

Dissemination of System Differential Learning Integrated Interactive Digital Modules Physics for Enhancing Scientific Inquiry Literacy

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Abstract

ABSTRACT

The dissemination aims to improve Scientific Inquiry Literacy (SIL) Among Teachers through the dissemination and implementation of System Differential Learning (SIDILAN) and Interactive Digital Module Physics (IDMP). Dissemination is a collaboration between the Physics Learning Physics Media Development Expertise Group, Physics Education Department, Jakarta State University (UNJ), and Kolej Dato' Onn Jaafar (KDOJ) Universiti Teknologi Malaysia, Malaysia. ICS is driven by the desire to implement research products developed by its team, funded by a prestigious research grant awarded by UNJ and DIKTI in 2024. The IDMP product URL: <https://sites.google.com/view/learnnglobalwarming101?usp=sharing> and SIDILAN <https://phylament.serral.org/>. Universiti Teknologi Malaysia, Malaysia, contributed to the collaboration to develop Laboratory Environments for Inquiry Skills and served as a speaker to strengthen future cooperation in the field of dissemination. The program targets Science teachers from Indonesia and Malaysia. The of study of method Through experimental methods with 35 teachers in Jakarta, Indonesia aged 28-45 years as participants, data were collected through the SIL pretest-posttest and implementation observations. The results showed an adoption rate of 86% of the IDMP, with 75% of teachers successfully integrating it into their lesson plans. The implementation of SIDILANM and IDMP to a significant improvement in teachers' scientific inquiry literacy, with N-Gain scores of 26%, 24%, and 21% in designing investigations, guiding inquiry, and evaluating scientific processes, respectively. The findings of this study indicate that the SIDILAN and IDMP for enhance SIL with immersive learning by providing interactive simulation. To encourage continuous practice and collaboration among teachers, future development should incorporate collaborative tools, including discussion forums and shared repositories for experimental data.

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INTRODUCTION

Background

Scientific inquiry literacy is an essential competency for science teachers in designing investigations, guiding inquiry processes, and evaluating scientific evidence (Diego et al., 2023;

Morris, 2025). This competency supports physics instruction that extends beyond conceptual mastery by training students to observe phenomena, formulate problems, analyze data, and construct evidence-based conclusions (Susilawati & Dari, 2026; Septyowaty et al., 2023). However, differences in teachers' competencies, limited access to technology, inadequate interactive media, and restricted experimental facilities continue to hinder the optimal implementation of inquiry-based learning (Rusdiyana et al., 2024).

The integration of System Differential Learning (SIDILAN) and the Interactive Digital Module Physics (IDMP) was developed to address these needs. SIDILAN supports learning that accommodates differences in users' learning needs, while IDMP provides physics content, interactive simulations, and digital inquiry activities. Their integration enables teachers to conduct variable exploration, observe physical phenomena, analyze data, and evaluate scientific processes in a more structured manner.

Educational products require systematic dissemination to support broad and sustainable implementation (Sliwka et al., 2023; Ivaldi et al., 2022; Cascone et al., 2024). This program was implemented through collaboration between Universitas Negeri Jakarta and Kolej Dato' Onn Jaafar, Universiti Teknologi Malaysia, involving science teachers from Indonesia and Malaysia. Accordingly, this study aims to analyze the implementation of SIDILAN and IDMP in improving teachers' abilities to design investigations, guide inquiry, and evaluate scientific processes.

Importance of Scientific Inquiry Literacy (SIL) in Physics Education

Scientific Inquiry Literacy helps teachers and students understand that scientific knowledge is constructed through a systematic process of investigation (Pols et al., 2022; Shintya et al., 2025). This competency includes the ability to formulate problems, develop hypotheses, identify variables, design experiments, analyze data, and draw evidence-based conclusions (AM et al., 2025). Therefore, physics learning should focus not only on mastering formulas but also on understanding scientific processes.

Many physics concepts are abstract and require experimentation and visualization for accurate understanding. Teachers with strong SIL can connect theoretical concepts to real-world phenomena and guide students in examining relationships among variables (Machado & Nahar, 2023; Walker & Nouri, 2025). SIL also supports critical thinking, problem-solving, and data-based decision-making skills (Kotsis et al., 2025; Orosz et al., 2022). Improving teachers' SIL requires learning media and instructional systems that directly support investigative activities. SIDILAN and IDMP can facilitate differentiated learning, interactive simulations, and structured inquiry activities. Their integration is expected to strengthen the quality of inquiry-based physics instruction.

