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CHEMLIT: Development and Feasibility of a Sensor-Based Chemistry Practicum Tool for Electrolyte Solutions

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Abstract

Chemistry learning requires the integration of macroscopic, submicroscopic, and symbolic representations. However, limited availability of practicum tools in senior high schools often hinders students' comprehensive understanding of chemical concepts, particularly in electrolyte and nonelectrolyte solutions. This study aimed to develop and implement CHEMLIT, a sensor-based chemistry practicum tool designed to support learning on solution electrical conductivity. The study employed a Research and Development (R&D) approach using the ADDIE model, consisting of analysis, design, development, implementation, and evaluation stages. Needs analysis was conducted through classroom observations and teacher interviews, followed by prototype design, assembly, calibration, and functional testing to ensure stability and safety. The implementation involved two senior high schools in the Minahasa region, with chemistry teachers serving as reviewers and students as trial users. Feasibility was evaluated by media experts, material experts, teachers, and students using five-point Likert-scale questionnaires, and the data were analyzed by converting scores into percentage-based feasibility criteria. Product feasibility was evaluated through validation by media experts, subject matter experts, chemistry teachers, and students using questionnaire instruments. The validation results indicated a very high level of feasibility, with scores of 91.7% from media experts, 96% from material experts, 92% from teachers, and student responses exceeding 93.99%, categorized as very good. These findings indicate that CHEMLIT meets technical, visual, and content feasibility standards and can serve as an alternative practicum tool for teaching electrolyte and non-electrolyte solutions, especially in schools with limited laboratory facilities. Its novelty lies in a portable sensor-based design that integrates quantitative conductivity measurement into conventional testing without complex digital systems.

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INTRODUCTION

Chemistry is a science that studies matter down to the atomic and molecular levels and involves three main representations in learning: macroscopic, submicroscopic, and symbolic (Wildan et al., 2023). These representations must be interconnected so that students not only understand observable phenomena but are also able to explain particle processes and chemical symbols. However, many students still experience difficulties in linking these three representations, particularly at the submicroscopic level. Safitri et al. (2019) reported that only 21.92% of students were able to successfully connect all representations, while 37.56% failed to understand any of them comprehensively.

One chemistry topic that strongly requires the integration of the three levels of representation is electrolyte and non-electrolyte solutions. Understanding the brightness of a lamp as an indicator of electrical conductivity (macroscopic), ion movement in solution (submicroscopic), and ionization reactions expressed in chemical equations (symbolic) must be integrated to prevent misconceptions. Research by Santi and Rahayu (2022) showed that out of 64 students, 28.45% experienced misconceptions in macroscopic–submicroscopic relationships, 22.20% in symbolic–submicroscopic relationships, and 20.85% in macroscopic–symbolic relationships. Meanwhile, Ishak et al. (2022) found that students' overall level of understanding reached only 53.44% (low category), with macroscopic understanding at 64% (moderate), symbolic at 58% (low), and submicroscopic at 39% (very low). These findings confirm that submicroscopic representation remains the greatest challenge in learning electrolyte concepts. Similar conclusions have been reported in international studies, which highlight that difficulties in representational integration are a persistent issue in chemistry education and require instructional support that goes beyond verbal explanation alone (Trivic & Milanovic, 2018). Therefore, chemistry learning requires appropriate instructional media that can help visualize complex concepts, enhance students' understanding, and make the learning process more engaging and comprehensive, thereby increasing students' motivation to learn (Assa & Gugule, 2025).

To address difficulties in understanding chemical concepts, teachers commonly employ laboratory practicum activities because they effectively develop students' observation, classification, experimentation, and scientific communication skills (Mutakinati et al., 2025). However, the implementation of practicum activities in senior high schools is often constrained by limited laboratory equipment, particularly for topics such as electrolyte and non-electrolyte solutions that require an understanding of the relationship between electrical phenomena and ionic processes (Sardjono, 2024). Conventional electrolyte testing tools generally provide only simple qualitative indications, offering limited opportunities for systematic observation and conceptual analysis (Mutakinati et al., 2025). This condition highlights the need for more representative and functional physical practicum tools that can support structured practicum activities and facilitate deeper conceptual engagement without relying on complex laboratory infrastructure (Kurniawan et al., 2025).

