural phenomena encountered in everyday life. are considered to have grasped a concept when they can construct its meaning through oral, written, or visual representations (Allen, 2022). To facilitate this deep understanding, it is essential to design effective learning strategies that enable students to engage with and internalize chemical concepts.

However, cognitive processes involving the transferability of concepts often pose significant challenges. Students frequently struggle to identify and solve problems rooted in abstract chemical concepts that are difficult to visualize. This difficulty underscores the need for interactive and innovative learning approaches, particularly through practical activities such as laboratory experiments. Chemistry practicums play a crucial role in learning, as they provide students with

**How to Cite:**
Raziana, E., Yamtinah, S., & Djono. (2025). Chemvilative: Enhancing Conceptual Understanding in Chemistry Through an Android-Based Virtual Laboratory. *Jurnal Penelitian Pendidikan IPA*, *11*(3), 678-686. https://doi.org/10.29303/jppipa.v11i3.9885

hands-on experiences that bridge the gap between abstract theories and real-world applications (Harahap & Sutiani, 2023). Through practicums, students engage in scientific processes relevant to the material being taught, fostering a deeper understanding of chemical principles.

Despite their importance, the implementation of practicum activities is often hindered by limited laboratory facilities, especially in remote or under-resourced schools (Ambarwati & Prodjosantoso, 2018; Anggereni et al., 2021; Harling & Martono, 2021). Constraints such as insufficient tools, materials, and laboratory space significantly reduce students' opportunities to reinforce their understanding through direct experimentation. Research by Anggereni et al. (2021) highlights that inadequate laboratory facilities are a primary barrier to effective chemistry practicums. In many cases, schools lack the necessary equipment to conduct experiments properly, leading to suboptimal learning experiences. This issue was further exacerbated during the COVID-19 pandemic, where remote learning made traditional laboratory-based practicums impossible.

Initial observations conducted on November 23, 2023, with grade XI chemistry teachers at SMA A and SMA B in Yogyakarta, corroborate these findings. The results revealed that the primary obstacle to effective chemistry learning is the lack of practical tools and materials, which limits students' ability to fully grasp chemical concepts. Table 1 summarizes the findings from these observations.

**Table 1.** Initial observation results

| Question | School A, Yogyakarta | School B, Yogyakarta | Total |
|---|---|---|---|
| Teacher difficulty rate (%) | 100 | 100 | 100 |
| Main Constraint | Practical Application Issues | Practical Application Issues | Practical Application Issues |
| Addressing Approach | Technology Use | Technology Use | Technology Use |

In response to these challenges, technological innovation in education is critical. One promising solution is the use of virtual laboratories, which are technology-based learning platforms that simulate chemical experiments digitally (Manyilizu, 2023). Virtual laboratories offer several advantages, including flexibility in time and location, the ability to repeat experiments as needed, and enhanced visualization of abstract concepts. These features make virtual laboratories a viable alternative to traditional practicums, particularly in settings where physical laboratory resources are limited.

Virtual laboratories not only replicate the experience of physical experiments but also provide greater flexibility and accessibility (Jaya et al., 2023). Students can repeat experiments multiple times to deepen their understanding and explore various scenarios that may be impractical in a physical laboratory due to time, equipment, or material constraints (Kidan, 2020). Additionally, virtual laboratories are cost-effective, addressing budget limitations faced by many schools. By minimizing the need for physical materials and equipment, virtual laboratories reduce costs while enhancing safety, particularly for experiments involving hazardous substances. As a result, virtual laboratories serve as an effective educational tool, offering interactive, safe, and immersive learning experiences.

Educational technology plays a pivotal role in the development and utilization of virtual laboratories, aiming to address learning challenges and enhance the effectiveness of the teaching process (AECT, 2022). Teachers, as facilitators, are expected to master and integrate these technologies into their instruction, aligning with the demands of 21st-century education (Roemintoyo & Wibawanto, 2022). Virtual laboratories not only overcome the limitations of physical labs but also increase student motivation and active participation in the learning process.