Challenges in Enhancing SIL Among Science Teachers

Efforts to improve SIL remain constrained by teaching practices that predominantly emphasize content delivery (Twizeyimana et al., 2024). Some teachers are not yet accustomed to designing activities that involve problem formulation, hypothesis testing, data analysis, and evaluation of scientific evidence (Chengere et al., 2025). This condition limits the comprehensive implementation of scientific inquiry. Limited laboratory facilities and interactive learning resources also hinder the implementation of investigative activities (Shivolo et al., 2024). Many physics concepts require experiments or visual representations to be understood contextually. Without adequate media, teachers face difficulties in developing systematic inquiry experiences. Other challenges concern digital competence and the pedagogical integration of technology. The ability to operate digital devices does not necessarily indicate the ability to use them effectively to support inquiry objectives, activities, and assessments (Parrales-Bravo et al., 2026). Therefore, improving SIL requires continuous training, mentoring, and professional collaboration among teachers.

Purpose and Scope of the Dissemination Program

This dissemination program aims to introduce and implement System Differential Learning (SIDILAN) integrated with the Interactive Digital Module Physics (IDMP). The program focuses on improving teachers' Scientific Inquiry Literacy through learning experiences involving simulations, investigations, and evaluation of scientific processes. It is also designed to promote the application of research-based educational products in physics teaching practices.

The scope of the program includes socialization, training in the use of SIDILAN and IDMP, and assistance in integrating both tools into lesson plans. The evaluation focuses on teachers' abilities to design investigations, guide inquiry, and evaluate scientific processes. The adoption rate of the products and their successful integration into instructional planning are also included as indicators of program implementation.

LITERATURE REVIEW

System Differential Learning (SIDILAN) Concept and Applications

System Differential Learning (SIDILAN) is a digital learning system developed to identify differences in students' characteristics and learning needs. The system assesses users' learning-style tendencies, learning habits, interests, and personal characteristics as a basis for generating instructional recommendations. This approach is intended to help teachers design more adaptive and inclusive learning experiences. SIDILAN identifies learning characteristics through online instruments integrated with a physics learning media platform. The resulting profiles can assist teachers in selecting instructional methods, media, and learning activities that correspond to students' needs. Its supporting platform also provides modules, simulations, animations, videos, educational games, and digital laboratory activities. In science education, SIDILAN can be used to design inquiry activities that accommodate differences in students' abilities and learning preferences. In this dissemination program, SIDILAN was integrated with the Interactive Digital Module Physics to support investigation, phenomenon exploration, and scientific data analysis.

Interactive Digital Module Physics (IDMP) in Science Education

The Interactive Digital Module Physics (IDMP) is a digital learning module that integrates physics content, visualizations, interactive simulations, and inquiry activities. The module helps users understand abstract concepts through the exploration of phenomena and relationships among variables. Consequently, physics learning can become more active and more closely oriented toward scientific processes. In science education, IDMP can support problem formulation, experimental simulation, data collection, and evaluation of investigation results. Its interactive features allow teachers and students to test concepts without relying entirely on physical laboratory facilities. The module can also be adapted for independent learning or teacher-guided classroom activities.

Previous Studies on SIL Improvement Through Digital and Experimental Methods

Previous studies indicate that digital technology can support the development of competencies related to Scientific Inquiry Literacy. Mobile Game-Based Inquiry Learning in Science modules have been shown to improve pre-service teachers' ability to integrate technology, pedagogy, and inquiry-based learning (Galimova et al., 2025; Pondee et al., 2021). However, these studies focused on improving TPACK and did not directly measure SIL.

Virtual laboratories can also help users understand experimental procedures, conduct measurements, and analyze data. Virtual reality-based learning has produced better outcomes

than conventional laboratory learning in simple physics experiment procedures (Lakka et al., 2023). Virtual laboratories can also broaden access to practical activities through simulations integrated into digital learning environments (Sanzana et al., 2024).

Nevertheless, physical experiments remain important for developing investigation and measurement skills. Physical laboratories have shown more consistent skill improvement than virtual laboratories in electronic circuit learning (Tokatlidis et al., 2024). These findings suggest that SIL improvement should integrate digital technology, experimental activities, and structured pedagogical guidance.

Collaborative Dissemination Efforts in Teacher Professional Development

Collaborative dissemination positions teachers as active participants in professional development. Teachers can share experiences, reflect on their practices, and jointly design instructional strategies. Participation in professional learning communities is associated with improvements in teachers' self-efficacy, job satisfaction, and instructional clarity (Christensen et al., 2025). Digital platforms expand professional collaboration beyond school and regional boundaries. The quality of interaction in online professional learning is associated with teachers' self-efficacy and learning achievement (Wang et al., 2023). Virtual communities of practice can also strengthen teacher agency and leadership through sustained professional interaction (Shal et al., 2024).

METHOD

Research Design: Experimental Approach

This study employed an experimental approach to examine changes in teachers' Scientific Inquiry Literacy (SIL) after participating in the dissemination and implementation of System Differential Learning (SIDILAN) integrated with the Interactive Digital Module Physics (IDMP). The research design involved measurements conducted before and after the intervention within the same group of participants. Initial measurement was conducted using the SIL pretest, while the final measurement was conducted using the SIL posttest.