In response to this need, CHEMLIT was developed as a sensor-based physical chemistry practicum tool designed to support learning on electrolyte and non-electrolyte solutions. CHEMLIT facilitates more objective and systematic observation of electrical conductivity phenomena by enabling students to obtain measurable data during practicum activities (Olympiou & Zacharia, 2021). The design emphasizes portability, ease of operation, and suitability for repeated use in school laboratory settings, allowing practicum activities to be conducted more efficiently and consistently. Through the use of direct measurement data and visual indicators, CHEMLIT supports students in observing, recording, and interpreting experimental results, thereby assisting the connection between macroscopic observations and conceptual understanding during practicum-based chemistry learning.

This study aims to describe the design, development, and validation process of CHEMLIT as a chemistry learning media, as well as to evaluate its technical and pedagogical feasibility in teaching electrolyte and non-electrolyte solutions at the senior high school level. The research employed a Research and Development (R&D) approach, which is defined as a systematic method used to develop educational products and test their effectiveness (Sugiyono, 2019). The development process followed the ADDIE model, consisting of analysis, design, development, implementation, and evaluation stages (Branch, 2009). The research subjects involved senior high school students from SMA Negeri 1 Kawangkoan and SMA Negeri 1 Tomohon, with chemistry teachers acting as material reviewers. Data were collected using primary data obtained through questionnaire instruments, administered to media experts, material experts, chemistry teachers, and students, as questionnaires are considered effective tools for collecting structured responses in educational research (Sugiyono, 2019).

Despite the recognized importance of laboratory-based learning in chemistry education, many senior high schools face limitations in laboratory equipment that hinder effective practicum implementation, particularly for topics such as electrolyte and non-electrolyte solutions. Conventional practicum tools generally provide only qualitative observations and lack measurable data, which restricts students' opportunities to conduct systematic analysis and develop deeper conceptual understanding. In addition, although Likert-scale instruments are widely used to evaluate educational products (Sugiyono, 2019), there remains a need for validated and reliable instruments capable of assessing technical, pedagogical, and usability aspects of newly developed practicum tools. Therefore, the central problem addressed in this study is the lack of representative, feasible, and systematically evaluated practicum media that can support meaningful chemistry learning, along with the need for appropriate feasibility assessment procedures (Arikunto, 2021). The results indicate that CHEMLIT demonstrates high technical reliability, ease of operation, and stability during practicum activities, making it suitable for repeated use in school laboratory settings. Furthermore, CHEMLIT effectively supports students' understanding of electrical conductivity concepts through direct observation and data-based analysis, thereby facilitating the integration of macroscopic, submicroscopic, and symbolic representations in chemistry learning.

METHOD

Figure 1. The Diagram of ADDIE Development Model

This study employed a research and development approach as proposed by Sugiyono (2019), which defines research and development as a method used to produce a specific product and to test its effectiveness. The product developed in this study is CHEMLIT, a sensor-based chemistry practicum tool designed to support the teaching and learning of electrolyte and non-electrolyte solutions at the senior high school.

The development model used is ADDIE, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. This model was chosen because it provides a systematic and structured workflow, making it suitable for developing technology-based educational media or products (Satria & Sutabri, 2025).

Research Procedure

Analysis

The analysis stage consisted of performance analysis and needs analysis. Performance analysis was conducted to identify problems in chemistry learning at schools, particularly related to the limited availability of practicum facilities and equipment. The results of observations and interviews with teachers and students indicated that chemistry practicum activities were still conventional and had not optimally supported students in connecting chemical representations, especially at the submicroscopic level.

Needs analysis was carried out to determine the characteristics of a practicum tool that align with school conditions and students' learning needs. The findings revealed the necessity for a practicum tool that is portable, safe, easy to operate, and capable of presenting measurable chemical phenomena. Based on these findings, the CHEMLIT sensor-based chemistry practicum tool was developed.

Design

At the design stage, the physical structure, working system, and electronic circuit of the CHEMLIT tool were planned.

Figure 2. Design of the CHEMLIT Practicum Tool

The circuit design consisted of several main components, including a Type-C charging module, a rechargeable lithium battery, a digital voltmeter, an ON/OFF switch, an indicator lamp, a jack adapter, and a battery level indicator.

