Development of WIV-S Physics e-Learning to Improve Inquiry Abilities and Digital Literacy of Prospective Science Teacher Students

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***Abstract*—Virtual inquiry has emerged as a new trend in science learning by conducting scientific investigations through digital platforms. The context of this study focuses on developing the Science Virtual Inquiry Web (WIV-S) to improve prospective science teacher students' inquiry abilities and digital literacy. The development method in this study refers to the Hannafin-Peck model with three main phases: needs assessment, design, and development/implementation. Research instruments included interview guidelines, observations, and questionnaires, with a sample size of 58 participants. The research produced a WIV-S physics e-learning prototype, which was declared feasible according to expert judgment of content, media, and learning. Students responded positively to WIV-S, which has provided meaningful, exploration-based learning opportunities and ease of conducting virtual-based scientific investigations.**

***Keywords*—virtual inquiry web, digital literacy, inquiry abilities, teacher professional development, technology-based science learning**

I. Introduction

In the era of globalization and the Industry 4.0 revolution, higher education in Indonesia faces significant challenges in equipping graduates who are both academically knowledgeable and skilled in digital literacy and inquiry abilities. This aligns with the National Higher Education Standards and Graduate Competence Curriculum, which emphasize the importance of these skills in preparing graduates to face future challenges [1, 2]. Nevertheless, research indicates millennials often display relatively low 21st-century learning skills, particularly in creative collaboration, innovation design, and information and communication technologies [3, 4].

One gap in the literature pertains to the ineffective integration of digital literacy and inquiry capabilities within science education curricula. Despite the recognition of the importance of these two facets, there remains a need for more innovative learning strategies that can effectively combine these elements within science teaching [5]. We recognize the urgency in addressing the digital divide within Indonesia's higher education system, particularly in science education. Recent data from the Indonesian Ministry of Education highlight that over 60% of higher education institutions in Indonesia face significant challenges in integrating digital literacy into their curricula, underscoring the need for innovative educational solutions. Previous research has explored various models in web development for the learning process; however, there is still room for improvement in the application of Inquiry-Based Learning (IBL) to facilitate more immersive and continuous learning experiences [6–8].

The significance of filling this gap is evident in the potential for enhancing the quality of graduates through the development of inquiry capabilities and digital literacy. The emergence of the Virtual Inquiry Web (WIV) as a promising innovative solution offers a platform to enrich students' learning experiences through inquiry-based virtual learning resources [9–14]. Integrating IBL within the Earth and Space Sciences (IPBA) course showcases how this pedagogical approach can bolster problem-solving skills and cultivate students' inquiry abilities while enhancing their digital literacy.

This research addresses the pressing need for more effective integration of digital literacy and inquiry skills in science education. Based on a needs analysis revealing students' difficulties in developing inquiry capabilities and digital literacy, along with challenges in implementing inquiry-based learning that supports digital literacy, this study seeks to develop and evaluate the effectiveness of the WIV-S Physics E-Learning in enhancing the inquiry abilities and digital literacy of prospective science teacher students. By focusing on the practical application of Inquiry-Based Learning (IBL) and leveraging virtual learning resources, this study endeavours to provide new insights into science teaching methodologies and better prepare graduates for the challenges of the digital era. Through this approach, the research contributes to a broader understanding of how digital technologies can be harnessed to improve science education in higher education institutions.

II. Literature Review

In response to the challenges presented by the Industry 4.0 era, incorporating digital technology into science education has become essential to meet the needs of learners in the 21st century. Sayegh emphasizes the significance of educational technology in science education to facilitate a more interactive and engaging learning experience, particularly for K-12 learners [15]. This standpoint is further reinforced by Karpenko and Golovko [16], who exhibit how integrating digital technology in chemistry can augment the quality of instruction and learning.

Indonesian's National Higher Education Standards heavily influence the development of a curriculum that promotes digital literacy and inquiry skills. Martinez [17], in his research, illustrates how integrating digital teaching resources can enhance science teaching and learning, thereby fostering the development of students' digital literacy and inquiry skills. In the context of millennial students, 21st-century learning skills such as digital literacy, creative collaboration, and innovation design are fundamental. Sayegh [18] highlights how the digital revolution in science education can prepare students for future challenges by integrating technology to strengthen 21st-century learning skills.

Inquiry-Based Learning (IBL) strategies in science education greatly benefit from incorporating digital technologies. Alnajjar investigated how a science curriculum based on digital technology can enhance student achievement and motivation in learning science, thus demonstrating the effectiveness of IBL supported by digital technology in improving students' conceptual understanding and inquiry abilities [19].