The intervention consisted of dissemination, training, and implementation of SIDILAN-IDMP in the context of science education. During the program, participants received explanations regarding the use of SIDILAN, the operation of IDMP, the utilization of interactive simulations, and strategies for applying both tools in inquiry-based learning. Implementation observations were conducted concurrently with the program to obtain information on technology use and teachers' engagement in learning activities. SIL assessment focused on three aspects: designing investigations, guiding inquiry, and evaluating scientific processes. This approach was used to examine changes in teachers' competencies while documenting the implementation process of SIDILAN and IDMP.

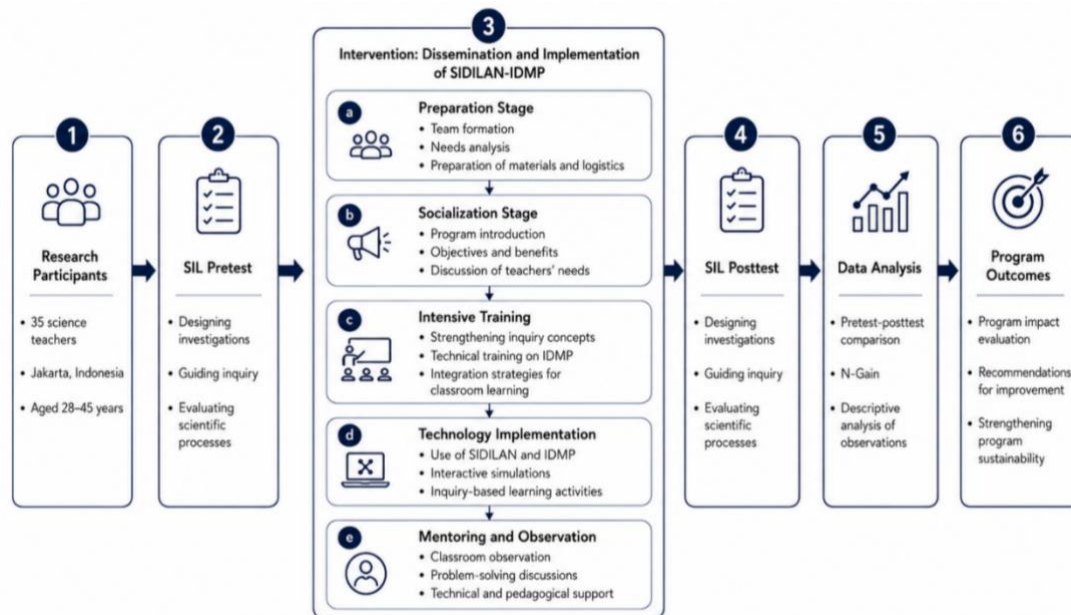


Figure 1. Experimental Design and SIDILAN-IDMP Implementation Flow

Figure 1 presents the research sequence, beginning with participant selection, followed by the SIL pretest, dissemination and implementation of SIDILAN-IDMP, implementation observation, the SIL posttest, and data analysis. The sequence indicates that measurements were conducted before and after the intervention within the same participant group. Observation data were used to complement the test data by providing information on the implementation process in the field.

Participants: Demographics and Selection Criteria

The participants consisted of 35 science teachers in Jakarta, Indonesia, aged between 28 and 45 years. All participants were involved in the dissemination and implementation of SIDILAN-IDMP. They also participated in the data collection process through the SIL pretest-posttest and implementation observations.

Participant selection was based on their involvement in science education and willingness to participate in the program. The age range of 28 to 45 years indicates that the participants were generally at the early to middle stages of their teaching careers. This group was considered relevant because they had teaching experience but still required further development in digital competence and inquiry-based learning. Participation criteria included involvement in the initial assessment, SIDILAN-IDMP training, implementation stage, observation, and final assessment. Participants were also expected to have access to the digital devices required during the program. Other demographic information, including gender, teaching experience, school level, and prior experience with technology, was not provided in the available document and was therefore not included as factual participant characteristics.

Instruments: SIL Pretest-Posttest and Observation Protocols

The primary research instruments consisted of the SIL pretest, SIL posttest, and implementation observation protocol. The SIL pretest was used to measure teachers' initial competencies before participating in the program. The SIL posttest was used to measure teachers' competencies after receiving the SIDILAN and IDMP intervention. The SIL instrument measured three main aspects. The first aspect was the ability to design investigations, including formulating scientific questions, identifying variables, designing procedures, and determining the required data. The second aspect was the ability to guide inquiry, including providing guiding questions, facilitating observations, and assisting with data interpretation. The third aspect was the ability

to evaluate scientific processes, including assessing procedures, data quality, evidence, and scientific conclusions.