CHEMLIT features a portable design measuring 25 cm × 10 cm × 15 cm, with a main frame constructed from PVC pipes that are lightweight, strong, and durable. The outer panel is covered with transparent acrylic, allowing internal components to be visible and easily studied by students. The overall weight of the device is approximately 0.5 kg, making it easy to transport and use in regular classrooms without the need for laboratory benches.

Development

The development stage involved the realization of the approved design into a functional CHEMLIT practicum tool. This process included assembling all hardware components at the Integrated Laboratory of Universitas Negeri Manado. The assembly covered the installation of the power supply system, the digital voltmeter sensor for measuring the electrical conductivity of solutions, and indicator lamps as visual output components.

Following assembly, an initial functional test was conducted to ensure that each component operated properly and safely. The testing focused on circuit stability, sensor responsiveness to electrolyte and non-electrolyte solutions, and clarity of the indicator output. This stage resulted in a fully functional CHEMLIT tool ready for feasibility testing and classroom implementation.

Implementation

The implementation stage aimed to examine the practicality and effectiveness of the CHEMLIT tool in chemistry learning. Field trials involved evaluations by media experts, material experts, and chemistry teachers who served as material reviewers at the implementation schools, namely SMA Negeri 1 Tomohon and SMA Negeri 1 Kawangkoan. Prior to the practicum activities, teachers and students received brief instructions on the operational procedures of the tool.

During the practicum sessions, students used CHEMLIT to observe the electrical conductivity of electrolyte and non-electrolyte solutions, record experimental data, and discuss the observed results. Implementation data were collected through observations, questionnaires, and interviews to evaluate the practicality, ease of use, and effectiveness of the tool in supporting conceptual understanding.

Evaluation

The evaluation stage was conducted to assess the feasibility, practicality, and effectiveness of the CHEMLIT tool as a chemistry practicum device. Both formative and summative evaluations were applied. Formative evaluation took place throughout the development process to ensure proper functionality of the tool. Expert validation was also conducted by chemistry education specialists to assess conceptual accuracy, instructional relevance, and usability.

Summative evaluation was carried out after the completion of field trials. Data were obtained through questionnaires, direct observations, and interviews with teachers and students. The results indicated that CHEMLIT demonstrated a high level of feasibility, was easy to use, and effectively supported students' understanding of electrolyte and non-electrolyte solution concepts. These findings served as the basis for final product refinement prior to broader implementation.

Data Analysis

The validation process involved two expert validators, consisting of one media expert and one material expert, who evaluated the CHEMLIT chemistry practicum tool according to their respective areas of expertise. The media validation instrument was administered to the media expert to assess the technical and design aspects of the product. The grid of media validation indicators is presented in Table 1. In addition to expert validation, practicality and user-response data were collected from chemistry teachers and students during field trials. The material validation instrument was given to material experts to assess the content contained in CHEMLIT in order to evaluate the suitability of the learning material embedded in the tool. Table 2 presents the grid of material assessment instruments used by material experts.

Table 1. Grid of Media Validation Instruments by Media Experts

Aspects	Indicators
Physical Appearance of the Simple Distillation Teaching Aid	1. Overall, is the shape and design of the CHEMLIT practicum tool attractive? 2. Is the tool comfortable for students to hold and use (not too heavy and easy to handle)? 3. Does the tool appear sturdy and durable for use in a senior high school laboratory?
Functionality of Technological Features	4. Do the integrated sensors in CHEMLIT function properly during practicum activities? 5. Does the digital voltmeter display measurement results clearly and accurately? 6. Do the indicator lights respond appropriately to changes in electrical conductivity of the solution? 7. Is the battery capacity sufficient to support several practicum sessions without frequent recharging? 8. Does the device operate stably without interruptions during continuous use?
Level of Practicum Design Implementation	9. Can teachers easily implement chemistry practicum activities using CHEMLIT based on the provided guidelines? 10. Can students follow the practicum procedures and operate CHEMLIT with ease? 11. Does CHEMLIT allow for variations in practicum methods, such as teacher demonstrations, group-based experiments, or independent learning?
Safety Aspects	12. Is the use of CHEMLIT hardware physically safe for teachers and students (e.g., no sharp components, risk of electric shock, or fragile parts)? 13. Is the device safe to use for repeated practicum sessions in a school laboratory environment?
Usability Aspects	14. Can teachers operate CHEMLIT easily after reading a brief user guide? 15. Are the buttons, indicators, and overall interface intuitive, allowing users to quickly understand and use the tool?
Learning Design Aspect	**Already Entirely Appropriate**