Previous research underscores the potential of virtual laboratories in improving students' conceptual understanding. Woodfield et al. (2006) found that students using virtual laboratories demonstrated a better grasp of chemical concepts compared to those relying solely on conventional methods. Similarly, Sreekanth et al. (2022) revealed that virtual laboratories enhance both conceptual understanding and critical thinking skills, enabling students to tackle complex chemical problems more effectively. The clear visualization and interactive nature of virtual laboratories make abstract concepts more accessible, fostering deeper engagement and comprehension (Peechapol, 2021). This makes virtual laboratories an effective tool in facilitating more interactive and in-depth chemistry learning.

Despite these advancements, gaps remain in the optimal application of virtual laboratories in formal education. Even in well-resourced regions like Yogyakarta, challenges related to limited laboratory facilities and materials persist (Ambarwati & Prodjosantoso, 2018). Furthermore, existing virtual laboratory platforms often lack comprehensive coverage of essential chemistry topics, leaving some critical concepts underrepresented. This research aims to address these gaps by developing an integrated and comprehensive Android-based virtual laboratory, Chemvilative, specifically designed for buffer solution material. Buffer solutions were selected due to the recurring difficulties students face in understanding this topic. Chemistry Virtual Laboratory Interactive (Chemvilative) is designed to provide an interactive and engaging learning experience, enabling students to explore chemical concepts without the constraints of physical laboratory limitations.

The feature that sets Chemvilative apart from existing virtual laboratory apps is its focus on interactivity, accessibility, and comprehensiveness. Unlike many current platforms, Chemvilative is designed specifically for Android devices, ensuring wide accessibility for students in diverse settings. The platform incorporates unique features such as real-time feedback, adaptive learning paths, and gamification elements to increase engagement and motivation. By incorporating these innovative features, Chemvilative aims to provide a more effective and immersive learning experience, ultimately improving students' conceptual understanding of chemistry.

Previous studies have explored virtual laboratories to enhance chemistry learning, each with distinct features and limitations. Peechapol (2021) developed a platform with static visualizations to aid conceptual understanding but lacked real-time feedback. Sreekanth et al. (2022) introduced guided simulations that improved problem-solving but did not offer adaptive learning pathways. Jaya et al. (2023) incorporated quizzes and assessments for knowledge retention, yet omitted gamification, which Kidan (2020) found to be crucial for motivation. Addressing these gaps, Chemvilative integrates real-time interactive feedback, adaptive learning pathways, and comprehensiveness. Unlike previous platforms with limited topic coverage, Chemvilative offers a comprehensive buffer solution experiment library and is optimized for Android, ensuring greater accessibility. These innovations make Chemvilative a more interactive, adaptive, and engaging virtual laboratory for chemistry education.

This research aims to develop an Android-based Chemvilative on buffer solution material that can be accessed by students anytime and anywhere. The selection of the material is based on the behavior of students' difficulties in understanding the material. This learning media is designed to help students understand chemical concepts better through interactive and fun practicum simulations. By utilizing virtual laboratory technology, it is expected that students can achieve a deeper understanding of chemical materials, without being hindered by the limitations of real laboratory facilities.

## Method

This study employs a Research and Development (R&D) approach. R&D is a model focused on developing new products and procedures based on research findings. These developments undergo systematic field testing, evaluation, and refinement. The process continues until the outcomes achieve predefined standards of effectiveness, quality, or similar benchmarks (Gall et al., 2003). This research refers to the ADDIE development model. The ADDIE model was chosen because of its relatively effective and efficient stages. The product developed in this research is Chemvilative learning media. This product is made to better understand chemical concepts on buffer solution material by providing clear visualization and practical experience for students. The R&D procedure is shown in Figure 1.