Implementing Web Virtual Inquiry (WIV) as a learning tool is an important platform that supports IBL and enhances students' digital literacy and inquiry skills. In the literature review, we delve into the theoretical underpinnings of digital literacy and inquiry-based learning within the context of science education. Drawing from the works of Maharani [20] and Talavera [21], we explore how digital environments can foster critical thinking and problem-solving skills essential for 21st-century educators. Riabov *et al*. [22] discuss how managing the educational and scientific system in integrating the "digital region-digital university" can incorporate tools such as WIV to support science learning and inquiry. Given the current trend towards e-learning, hybrid, and online learning in science education, it is crucial to integrate digital technologies, such as WIV, to advance digital literacy and inquiry capabilities. Ramaila *et al.* demonstrated the potential of e-learning in supporting independent and inquiry-based science learning through technology integration [23].

III. Materials and Methods

A. Study Design and Sample

Science Virtual Inquiry Web (WIV-S) research was conducted to improve students' inquiry abilities and digital literacy at the Physics Education Study Program, Faculty of Tarbiya and Teacher Sciences at UIN Syarif Hidayatullah Jakarta. This study was conducted on 58 students. The students used as samples were sixth-semester students in the Earth and Space Sciences course. The research method used was the development of teaching material products. The developed instructional product was the science Virtual Inquiry Web (WIV-S). The Hannafin-Peck Model was chosen as the research method for developing educational materials in this study. This model includes three major phases: requirements assessment, design, and development/implementation [24]. In this study, the design of the Hannafin-Peck model is described as follows Fig 1:

Research phases comprised of:

1) Need Assessment: The initial phase evaluated the needs of various entities such as (1) Students, (2) Degree program needs, (3) Analysis of learning environment needs, and (4) Development of learning objectives and activities.
2) Design: Web design was carried out based on the results of the needs analysis during the design phase. The next phase was creating a storyboard or outline highlighting learning via the web, media components, teaching materials/content, and assessment instruments. This phase was critical because good web design could improve the student learning experience and the effectiveness of online learning. Web design considers several aspects such as page layout, type of font used, colour settings, and other visual elements that can improve the student learning experience. Additionally, web design should consider using the latest relevant technologies and media, such as video, animation, and interactive images. Web design must also be able to adapt to various student devices, such as computers, tablets, or smartphones. After the web design was completed, it was evaluated and validated before the learning process was implemented.
3) Develop/Implementation: In this third phase, the main focus was the realization of the web based on the initial design. This phase involved a web development team of technologists, web designers, content developers, and instructional specialists. They must ensure that all aspects designed, such as teaching materials/content, media, assessment instruments, and interactive features, can effectively be implemented on the web. After development, Tessmer's formative evaluation phase was used to see whether the website addressed the learners' and the institution's first needs. Formative assessment was performed throughout the web development process so that developers could modify and update the website based on feedback from the evaluation. The evaluation must consider numerous factors, including learning, material content, medium, and language. To ensure the quality and efficacy of the web, evaluation must be done by web developers as well as various students acting as early users.

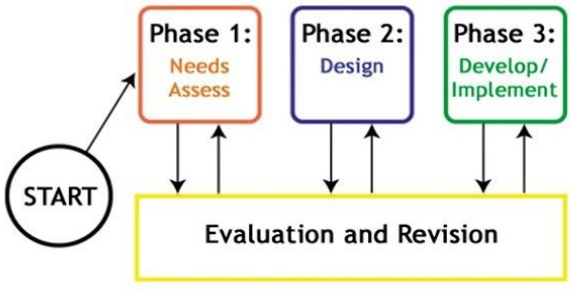

Fig. 1. Phases of development research based on the Hannafin-Peck model [24].

Evaluation and Revision: Continuous evaluation and revision were conducted to ensure the instructional product met the desired outcomes and quality standards. This phase involved gathering feedback from users and stakeholders, analyzing the data, and making necessary adjustments to improve the web-based learning environment. The goal was to refine the instructional materials and delivery methods to enhance student engagement and learning effectiveness.

B. Collecting Data

The research instrument was a guide for conducting interviews, questionnaire completion, and observation. The questionnaire instruments used in this study were tested for validity and reliability using Cronbach's Alpha method, where the obtained alpha value was 0.87, indicating a high level of reliability. Experts in subject matter and research methodology also confirmed the validity of the instruments. Interviews were conducted with students, course instructors, and study program administrators. Students and validators were handed questionnaires and expert judgment observation sheets to evaluate the media's suitability. We employed a triangulation approach combining quantitative and qualitative data to ensure methodological rigour.