Source: Walker and Hess (as cited in Arsyad, 2017)

Table 2. Grid of Material Validation Instruments by Material Experts

Aspects	Indicators
Alignment with the Principles of the Merdeka Curriculum	1. Does the tool facilitate differentiated learning by providing various learning modalities (visual, kinesthetic through sensors, and auditory) to accommodate diverse student learning needs? 2. Can the tool be used as part of Project-Based Learning (PjBL) or Problem-Based Learning to foster students' inquiry and problem-solving skills? 3. Can the tool be used as part of Project-Based Learning (PjBL) or Problem-Based Learning to foster students' inquiry and problem-solving skills? 4. Does the use of the tool support the development of the Pancasila Student Profile dimensions, particularly collaboration (working together during experiments) and global awareness (through access to advanced technology)? 5. Does the AI-assisted virtual learning environment provide personalized feedback (assessment for learning) to support teachers in conducting formative assessment? 6. Does the tool create opportunities for teachers to design innovative, contextual, and student-centered learning experiences in accordance with the philosophy of the Merdeka Curriculum? 7. Does the practicum using this tool not only achieve conceptual learning objectives but also develop 21st-century skills (4C: Critical Thinking, Creativity, Collaboration, and Communication) and students' digital literacy?

Aspects	Indicators
Technopedagogical Aspects (Integration of Technology, Pedagogy, and Content Knowledge)	8. How well are technological features (sensors and digital visualization) integrated with pedagogical strategies to achieve deep understanding of chemistry concepts?
	9. Is the interface of the tool and its supporting application user-friendly for both teachers and students, without hindering the learning process?
	10. Does the technology truly enrich the learning experience rather than merely serving as a "gimmick" or entertainment?
Pedagogical and Classroom Implementation Aspects	11. Can the tool replace or complement conventional experiments (e.g., lamp brightness and gas bubble tests) by providing more quantitative and objective data?
	12. Does the tool support the implementation of innovative learning models such as Problem-Based Learning or inquiry-based learning in teaching electrolyte concepts (e.g., investigating why seawater conducts electricity while pure water does not)?
Conceptual Understanding Aspects	13. Does the use of this practicum tool help students understand the chemistry concepts being taught?
	14. Does the tool help students develop a clear causal understanding between ion concentration in solution and electrical conductivity?
	15. How effectively does the tool differentiate students' understanding of strong electrolytes, weak electrolytes, and non-electrolytes at the macroscopic (lamp brightness), submicroscopic (ion behavior), and symbolic (ionization equations) levels?
	16. Is the conceptual understanding gained through the use of this tool retained over the long term compared to conventional practicum methods?

Source: Walker and Hess (as cited in Arsyad, 2017)

To determine the scores given by media experts, material experts, teachers, and students to the CHEMLIT chemistry practicum tool, media assessment criteria are required. All instruments used a five-point Likert scale to ensure consistency in scoring and interpretation. The assessment scale is presented in Table 3.

Table 3. Likert Scale Assessment Criteria

Score	Criteria
1	Very inappropriate
2	Inappropriate
3	Moderately appropriate
4	Appropriate
5	Very appropriate

Source: (Sugiyono, 2022)

After the media validator, material validator, teacher, and students give scores on the validation sheet and questionnaire instrument, the next step is to calculate the score using a Likert scale pattern then proceed to calculate the percentage value of each based on the score that has been given using the formula. Media eligibility criteria according to Arikunto can be seen in Table 4.

$$Percentage\ of\ Feasibility\ (\%) = \frac{Score\ obtained}{Maximum\ scroe} \times 100\%$$

Table 4. Media Feasibility Criteria

No	Score in Precent (%)	Eligibility Categories
1	<21%	Very Unworthy
2	21-40%	Not Eligible
3	41-60%	Quite Decent
4	61-80%	Proper
5	81-100%	Highly Eligible

Source: (Arikunto, 2021)

RESULTS AND DISCUSSION

CHEMLIT is a sensor-based chemistry practicum tool that has been developed and declared feasible for use in learning electrolyte and non-electrolyte solutions at the senior high school level. In general, CHEMLIT features a simple, functional, and ergonomic physical design that supports ease of use during practicum activities. The design allows students and teachers to directly observe the electrical conductivity of solutions through clearly displayed visual indicators and quantitative data.