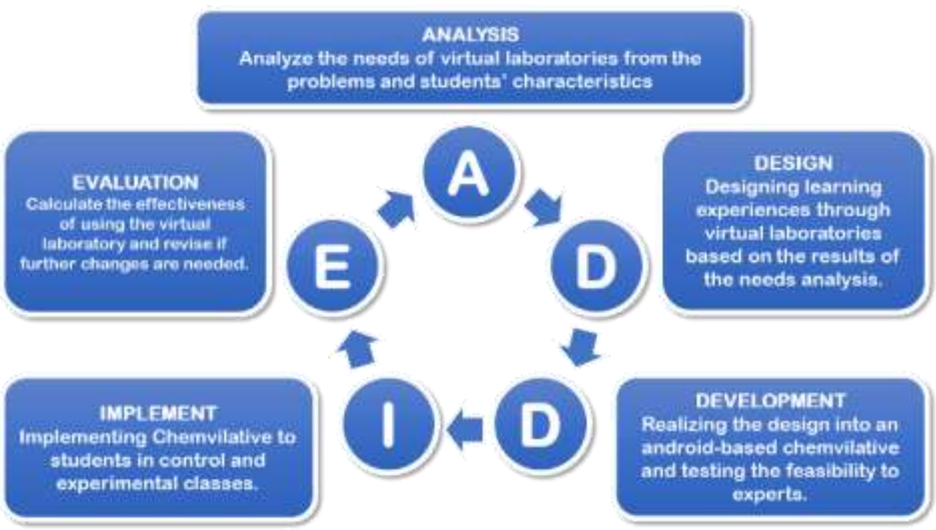


**Figure 1.** Chemvilative R&D with ADDIE model

This development model involves five distinct phases: analysis, design, development, implementation, evaluation (Branch). The analysis phase identifies learning needs and objectives. The design stage designs the learning structure and flow. The develop stage explains the process of making media. The implementation stage explains the application of the media to students. The assessment of product effectiveness by experts, practitioners, and students is called the evaluation stage. This study focuses specifically on the development, implementation, and evaluation phases.

Participants in the research include educators, students, and validators such as subject matter and media experts. The study involved 3 material experts, 3 media experts, 4 teachers, and 120 high school students from Grade XI in Yogyakarta. A sample consisting of 60 students in a control class and 60 in an experimental class was selected using random cluster sampling from SMA A and SMA B Yogyakarta.

Data collection utilized questionnaires and assessments of learning outcomes, which included pre-tests and post-tests (Cresswell et al., 2003). Descriptive analysis was employed for the questionnaire data, while an independent sample t-test was conducted to analyze pre-test and post-test results. The instrument underwent validity and reliability tests prior to use. Each item's validity test resulted in values exceeding $r_{table}$ = 0.76, while the Cronbach's alpha reliability test yielded a score of 0.828, surpassing the acceptable threshold (≥ 0.60). These findings confirm that the instrument is valid and reliable for data collection.

The feasibility and effectiveness of Chemvilative were evaluated through expert validation and user assessments using structured questionnaires. The study used a Likert scale questionnaire to assess different aspects of Chemvilative, ensuring a systematic and quantifiable evaluation. The validation instruments for material experts and media experts were adapted (Lee & Owens, 2004). Each expert rated specific aspects of Chemvilative using a 4-point Likert scale, where: 4 = Strongly Agree; 3 = Agree; 2 = Disagree; 1 = Strongly Disagree.

For material validation, experts assessed content relevance, accuracy, and language clarity, while media experts evaluated aspects such as theme design, interface usability, interactivity, audio narration, typography, and animations. Table 2 and Table 3 detail the product validation instruments.

To determine Chemvilative's feasibility, responses were analyzed using the percentage formula (Arikunto, 2013; Wibawanto et al., 2022).

$$P = \frac{\sum x}{\sum xi} \times 100\% \quad (1)$$

Formula explanation:
P : percentage anticipated score
$\sum x$ : total obtained score
$\sum xi$ : maximum possible score

**Table 2.** Material expert validation on Chemvilative

| Aspects | Statement | Total Items |
|---|---|---|
| Content Relevance | Clear statement of learning objectives | 3 |
| | Content matches basic competencies | |
| | Content aligns with learning goals | |
| Content Accuracy | Content is structured logically | 3 |
| | Key points are highlighted | |
| | Relevant examples are included | |
| Language | Using Indonesian EYD standards | 4 |
| | Accurate terms in learning materials | |
| | Correct language in text and narration | |
| | Clear language without misunderstandings | |
| Total Items | | 10 |