C. Data Analysis

The interview results were analyzed in depth to identify and classify the emerging findings or patterns related to the learning needs. The results of the questionnaires and expert judgment observation sheets were analyzed quantitatively using descriptive statistics.

IV. Result and Discussion

A. Need Assessment Analysis

According to the needs assessment analysis, Physics Education Study Program students had difficulty developing their inquiry abilities and digital literacy. From a survey conducted on 58 students, only 25% had good inquiry abilities, and 30% had excellent digital literacy. While the remaining 20% of students had moderate inquiry abilities and digital literacy, as many as 25% struggled with developing inquiry abilities and digital literacy. In measuring inquiry abilities, participants were engaged in a series of tasks designed to simulate scientific inquiry, with their performance evaluated against a rubric developed in line with National Science Education Standards.

Table 1 provides a detailed summary of the needs assessment analysis, highlighting the specific requirements of students, the degree program, the industry, and the community. According to the table, students require more interactive and practical learning to enhance their inquiry abilities and digital literacy. The degree program must align learning with the curriculum to develop these skills. The industry and community also need graduates with inquiry abilities and digital literacy to meet job market demands and societal challenges.

Table 1. Results of needs assessment analysis

Parameter	Analysis Results
Student Needs	Students require more interactive and practical learning to enhance their inquiry abilities and digital literacy.
Degree Program Needs	Physics Education requires learning that is aligned with the curriculum and can develop students' inquiry abilities and digital literacy.
Industrial Needs	The industry needs graduates with inquiry abilities and digital literacy to face the demands of an increasingly complex job market.
Community Needs	Society needs graduates with inquiry abilities and digital literacy to face various societal problems.

The results of the needs assessment analysis show (Table 1) that students need learning that can improve their inquiry abilities and digital literacy. Students need more interactive and practical learning, while the Study Program requires learning that aligns with the curriculum and can develop students' inquiry abilities and digital literacy. Users of graduates such as the industrial world need graduates who have inquiry abilities and digital literacy to face increasingly complex job market demands. In addition, society also needs graduates with inquiry abilities and digital literacy to face various problems. Therefore, Web Virtual Inquiry Science (WIV-S) was developed to answer these needs. Furthermore, the current higher education curriculum must be made relevant and synchronized with the industrial world, including establishing partnerships with industries. This ensures that the skills and competencies required by the industry are imparted to students. By doing so, graduates will be better prepared to meet industrial needs and community needs, effectively bridging the gap between academic knowledge and practical application in the workforce and society.

The results of interviews with course lecturers and students found that the current teaching materials must be more effective in helping students develop inquiry abilities and digital literacy. Course lecturers still need systematic teaching materials to develop integrative inquiry abilities with lecture material. Students feel less involved in learning, and the teaching materials could be more interactive and attract attention.

The results of the needs assessment analysis show (Table 1) that students in Physics Education need teaching materials that are effective in developing inquiry abilities and digital literacy. According to Pinto and Lite, using technology in education can improve students' digital literacy and inquiry skills [25]. Inquiry skills were measured using a questionnaire based on the scientific inquiry abilities framework, including problem identification, hypothesis formulation, experiment design, data collection, data analysis, and conclusion drawing. Scores obtained from this questionnaire were then analyzed to evaluate the improvement of students' inquiry abilities after participating in learning through WIV-S. With this rationale in mind, teaching materials were developed as a Science Virtual Inquiry Web (WIV-S) that was interactive and attracted students' attention. Interactive learning media can increase student involvement in teaching and learning [26]. Using WIV-S, it is hoped that students can be more involved in learning and better develop their inquiry abilities and digital literacy. In addition, the development of WIV-S also follows the latest developments in educational technology, which can help students learn independently and flexibly. Our findings indicate a significant improvement in both inquiry abilities and digital literacy among participants, aligning with Vygotsky's theory of social constructivism, which emphasizes the role of interactive environments in learning [27–29].

Data from surveys and interviews with students and lecturers also form the basis for developing WIV-S teaching materials that suit student needs and expectations. In making WIV-S, aspects considered necessary by students and lecturers were considered, such as being interactive, attracting attention, and being accessible to understand. Therefore, WIV-S can help students develop inquiry abilities and digital literacy more effectively and efficiently.