Description of the Physical Appearance of the Tool

Front View

The front view of CHEMLIT displays a digital indicator screen and LED lights that function to show the level of electrical conductivity of the solution. The information presented is both quantitative and visual, making it easier for users to directly observe differences in the characteristics of electrolyte and non-electrolyte solutions.

Figure 2. Front View of The CHEMLIT Chemistry Practicum Tool

Side View

The side view of CHEMLIT shows the rechargeable battery charging port and the ON/OFF button used to operate the tool. The placement of these components is designed to be easily accessible and safe for students during practicum activities.

Figure 3. Side View of The CHEMLIT Chemistry Practicum Tool

Charging Port and Control Button

This section presents a detailed view of the rechargeable battery charging port and the ON/OFF button as the main control system of the tool. The presence of these features supports efficient use and allows CHEMLIT to be used repeatedly across multiple practicum sessions.

Figure 4. Rechargeable Battery Charging Port and On/Off Button of CHEMLIT

Scoring Procedure and Feasibility Criteria

The feasibility of CHEMLIT was evaluated using Likert-scale questionnaires with a score range of 1–5, where 1 represents *very poor* and 5 represents *very good*. Each assessment aspect consisted of several indicators evaluated by media experts, material experts, chemistry teachers as reviewers, and students. The total score obtained for each aspect was divided by the maximum possible score and then converted into a percentage value. These percentage values were subsequently interpreted using the feasibility criteria presented in Table 4, which classify the product into categories ranging from *Very Unworthy* to *Highly Eligible*.

This scoring procedure was applied consistently across all evaluation stages, including expert validation, teacher review, and student response trials. Therefore, a clear methodological relationship exists between the scoring process and the feasibility categorization, ensuring transparency and consistency in data interpretation.

Media Expert and Material Expert Evaluation

Table 5. Media expert validation results of the CHEMLIT practicum tool

No	Assessment Aspect	%	Category
1	Physical Appearance of the Simple Distillation Teaching Aid	86.6%	Highly Eligible
2	Functionality of Technological Features	90%	Highly Eligible
3	Level of Practicum Design Implementation	100%	Highly Eligible
4	Safety Aspects	90%	Highly Eligible
5	Usability Aspects	90%	Highly Eligible
	Total	**91.7%**	**Highly Eligible**

Based on the media expert evaluation results presented in Table 5, CHEMLIT obtained an overall feasibility score of 91.7%, categorized as Highly Eligible. High scores across aspects of physical appearance, technological functionality, practicum design, safety, and usability indicate that the device meets technical standards for educational laboratory media (Seery, 2020).

Conceptually, this strength is significant because the quality of practicum media is determined not only by technical feasibility but also by its capacity to support scientific knowledge construction. The voltage sensor and visual indicators in CHEMLIT enable students to observe conductivity phenomena systematically, allowing macroscopic observations to extend beyond simple visual perception toward data-based interpretation (Kapici, 2023). This approach aligns with chemical representation theory emphasizing integration between observable phenomena and conceptual scientific models.

Furthermore, the availability of quantitative data provides a stronger basis for symbolic discussion. Conductivity values displayed by the tool can be linked to ionization equations, enabling students not only to recognize that a solution conducts electricity but also to understand the underlying scientific explanation at the particle level. Thus, CHEMLIT has the potential to facilitate cognitive transitions from macroscopic representation to symbolic representation through measurable empirical evidence.

Table 6. Material expert validation results of the CHEMLIT practicum tool

No	Assessment Aspect	%	Category
1	Alignment with the Principles of the Merdeka Curriculum	93.3%	Highly Eligible
2	Technopedagogical Aspects (Integration of Technology, Pedagogy, and Content Knowledge)	93.3%	Highly Eligible
3	Pedagogical and Classroom Implementation Aspects	100%	Highly Eligible
4	Conceptual Understanding Aspects	100%	Highly Eligible
	Total	**96%**	**Highly Eligible**

Material expert validation results summarized in Table 6 show an overall feasibility score of 96%, categorized as Highly Eligible. High ratings in curriculum alignment, technopedagogical integration, instructional implementation, and conceptual relevance indicate that the content embedded in CHEMLIT is scientifically accurate and appropriate for senior high school chemistry learning. The integration of digital tools with pedagogical strategies has been widely recognized as improving conceptual understanding and learning engagement in chemistry education (Salame & Thompson, 2020).