**Table 3.** Media expert validation on Chemvilative

| Aspects | Statement | Total Items |
|---|---|---|
| Theme Design | Attractive theme design | 3 |
| | Combines multimedia elements | |
| | Consistent and cohesive theme design | |
| Interface | Simple and clear interface | 3 |
| | Accurate navigation | |
| | Consistent layout | |
| Interaction | User interactivity | 1 |
| Audio & Narration | Proper use of audio effects without distraction | 3 |
| | Relevant music that doesn't distract | |
| | Accurate narration alignment with visuals | |
| Typography | Appropriate font type and size | 4 |
| | Correct color choices and font highlights | |
| | Readable text | |
| | Proper text layout and positioning | |
| Animation & Special Effects | Engaging animations and effects | 3 |
| | Supports learning objectives | |
| | No excessive use of animations and effects | |
| Total Items | | 17 |

The media's validation category is determined by the percentage obtained from these calculations. The criteria for assessing the feasibility of Chemvilative media serve as a basis for evaluation and improvement, drawing on guidelines from (Arikunto, 2013; Perdana et al., 2021; Wibawanto et al., 2022). The percentage scores were then categorized into feasibility levels (Table 4).

A media product is considered very feasible if it scores at least 80%, indicating that it meets high-quality standards in both content and usability. This rating serves as the basis for further refinement before implementation.

**Table 4.** The criteria of feasibility for Chemvilative development

| Percentage Range (%) | Category |
|---|---|
| 80.0 – 100 | Very Feasible |
| 0.0 – 79.9 | Feasible |
| 40.0 – 59.9 | Less Feasible |
| 20.0 – 39.9 | Not Feasible |

The study utilized pre-test and post-test groups for both experimental and control classes. These results were then subjected to an independent sample t-test. The evaluation of experimental data determined the selection of statistical tests based on specific hypotheses:

H0 : There is no significant effect on improvement of learners' chemistry concept understanding.

Ha : There is a significant effect on improvement of students' chemistry concept understanding.

The decision-making criteria are: If the Sig value is $< 0.05$ or if $t_{value} > t_{table}$, Ha is accepted, and H0 is rejected; If the Sig value is $\geq 0.05$ or if $t_{value} < t_{table}$, Ha is rejected, and H0 is accepted.

## Result and Discussion

The ADDIE model was employed to develop the virtual laboratory media. This section discusses the development process, which includes product feasibility assessments by experts and product effectiveness evaluations by students, who are the primary users.

Initially, material experts, media experts, teachers, and students conducted feasibility evaluations. The virtual lab media covers practical activities involving buffer solutions, integrating multimedia components developed with Adobe Animate. The software was chosen for its user-friendly interface and the flexibility it offers in accessing media across different types of smartphones. A notable advantage of this media is its ability to present content through a combination of text, animated videos, and interactive simulations. These simulations are designed to closely mimic real-world activities involving buffer solutions. Figure 2 illustrates the media's user interface.

Before testing the media on students, it underwent validation by material experts, media experts, and teachers. Based on the validation outcomes, the virtual laboratory interactive media is considered suitable for use in chemistry education. The assessment results from experts and teachers are summarized in Table 5.


**Figure 2.** Chemvilative interface

**Table 5.** Results of media assessment by teachers and experts

| Validator | Percentage (%) | Interpretation |
|---|---|---|
| Material expert A | 95 | |
| Material expert B | 90 | Very Feasible |
| Material expert C | 92.5 | |
| Media expert A | 88.2 | |
| Media expert B | 94.1 | Very Feasible |
| Media expert C | 89.7 | |

| Validator | Percentage (%) | Interpretation |
|---|---|---|
| Teacher A | 90.7 | Very Feasible |
| Teacher B | 89.8 | |
| Teacher C | 93.5 | |
| Teacher D | 88 | |

After using the media, students are asked to assess based on several aspects of media development assessment. Table 6 shows the opinion of students about the Chemvilative media developed by researchers and obtained a score of 81.9% in the very feasible criteria.