Although the R&D cycle is expensive, it produces quality products that meet specific educational needs. School personnel who are consumers of R&D efforts may, for the first time, truly see the value of educational research [30]. The needs analysis phase reveals the discrepancy between the field facts and the required educational process standards. Therefore, as the first step in research and development, needs analysis is the foundation for finding solutions to meet educational needs. Mumbai reports several actions in the needs analysis phase [31], which is part of qualitative research to obtain a description of students' learning achievements and learning, usability, obstacles, and constraints in media utilization, as well as the criteria for the required media when it comes to the use of learning that adheres to ICT principles.

Novitra indicates that Information and Communication Technology (ICT) literacy is a crucial component of 21st-Century Skills [19], which, in its development, can be applied to the 4C skills (creativity, critical thinking, collaboration, and communication) within a digital context. The optimal development of 21st-century Skills in students should be accomplished through learning that creates a balance between a scientific approach and the use of technology [32].

B. Design Analysis

Science Virtual Inquiry Web (WIV-S) design can follow several principles of good web design, such as sustainability, responsiveness, and ease of use. Here are some components of web design:

1) Layout and display

1) Create a clean, structured layout so users can easily navigate and find the necessary information.
2) Use colors that match the purpose and identity of WIV-S. Bright and attractive colors can increase user interest.
3) Please ensure the web display is responsive so it can be accessed well on various devices, such as computers, tablets, and smartphones.

2) Navigation

1) Create a straightforward and easy-to-understand navigation menu so users can easily find various existing features and content.
2) Use intuitive icons or symbols to help users understand the function of buttons or menus.
3) Add a search feature to make it easier for users to search for specific content.

3) Existing web models

1) Consider using web models that have been proven effective, such as the three-column model (header, content, footer), to make it easier to place essential elements such as titles, descriptions, and navigation.
2) Use responsive design to ensure your web interface still looks good across devices.

4) Inquiry phases

1) WIV-S web design can include the phases of inquiry used in science learning, such as observation, problem formulation, experimental design, data collection, analysis and conclusions.
2) Ensure each inquiry phase is clearly explained and presented logically on the web page.
3) Provide instructions, resources, and tools for each inquiry phase, such as observation forms, questionnaires, or analysis charts.

Table 2 below is the result of the design analysis of WIV-S teaching materials:

Table 2. Results of analysis of teaching material design

Parameter	Analysis Results
Learning objectives	Curriculum objectives clearly define WIV-S learning objectives.
Structure of Teaching Materials	The structure of WIV-S teaching materials has been well-designed and is easy for students to follow.
Contents of Teaching Materials	The content of WIV-S teaching materials is well integrated with the learning objectives and structure of teaching materials.
Learning approaches	The learning approach at WIV-S aligns with inquiry and digital literacy.
Use of Learning Media	WIV-S uses various types of learning media that suit the learning approach.

The teaching material design analysis results show that the WIV-S learning objectives are clearly defined and in line with the curriculum objectives. The structure of WIV-S teaching materials has been well-designed and is easy for students to follow. The content of WIV-S teaching materials is well integrated with the learning objectives and structure of teaching materials. The learning approach at WIV-S aligns with inquiry and digital literacy. Apart from that, WIV-S also uses various types of learning media that suit the learning approach. Therefore, WIV-S teaching materials have been well designed and in line with student learning needs.

Based on the analysis of the design of teaching materials (Table 2), a Science Virtual Inquiry Web (WIV-S) was developed, which consists of several learning modules that include science material relevant to the Physics Education curriculum. These modules help students develop inquiry abilities and digital literacy effectively and efficiently. Each module has multiple components, including pre-assessment, learning materials, learning tasks, and post-assessment. Pre-assessment and post-assessment are tests used to measure students' inquiry abilities and digital literacy before and after taking the learning module. Meanwhile, learning tasks are designed to help students independently develop inquiry abilities and digital literacy.

The module structure is designed with inquiry phases synergized with several indicators of digital literacy skills. The latest innovations in WIV can be applied to online or blended learning. Inquiry activities at the prospective teacher level are designed with a guided inquiry pattern so that the investigation process leads to opportunities for student creativity and independence. Callaghan states that using open inquiry as a pedagogical strategy for students encourages creativity and student interest in posing answerable questions and devising designs or experiments to solve their problems [33]. Students are introduced to the analytical workflow required to solve data-related problems through guided workflows and explicit objectives presented in virtual laboratories. This includes improving pupil scheduling consistency, with successful simulation being the initial achievement of this program. Challenges associated with simulating raw data (instrument readings, micrographs of cell cultures, etc.) are also addressed. The virtual experiments entail entering experimental parameters into a closed model through a graphical user interface. In addition, students must validate their investigations despite the technical simplicity of data collection. In order to evaluate the data, analysis is required at each phase.