The observation protocol was used to document the implementation process of SIDILAN and IDMP. Observations focused on the use of interactive simulations, implementation of inquiry stages, teacher engagement, and the ability to integrate IDMP into lesson plans. The observations also recorded technical and pedagogical challenges encountered during the program. The observation instrument served as supporting data for interpreting the SIL assessment results. Test data provided information on changes in teachers' competencies, while observation data explained how the learning media were used during the intervention. The available document did not specify the number of test items, scoring scale, validity, reliability, or detailed structure of the observation sheet.

Description of SIDILAN and IDMP Implementation

Program implementation began with the preparation stage. The implementation team prepared the dissemination materials, SIDILAN system, IDMP access, SIL instruments, and observation protocols. Preparation also included arranging technical requirements and adapting the materials to the context of science education. The next stage involved introducing the program to the participants. The socialization session explained the program objectives, the benefits of SIDILAN and IDMP, the concept of SIL, and the relationship between digital technology and inquiry-based learning. Participants were also given opportunities to express their needs and the challenges they encountered in teaching.

Training was then conducted to strengthen teachers' understanding of inquiry-based learning and the use of IDMP. Teachers learned how to access the module, use interactive simulations, and connect digital features with investigative activities. SIDILAN was used as a framework to help structure learning according to differences in users' needs.

During the implementation stage, teachers used SIDILAN and IDMP in science learning. IDMP was used to present physics phenomena, support variable manipulation, facilitate observation, and provide digital inquiry activities. SIDILAN helped organize the learning stages so that technology use remained connected to the inquiry process. Implementation activities included observing phenomena, identifying problems, formulating questions, designing investigations, collecting information, and discussing findings. Throughout this process, the team provided mentoring and conducted observations. Mentoring focused on resolving technology-related challenges and strengthening the integration of digital media into lesson plans.

Data Collection and Analysis Procedures

Data collection was conducted in several stages. The first stage involved administering the SIL pretest to all participants before the program began. These data were used to obtain an initial profile of teachers' abilities to design investigations, guide inquiry, and evaluate scientific processes. The second stage consisted of the dissemination, training, and implementation of SIDILAN-IDMP. During this stage, observations were conducted to record media use, teacher engagement, implementation of inquiry activities, and integration of IDMP into lesson plans. Observation notes were also used to document challenges that emerged during the program. The third stage involved administering the SIL posttest after the entire intervention had been completed. The final instrument measured the same aspects as the initial assessment. A comparison between pretest and posttest scores was used to identify changes in teachers' SIL.

Improvement was analyzed using the Normalized Gain, or N-Gain. The analysis was conducted separately for each SIL aspect to identify differences in the level of improvement. The N-Gain formula is expressed as follows:

$$\langle g \rangle = \frac{S_f - S_i}{\text{Score maximum} - S_i}$$

Information:

$\langle g \rangle = \text{Skor } N - \text{gain}$

$S_f = \text{Skor Posttest}$

$S_i = \text{Skor Pretest}$

In addition to N-Gain analysis, observation data were analyzed descriptively. The analysis focused on the level of IDMP use, integration of the module into lesson plans, use of interactive simulations, and implementation of inquiry stages. Test and observation data were then interpreted together to explain changes in SIL and the implementation context of SIDILAN-IDMP.

The IDMP adoption percentage was calculated based on the number of participants who used the module during the program. The integration percentage was calculated based on the number of teachers who incorporated IDMP into their lesson plans. The resulting values were presented in the results section rather than in the methodology section.

DISSEMINATION COLLABORATION

Roles and Contributions of Jakarta State University and Universiti Teknologi Malaysia

The dissemination program was conducted through collaboration between the Physics Learning Media Development Expertise Group, the Physics Education Study Program at Universitas Negeri Jakarta, and Kolej Dato' Onn Jaafar, Universiti Teknologi Malaysia. Universitas Negeri Jakarta was responsible for developing SIDILAN and IDMP, preparing training materials, implementing the program, and evaluating teachers' Scientific Inquiry Literacy. These responsibilities positioned UNJ as both the product developer and the principal coordinator of the dissemination activities. The collaboration also provided a means of applying research-based products in authentic science learning contexts.

Universiti Teknologi Malaysia contributed to the development of Laboratory Environments for Inquiry Skills and provided speakers for the dissemination activities. Its contribution focused on strengthening teachers' understanding of laboratory environments that support scientific investigation. UTM's involvement also expanded academic cooperation between Indonesia and Malaysia in physics education and digital learning media development. This division of roles combined UNJ's expertise in SIDILAN-IDMP development with UTM's contribution to strengthening inquiry-based learning environments.