**Tabel 6.** Results of media assessment by student

| Aspects | Percentage (%) | Interpretation |
|---|---|---|
| Material | 86.3 | Very Feasible |
| Interaction | 86.7 | Very Feasible |
| Interface | 80.2 | Very Feasible |
| Typography | 82.1 | Very Feasible |
| Language | 80.0 | Very Feasible |
| Audio & Narration | 77.6 | Feasible |
| Animation & Special effects | 80.4 | Very Feasible |
| Average | 81.9 | Very Feasible |

Following the media validation, findings indicate that Chemvilative media is classified as suitable for instructional purposes, though suggestions for improvement were provided. According to Sugiyono (2010), enhancements are necessary to produce a superior product. Revisions will incorporate feedback from validators to refine the media and achieve optimal quality (Sari et al., 2022). After these refinements, the media will be implemented in actual learning settings.

The subsequent phase is the test of the effectiveness of Chemvilative media in enhancing students' conceptual understanding. This assessment employs an experimental setup involving an experimental class and a control class. In the experimental group, students engage with the developed media, whereas the control group utilizes traditional teaching methods and materials typically used by teachers.

A statistical analysis was performed on data from both the experimental and control groups, using pre-test and post-test results. The proposed hypothesis aimed to determine whether there was a significant difference in conceptual understanding improvement between the two groups.

**Table 7.** Hypothesis test results of Chemvilative influence with independent sample t-test SMA A

| | t | df | Sig. (2-tailed) |
|---|---|---|---|
| Equal variances assumed | 8.840 | 58 | .000 |
| Equal variances not assumed | 8.840 | 114.598 | .000 |

Results from the independent sample t-test, displayed in Table 7, demonstrate that Chemvilative media significantly enhances students' conceptual understanding in high school chemistry. The statistical evidence, with a sig. (2-tailed) value of 0.00, which is less than 0.05, and a $t_{count}$ of 8.840 hinger than the $t_{table}$ value of 1.65787, supports the acceptance of Ha, indicating a notable difference between the means of the experimental and control groups. Furthermore, the post-test scores in the experimental class were significantly higher than those in the control class (78.52 > 67.17). These findings confirm that chemistry learning is more effective when supported by interactive virtual laboratory media. Figure 3 details the comparison of students' average pre-test and post-test scores.

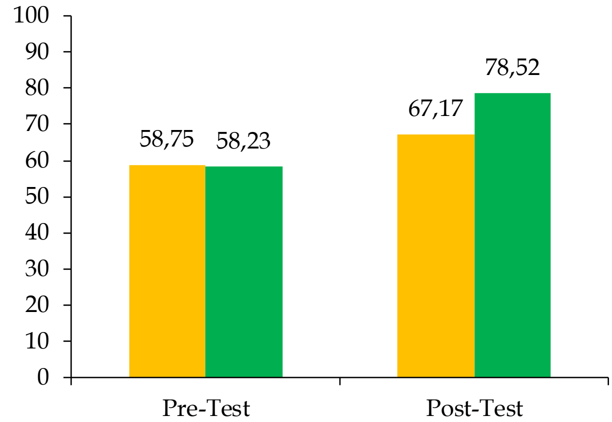


**Figure 3.** Comparison of students' average pre-test and post-test scores

Validation results from experts, teachers, and students confirm that Chemvilative falls into the good category. This suggests that Chemvilative media is a suitable tool for supporting chemistry practicum activities. Students find the information provided highly relevant to their needs during practical sessions, which boosts their motivation to learn due to its ease of access anytime and anywhere.

These findings align with previous research that highlights the positive impact of structured exposure on student learning (Ziadat, 2019). The use of educational media for practice has the potential to enhance attitudes and understanding of the subject, particularly when multimedia is combined with innovative and engaging methods, such as stimulating simulations (Banda & Nzabahimana, 2021; Japar et al., 2024; Mosler et al., 2020). Therefore, teachers are encouraged to integrate virtual media to improve student outcomes in practical learning and ensure that educational goals are achieved.

A comparison of student learning outcomes further demonstrates that using Chemvilative media for chemistry practicum leads to better results than traditional methods alone. Research confirms that interactive media positively enhances student understanding (Amelia & Harahap, 2021; Komalasari et al., 2019; Widodo et al., 2020). Additionally, the practicum integrated into the media can serve as an effective assessment tool, especially when combined with multimedia elements (Pilegard & Mayer, 2016). The interactive features of Chemvilative enable students to engage in various experimental scenarios, overcoming limitations typically encountered in physical labs, such as restricted time, equipment, or resources.