High scores in pedagogical and conceptual understanding aspects suggest that CHEMLIT is perceived as capable of supporting practicum-based learning emphasizing interconnection among representations. Chemistry learning requires students to connect macroscopic observations, submicroscopic particle processes, and symbolic representations, which is often challenging for learners (Talanquer, 2022). In electrolyte concepts, students' learning difficulties commonly arise because they cannot relate lamp brightness phenomena to ionization processes at the particle level and symbolic chemical expressions. Previous studies show that students frequently struggle to interpret electrolyte behavior due to weak representational competence and limited visualization of ionic processes (Permatasari et al., 2022).

CHEMLIT helps bridge this gap by providing measurable data that teachers can use to guide conceptual discussion. The use of technology-supported laboratory tools has been shown to enhance students' ability to construct relationships between experimental observations and theoretical explanations (Salame & Thompson, 2020). This indicates that the tool functions not merely as an experimental device but as a conceptual mediator that allows students to construct scientific mental models progressively. In other words, the device acts as a cognitive bridge between observational experience and abstract reasoning, supporting meaningful learning through guided conceptual change (Talanquer, 2022).

Material Review Assessment

The material expert evaluation stage was conducted to assess the feasibility of the instructional content contained in the CHEMLIT learning media, particularly on the topic of electrolyte and non-electrolyte solutions. This evaluation involved chemistry teachers from two senior high schools, SMA Negeri 1 Kawangkoan and SMA Negeri 1 Tomohon, who served as material reviewers. The purpose of this evaluation was to determine the extent to which the developed media aligned with the curriculum, ensured scientific accuracy, presented appropriate depth and clarity of content, and supported its implementation in classroom chemistry learning (Salame & Thompson, 2020; Widarti et al., 2019).

Based on the review results, both participating schools obtained an average feasibility score of 92%. These results fall within the Highly Eligible category, indicating that the CHEMLIT learning media is considered effective, relevant, and highly acceptable for supporting chemistry learning at the senior high school level.

Table 7. Material Expert Review Results by SMA Negeri 1 Tomohon

No	Assessment Aspect	%	Category
1	Alignment with the Principles of the Merdeka Curriculum	100%	Highly Eligible
2	Technopedagogical Aspects (Integration of Technology, Pedagogy, and Content Knowledge)	80%	Highly Eligible
3	Pedagogical and Classroom Implementation Aspects	90%	Highly Eligible
4	Conceptual Understanding Aspects	90%	Highly Eligible
	Total	**92%**	**Highly Eligible**

Table 8. Material Expert Review Results by SMA Negeri 1 Kawangkoan

No	Assessment Aspect	%	Category
1	Alignment with the Principles of the Merdeka Curriculum	90%	Highly Eligible
2	Technopedagogical Aspects (Integration of Technology, Pedagogy, and Content Knowledge)	86.6%	Highly Eligible
3	Pedagogical and Classroom Implementation Aspects	100%	Highly Eligible
4	Conceptual Understanding Aspects	95%	Highly Eligible
	Total	**92%**	**Highly Eligible**

Overall, the material expert evaluation results indicate that the CHEMLIT learning media achieved an overall average feasibility score of 92%, classified as Highly Eligible. These findings demonstrate that CHEMLIT meets feasibility criteria in terms of content quality, curriculum alignment, and effectiveness of implementation in chemistry learning. Therefore, CHEMLIT is deemed highly suitable for use as an innovative learning medium that supports students' conceptual understanding and the integration of technology in senior high school chemistry education (Tima & Sutrisno, 2018; Rahmanian et al., 2023).