Development of Laboratory Environments for Inquiry Skills

The development of laboratory environments was intended to support teachers in conducting inquiry activities in a more structured manner. These environments facilitated the observation of phenomena, problem identification, question formulation, investigation design, information collection, and discussion of observational findings. IDMP provided interactive simulations that allowed physical phenomena to be observed, manipulated, and analyzed digitally. SIDILAN, meanwhile, helped organize the instructional stages so that technology use remained connected to the scientific inquiry process.

Digital laboratory environments can also be used when physical experimental facilities are limited or when certain phenomena are difficult to observe directly. Through simulations, teachers can manipulate variables, compare changes, and use generated data as the basis for scientific discussion. This approach supports a more immersive learning experience because students do not merely receive conceptual explanations but also interact with representations of physical phenomena. However, the research document does not provide detailed information regarding the technical design, equipment, or development procedures of the laboratory environment.

Dissemination Activities and Stakeholder Engagement

The dissemination activities included program socialization, training in the use of SIDILAN and IDMP, interactive simulation practice, and assistance in integrating the modules into instruction. Teachers participated in discussions about their needs, challenges, and expectations regarding inquiry-based science learning. This involvement ensured that dissemination was not limited to one-way information delivery but was also adjusted to participants' conditions. The program targeted science teachers from Indonesia and Malaysia as the primary users of the developed products.



Figure 2. Documentation of the SIDILAN-IDMP Dissemination Activities and Stakeholder Engagement

Figure 2 presents the implementation of the SIDILAN-IDMP dissemination program involving the UNJ academic team, academic partners from UTM, invited speakers, and science teachers as participants. The university teams served as developers, facilitators, and mentors, while the teachers acted as users who learned, tested, and integrated SIDILAN-IDMP into their lesson plans. The documentation also shows material presentations, discussion sessions, and participant engagement throughout the activities. Interaction between developers and users provided a basis for identifying implementation challenges and product improvement needs.

Mentoring was provided to help teachers address technical and pedagogical challenges during the implementation of SIDILAN-IDMP. Implementation observations were used to document the use of simulations, the application of inquiry stages, and teachers' ability to connect the media with learning objectives. Problem-solving discussions allowed participants to communicate their difficulties and receive solutions during the program. To support sustainability, future development should include discussion forums and experimental data repositories that can facilitate continuous teacher collaboration.

RESULTS

This The dissemination and implementation of System Differential Learning (SIDILAN) integrated with the Interactive Digital Module Physics (IDMP) involved 35 science teachers in Jakarta, Indonesia, aged 28–45 years. The evaluation focused on the IDMP adoption rate, its integration into lesson plans, changes in teachers' Scientific Inquiry Literacy, and observational findings during implementation. Data were obtained through the SIL pretest and posttest, as well as observations of program implementation.

IDMP Adoption Rate Among Participants

The implementation results showed that the IDMP adoption rate among participating teachers reached 86%. This finding indicates that most teachers involved in the dissemination activities were able to accept and use the interactive digital module in science learning contexts. The high adoption rate also suggests that the features available in IDMP, particularly the digital materials and interactive simulations, were accessible and usable for most participants during the program. An adoption rate of 86% reflects strong acceptance of digital technology as a supporting tool for inquiry-based learning. Nevertheless, the result also shows that not all participants adopted IDMP. Therefore, further assistance is required to help teachers who have not yet adopted the module improve their understanding of its functions, operating procedures, and relevance to science education.

Integration of IDMP into Lesson Plans

A total of 75% of the participating teachers successfully integrated IDMP into their lesson plans. This integration indicates that most teachers were not only able to access and explore IDMP but were also able to plan its use as part of instructional activities. IDMP was positioned as a digital learning resource and simulation medium supporting the stages of inquiry-based learning.

The percentage of integration into lesson plans was lower than the IDMP adoption rate, with a difference of 11 percentage points. This finding indicates that acceptance of an educational technology is not always directly followed by the ability to integrate it into instructional planning. Integration requires additional competencies, including aligning digital materials with learning objectives, determining the stages for using simulations, designing investigation activities, and developing relevant evaluation procedures.

Overall, the 75% integration rate indicates that IDMP has the potential for broader application in science education. However, further training remains necessary, particularly to help teachers connect IDMP features with learning objectives, inquiry activities, time allocation, and assessment strategies.

Improvement in Scientific Inquiry Literacy Based on N-Gain Analysis

The N-Gain analysis showed improvements in teachers' Scientific Inquiry Literacy across all measured aspects. The highest improvement occurred in designing investigations, with an N-Gain score of 26%. Guiding inquiry obtained an N-Gain score of 24%, while evaluating scientific processes obtained an N-Gain score of 21%.

The N-Gain score of 26% for designing investigations indicates that, after participating in the implementation of SIDILAN and IDMP, teachers improved their ability to plan scientific investigations. This ability included formulating investigative questions, determining investigation procedures, identifying variables, and selecting the data required to answer scientific questions.