The superiority of Chemvilative over traditional methods is consistent with studies in physics and general science, where interactive media such as simulations and virtual laboratories have been shown to enhance science literacy by enabling students to apply concepts in real-world contexts (Adwan et al., 2024; Amaaz et al., 2024; Lailiyah, 2022; Solihati et al., 2024). Research indicates that problem-based learning models using interactive PowerPoint significantly improved students' physics problem-solving skills, with an average score of 84.12 compared to 71.03 in conventional methods (Adwan et al., 2024). Additionally, interactive media based on iSpring Suite 11 resulted in an N-gain of 71.05% in physics learning, demonstrating the effectiveness of digital tools in improving conceptual understanding (Solihati et al., 2024). Virtual laboratories, in particular, have proven to enhance student engagement and attitudes toward science learning by providing simulated environments for conducting experiments (Lailiyah, 2022). Furthermore, integrating mobile learning with LMS-based practical work in physics has improved student performance and reduced completion time for experimental tasks (Amaaz et al., 2024). These findings reinforce Chemvilative's role in bridging theoretical and practical learning gaps through interactivity, aligning with evidence-based strategies in STEM education.

The integration of practicum scenarios within Chemvilative also addresses common physical lab limitations, such as resource constraints, which persist even in well-resourced regions like Yogyakarta, there are still constraints related to limited physical laboratory facilities and practicum materials (Ambarwati & Prodjosantoso, 2018). This suggests that virtual media such as Chemvilative is essential, even in areas with more advanced educational infrastructure, to overcome these limitations (Komisia et al., 2022). In addition, this study identified a gap in the availability of materials supplied by the current virtual laboratory. Some important concepts in the chemistry curriculum, such as buffer solutions, are still not widely developed in existing virtual media (Zikri & Handayani, 2024).

Chemvilative's potential extends beyond conceptual understanding to fostering practical skills, as seen in biology and geography education, where interactive media improved students' scientific attitudes and problem-solving abilities (Adwan et al., 2024; Solihati et al., 2024). In addition to supporting more interactive and efficient learning, this media also has the potential to improve students' practical skills, while supporting the achievement of learning objectives optimally. Teachers are thus encouraged to adopt such tools not only to overcome infrastructural barriers but also to cultivate higher-order thinking skills. Future development should prioritize diversifying content (e.g., acid-base equilibria, electrochemistry) and incorporating adaptive features, such as real-time feedback, which have proven effective in physics and environmental science modules (Yao, 2023).

## Conclusion

The feasibility and effectiveness tests confirm that Chemvilative is a viable and impactful tool for teaching buffer solutions, particularly in resource-constrained settings. Its integration of interactive simulations and accessible design significantly enhanced students' conceptual understanding, outperforming traditional methods by 15% in post-test assessments. These results resonate with existing literature on virtual laboratories, which emphasize the role of visualization and interactivity in overcoming practical barriers in STEM education. For teachers, Chemvilative provides a flexible, low-cost solution to deliver hands-on learning experiences, enabling them to focus on conceptual depth rather than logistical constraints. For educational technology developers, this study underscores the importance of aligning digital tools with curriculum-specific needs and user-centered design principles. The findings also advocate for broader adoption of virtual labs in national education policies to democratize access to quality chemistry education. Future research should explore Chemvilative's adaptability to other abstract topics (e.g., acid-base equilibria, electrochemistry) and investigate its long-term impact on student performance and motivation across diverse demographic and institutional contexts.

**Acknowledgments**
The authors sincerely thank [Institution/University Name] for their support and resources. We also appreciate the valuable feedback from colleagues and the contributions of all participants involved in this study. Lastly, we extend our gratitude to our families and friends for their encouragement.

**Author Contributions**
All contribution, including conceptualization, methodology, software, formal analysis, investigation, resources, data

curation, writing—original draft preparation, writing—review and editing, and visualization, were carried out by E.R. Validation and supervision, were provided by S.Y. and D. All authors have read and agreed to the published version of the manuscript.

**Funding**

This research was conducted without any external funding.

**Conflicts of Interest**

The authors confirm that there are no conflicts of interest associated with this study.

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