Subject Trial Results

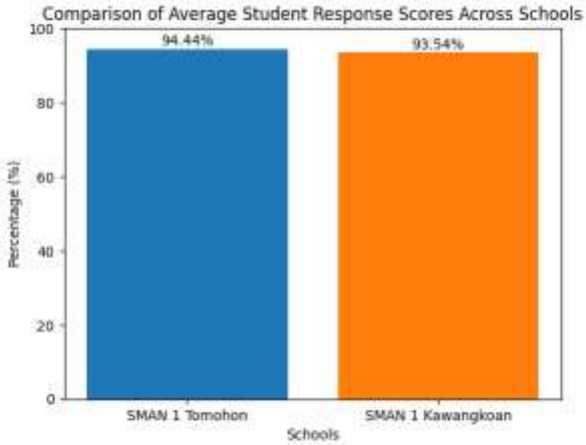

Figure 5. Comparison of Average Student Response Scores Across Schools

Student response trials showed average scores of 94.44% and 93.54% at the two schools, both categorized as Highly Eligible. These findings indicate that students perceived CHEMLIT as easy to use, engaging, and helpful during practicum activities.

High scores in pedagogical and conceptual understanding aspects suggest that CHEMLIT is perceived as capable of supporting practicum-based learning emphasizing interconnection among representations. In electrolyte concepts, students' learning difficulties commonly arise because they cannot relate lamp brightness phenomena to ionization processes at the particle level and symbolic chemical expressions (Santi & Rahayu, 2022). Beyond local context, international research likewise highlights that students frequently struggle to integrate macroscopic, submicroscopic, and symbolic representations, and that targeted instructional tools can help mitigate these challenges by making invisible processes more accessible (Ye et al., 2019; Ferreira & Lawrie, 2019). Specifically, Ye *et al.* (2019) found that the use of sensor-supported laboratory data facilitated students' translation between observable phenomena and underlying particle interactions in ionic reactions, which supports the idea that quantitative data can strengthen conceptual discussions.

CHEMLIT helps bridge this gap by providing measurable data that teachers can use to guide conceptual discussion. This indicates that the tool functions not merely as an experimental device but as a conceptual mediator that allows students to construct scientific mental models progressively. In other words, the device acts as a cognitive bridge between observational experience and abstract reasoning, aligning with educational research that emphasizes the importance of representational coherence and sensemaking in science learning (Moju, 2025).

CONCLUSION

This study developed CHEMLIT, a sensor-based chemistry practicum tool designed to support the learning of electrolyte and non-electrolyte solutions at the senior high school level through a systematic Research and Development process based on the ADDIE model. The findings demonstrate that CHEMLIT fulfills essential feasibility requirements in terms of technical performance, usability, safety, and instructional relevance, as evidenced by consistently positive evaluations from experts, teachers, and students. These results indicate that the developed tool is considered appropriate and practical for classroom implementation as a supporting medium for practicum-based chemistry learning.

Student responses suggest that the use of CHEMLIT was perceived to facilitate observation, interpretation, and discussion of electrical conductivity phenomena during laboratory activities. This indicates that sensor-supported practicum tools may function not only as instructional media but also as representational bridges that assist learners in connecting observable macroscopic phenomena with underlying submicroscopic processes and symbolic representations. Such a role is particularly important in chemistry learning, where conceptual understanding depends on the integration of multiple levels of representation.

The novelty of this study lies in the development of a portable physical practicum tool that integrates quantitative conductivity measurement into conventional electrolyte testing without requiring complex digital laboratory infrastructure. This design demonstrates how simple sensor technology can be systematically incorporated into school laboratory learning to support more structured observation and data-based reasoning.

This study has several limitations. The research focused on feasibility and user responses rather than direct measurement of learning outcomes, and field trials were limited to two schools. Therefore, further research is recommended to examine instructional effectiveness through experimental or quasi-experimental designs involving larger samples and objective assessments of conceptual understanding. Despite these limitations, the study contributes to chemistry education research by providing an empirically validated prototype that illustrates the potential of accessible sensor-based laboratory tools to enhance practicum design and support meaningful concept construction in secondary-level chemistry learning.

RECOMMENDATION

Future studies should increase the number of samples and experimental repetitions for each variation of solution concentration and electrode cross-sectional area to enhance measurement reliability and statistical robustness. More extensive data collection would reduce potential experimental bias and provide stronger empirical evidence regarding the observed conductivity patterns.

Further research is also recommended to evaluate the instructional effectiveness of CHEMLIT through controlled experimental or quasi-experimental designs involving larger and more diverse participant groups. In addition, future development may focus on improving sensor precision and extending the range of measurable parameters to strengthen the tool's functionality and applicability in chemistry practicum settings.

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