For the guiding inquiry aspect, the N-Gain score of 24% indicates an improvement in teachers' ability to direct students during the investigation process. This improvement was related to the ability to provide guiding questions, facilitate observations, assist with data interpretation, and encourage students to develop explanations based on the evidence obtained.

Meanwhile, the evaluating scientific processes aspect obtained an N-Gain score of 21%. Although this improvement was lower than those of the other two aspects, it still indicates progress in teachers' ability to assess procedural accuracy, data quality, the appropriateness of evidence, and the validity of conclusions generated through investigation activities.

A comparison of the three scores shows that the strongest improvement occurred in designing investigations, followed by guiding inquiry and evaluating scientific processes. Overall, these results indicate that the implementation of SIDILAN and IDMP contributed

positively to the development of teachers' Scientific Inquiry Literacy. However, the relatively lower improvement in evaluating scientific processes suggests that this aspect requires reinforcement through more intensive and sustained practice.

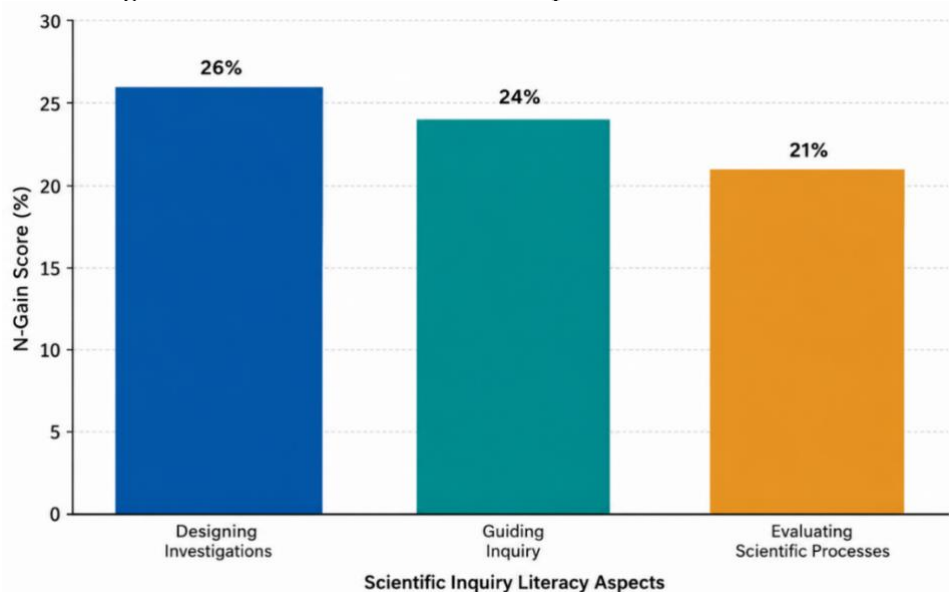


Figure 3. N-Gain Scores of Teachers' Scientific Inquiry Literacy After the Implementation of SIDILAN and IDMP

Figure 3 shows that all aspects of Scientific Inquiry Literacy improved after the program. Designing investigations obtained the highest score at 26%, followed by guiding inquiry at 24% and evaluating scientific processes at 21%. This pattern indicates that the use of SIDILAN and IDMP particularly supported teachers' ability to design and facilitate scientific investigation activities.

Observational Findings During Implementation

The observation results showed that teachers were able to use the interactive simulation features in IDMP as part of inquiry-based learning activities. The simulations helped teachers present physical phenomena in forms that students could observe, manipulate, and analyze. The use of these features supported a more immersive learning experience because students did not merely receive conceptual explanations but could also observe changes in phenomena through interaction with digital media.

During implementation, teachers used IDMP to support several stages of inquiry activities, including observing phenomena, identifying problems, formulating questions, designing investigations, collecting information, and discussing observational findings. Integration with SIDILAN helped provide structure to these instructional stages, ensuring that technology functioned not only as a means of presenting content but also as a tool for conducting scientific inquiry.

The observational findings also revealed a difference between teachers' ability to operate IDMP and their ability to integrate it comprehensively into lesson plans. Some teachers were able to use the digital features and simulations but still required further support in connecting these activities with learning objectives, inquiry stages, and evaluation strategies. This finding is consistent with the difference between the 86% IDMP adoption rate and the 75% integration rate into lesson plans.

Overall, the implementation observations indicate that the combination of SIDILAN and IDMP can support interactive and inquiry-oriented physics learning. Interactive simulations provide opportunities for teachers to facilitate the exploration of scientific phenomena, while SIDILAN provides a systematic framework for directing the investigation process. To sustain

implementation after the dissemination activities, future development should include collaborative features such as discussion forums and experimental data repositories. These features could be used to share implementation experiences, discuss instructional challenges, store investigation data, and support teachers' continuous professional practice.

DISCUSSION

Interpretation of Adoption and Integration Results

The IDMP adoption rate of 86% indicates that most teachers were able to accept and use the digital module in science learning. However, only 75% of participants successfully integrated IDMP into their lesson plans, resulting in an 11-percentage-point gap between technology use and pedagogical integration. This difference suggests that the ability to operate technology does not automatically lead to well-structured instruction. Effective integration requires the alignment of technological, pedagogical, and content knowledge, as described in the TPACK framework (Ali et al., 2023; Jibril & Adedokun-Shittu, 2024).

Teachers who had adopted IDMP still needed to establish clear connections among module features, learning objectives, inquiry activities, and assessment procedures. Technology should function as a means of achieving learning objectives rather than becoming an instructional goal in itself. Studies on science technology use in classroom contexts also show that sustained implementation is influenced by ease of use and the pedagogical value perceived by teachers (Chua et al., 2023; Utaminingsih et al., 2023). Therefore, dissemination programs should balance technical training with lesson-design practice and implementation support.

Effectiveness of SIDILAN and IDMP in Enhancing SIL

The implementation of SIDILAN and IDMP produced improvements across the three measured aspects of Scientific Inquiry Literacy. Designing investigations achieved an N-Gain of 26%, followed by guiding inquiry at 24% and evaluating scientific processes at 21%. This pattern indicates that the intervention provided stronger support for planning and facilitating investigations than for evaluating scientific procedures, data, and conclusions. Overall, these results demonstrate the positive contribution of SIDILAN-IDMP to the development of teachers' inquiry competencies.

The improvement in designing investigations may be associated with module activities that allowed teachers to identify problems, variables, procedures, and the data required for scientific inquiry. This finding is consistent with research showing that the integration of inquiry-based learning and digital simulations can support virtual experimentation and address limitations in laboratory facilities (Umiliya, Wati, & Mahadi, 2023). The lower score in evaluating scientific processes suggests that assessing evidence quality and conclusion validity requires more complex practice. Therefore, future development should include activities involving data analysis, error evaluation, evidence-based argumentation, and feedback on investigation results.

Role of Interactive Simulations in Immersive Learning

The interactive simulations in IDMP allowed physical phenomena to be observed, manipulated, and analyzed within a digital environment. Teachers could modify variables, compare outcomes, and use visual representations as a basis for formulating questions and discussing scientific evidence. Such interaction supports immersive learning because users are directly engaged in exploring phenomena rather than merely reading or listening to explanations. The observation findings showed that simulations were used during the stages of observation, problem identification, investigation design, and discussion of results.

The effectiveness of simulations is determined not only by their visual presentation but also by the scientific activities that accompany them. Visual technologies can support physics learning by providing additional representations, managing cognitive load, and facilitating collaborative

inquiry activities (Vidak et al., 2023). In this study, SIDILAN provided a pedagogical structure that connected simulation use with the stages of scientific investigation. Therefore, the combination of SIDILAN and IDMP is more appropriately understood as a structured learning environment rather than merely the use of a digital module.

Implications for Teacher Professional Development and Curriculum Design

The findings indicate that teacher professional development should include technological competence, inquiry pedagogy, and direct application in lesson planning. The high adoption rate but lower integration rate suggests that one-off training is insufficient to produce meaningful and sustained use. Practical, collaborative, and needs-based training can improve teachers' understanding and confidence in integrating technology (Cer, 2025). Therefore, teacher development programs should continue through mentoring, reflective practice, and periodic evaluation.

In curriculum design, SIDILAN and IDMP can be positioned as tools for supporting investigation- and evidence-based learning. Their use should be explicitly incorporated into learning objectives, activities, learning resources, and assessment so that they do not function as separate supplementary media. The curriculum should also provide teachers with sufficient flexibility to adapt activities to students' characteristics and school facility conditions. The development of discussion forums and experimental data repositories could strengthen the exchange of practices, collaborative problem-solving, and the sustained use of SIDILAN-IDMP after the dissemination program.

RECOMMENDATIONS AND FUTURE DIRECTIONS

Incorporation of Collaborative Tools (Discussion Forums, Shared Repositories)

Future development of SIDILAN and IDMP should incorporate discussion forums that enable teachers to exchange experiences during the implementation of inquiry-based learning. These forums can be used to discuss technical challenges, strategies for utilizing simulations, and adjustments of learning activities based on students' characteristics. Such features can also facilitate peer feedback on investigation designs and lesson plans. This need arises because sustainable practice is not only determined by teachers' ability to use the module but also by continuous professional support after the dissemination program has been completed.

Shared repositories should also be developed to store lesson plans, experimental guidelines, investigation data, and examples of scientific process evaluations. Access to shared resources can reduce duplicated efforts and assist teachers in adapting materials that have been tested by other users. Each resource should include information regarding learning objectives, implementation context, inquiry stages, and implementation outcomes. Repository management should be conducted systematically to maintain the quality and relevance of available resources.

Strategies for Sustained Practice and Teacher Collaboration

Program sustainability requires mentoring that continues beyond the initial training stage. Teachers need opportunities to implement SIDILAN-IDMP, reflect on the outcomes, and improve their lesson designs based on classroom experiences. Periodic mentoring can focus on aligning learning objectives, interactive simulations, inquiry stages, and assessment strategies. This approach is important because observational findings indicate that the ability to operate IDMP does not always correspond with the ability to fully integrate it into instructional practice.

Teacher collaboration can be strengthened through professional working groups, reflective meetings, and sharing practices related to lesson design. Teachers who have successfully integrated SIDILAN-IDMP can be involved as peer mentors for other participants. This mechanism can expand professional support without relying entirely on the development team.

Periodic evaluation remains necessary to assess consistency of use, implementation quality, and the development of teachers' Scientific Inquiry Literacy.

Potential for Expansion to Other Regions and Disciplines

This program has the potential to be expanded to other regions because the current implementation was limited to 35 science teachers in Jakarta. Expansion should consider factors such as device availability, internet access, teachers' digital experience, and the characteristics of schools in different regions. Before wider implementation, SIDILAN and IDMP should be tested through pilot programs to evaluate content suitability and infrastructure readiness. The results of these trials can serve as a basis for adapting training models and technical support according to regional conditions.

The integration concept of differentiated learning, digital modules, and inquiry activities may also be applied to other disciplines. Adaptation can be conducted in chemistry, biology, environmental science, and other fields involving observation, experimentation, data analysis, and evidence evaluation. However, the content, simulations, and assessment instruments must be adjusted according to the characteristics of each discipline. Further research is needed to examine the effectiveness of these adaptations before concluding that the model can be applied universally.

CONCLUSION

The SIDILAN dissemination program integrated with IDMP involved 35 science teachers in Jakarta, Indonesia, aged between 28 and 45 years. The results showed that the IDMP adoption rate reached 86%, while 75% of participants successfully integrated it into their lesson plans. This difference indicates that technology acceptance was higher than teachers' ability to apply it pedagogically within instructional planning. Improvements in SIL were observed across all measured aspects, with N-Gain scores of 26% for designing investigations, 24% for guiding inquiry, and 21% for evaluating scientific processes. The highest improvement occurred in designing investigations, while the evaluation of scientific processes requires further strengthening.

The integration of SIDILAN and IDMP contributed positively to strengthening teachers' abilities to design, guide, and evaluate inquiry activities. IDMP provided interactive simulations that helped teachers observe phenomena, manipulate variables, and utilize data during learning activities. SIDILAN provided a structured framework that guided the use of digital media within systematic scientific inquiry stages. The main contribution of this program was not only the utilization of technology but also the strengthening of the relationship between digital media and inquiry-based pedagogy. Through this program, teachers gained experience in connecting simulations with learning objectives, investigation activities, and scientific evidence evaluation. However, the findings also indicate that improvements in SIL remain at a limited level, suggesting the need for continuous training and further professional development to strengthen teachers' inquiry competencies.

The dissemination of SIDILAN and IDMP demonstrates that research-based educational products can be implemented through collaboration between higher education institutions and science teachers. The collaboration between Universitas Negeri Jakarta and Universiti Teknologi Malaysia strengthened media development, inquiry-based laboratory environments, and knowledge exchange across institutions. The program also highlights that technical support should be accompanied by pedagogical reinforcement to ensure deeper and more meaningful technology integration. The sustainability of the program requires continuous support through discussion forums, experimental data repositories, and periodic mentoring. These features can assist teachers in sharing practices, addressing implementation challenges, and collaboratively developing inquiry-based learning designs. Expansion of the program to other regions and

disciplines requires further investigation to evaluate its effectiveness across more diverse educational contexts.

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AUTHOR CONTRIBUTION STATEMENT

FCW: Conceptualization, supervision, project administration, and manuscript review. DRD: Methodology, instrument development, data collection, and interpretation of results. DSU: Program implementation, participant coordination, observation, and data curation. AHP: SIDILAN-IDMP development, validation, and interpretation of results. DST: Dissemination facilitation, documentation, data collection, and analysis. AM: Data analysis, visualization, writing–original draft, and writing–review and editing. MAHB: Development of inquiry-based laboratory environments, international collaboration, scientific consultation, and critical review. All authors have read and approved the final version of the manuscript.

AI DISCLOSURE STATEMENT

OpenAI's ChatGPT was used to assist with language refinement, grammatical correction, and manuscript organization. The AI tool was not used to generate research data or determine the study findings. All AI-assisted content was thoroughly reviewed, verified, and edited by the authors, who remain fully responsible for the originality, accuracy, and integrity of the manuscript.

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