C. Development and Implementation Analysis

After going through the development phases, the Science Virtual Inquiry Web (WIV-S) was implemented for 58 Physics Education students for three months. Implementation is done by providing WIV-S access to students and asking them to follow the designed learning modules.

The development and implementation analysis results show that WIV-S was developed using the Hannafin-Peck Model and following the appropriate development phases (Table 3).

Table 3. Results of development and implementation analysis

Parameter	Analysis Results
Development of Teaching Materials	WIV-S has been successfully developed using the Hannafin-Peck Model and following the appropriate development phases.
Implementation of Teaching Materials	WIV-S implementation was also carried out in the Tadris Biology and Physics Education Degree Programs, involving 80 students from both study programs for three months. WIV-S is considered successful in increasing students' inquiry abilities and digital literacy.
Learning Technologies	WIV-S uses web-based technology and can be accessed via various devices with internet access.
Graphic and Interaction Design	WIV-S has an attractive graphic design and interactions that are easy for students to understand.
Use of Learning Media	WIV-S combines various types of learning media, such as images, videos, and interactive simulations, to enrich student learning experiences.

According to observations made during implementation, WIV-S significantly aided students in developing inquiry abilities and digital literacy. Students feel more involved in learning, and the teaching materials presented are more interactive and attract attention. In addition, the learning activities offered by WIV-S aid students in developing independent inquiry abilities and digital literacy. At this phase, before being tested on WIV students, it is validated by experts; the following Table 4–7 are the validation results.

Table 4. Expert validation-material—feasibility aspects of WIV-S physics web module teaching material content

Assessment Indicators	Assessment Items	Scores	Description
Suitability of material to learning outcomes	Material completeness	4.05	Good
	Breadth of material	4.70	Good
	Depth of material	4.70	Good
Accuracy of the material	Accuracy of concepts and definitions	5.00	Very Good
	Accuracy of data and facts	5.00	Very Good
	Accuracy of examples and cases	5.00	Very Good
	Accuracy of images and illustrations	4.70	Good
	Accuracy of terms	4.70	Good
Up-to-date material	Suitability of material with scientific developments	5.00	Very Good
	Using examples of cases found in everyday life	5.00	Very Good
Encourage curiosity	Encourage curiosity	5.00	Very Good
	Creates the ability to ask questions	4.70	Good

Table 5. Media expert validation—feasibility aspects of presenting physics teaching materials

Assessment Indicators	Assessment Items	Scores	Description
Presentation technique	Sequential concepts	5.00	Very Good
Presentation of Learning	Student-centred orientation	5.00	Very Good
	Encourage critical thinking	5.00	Very Good

Table 6. Validation of language aspects—language suitability aspects of WIV-S physics web module teaching materials

Assessment Indicators	Assessment Items	Scores	Description
Conformity to the rules	Correct use of words	4.4	Good
	Sentence effectiveness	4.4	Good
Language	Spelling accuracy	4.7	Good
Communicative	Easy to understand	4.4	Good

Table 7. Expert media validation—evaluation results of WIV-S physics web module teaching materials

Parameter	Teaching Material Evaluation Results
Instructional Design	Very Good
Suitability of Learning Materials	Very Good
Relevance to the Curriculum	Very Good
Quality of Teaching Material Content	Very Good
Suitability of Difficulty Level	Very Good
Ease of Use	Very Good
Availability of Reference Sources	Very Good
Clarity of Material Explanation	Very Good

The following Table 8 are the results of the evaluation of the feasibility of the Science Virtual Inquiry Web (WIV-S) media.

Table 8. Media expert validation—media feasibility of WIV-S physics web module teaching materials

Assessment Indicators	Assessment Items	Scores	Description
Aspects of screen design display	The choice of font size is standard	4.70	Good
	The choice of font is standard	5.00	Very Good
	The composition of the writing colour and background colour is correct	4.05	Good
	Have attractive colours, images, illustrations, and letters (bold, italics, underlined, etc.)	4.70	Good
Convenience Aspect	The web-based electronic module is easy to operate	4.70	Good
	The instructions in the module are easy to understand	4.40	Good
Consistency and Format Aspects	Use consistent words, terms and sentences	4.70	Good
	Use consistent letters	4.40	Good
	Use a consistent display layout	4.70	Good

The evaluation results of teaching materials show that, in general, WIV-S is of good quality and meets the needs of students in the Degree Program. The content of teaching materials, instructional design, curriculum suitability, difficulty level, ease of use, and clarity of explanation are considered very good. However, several things need to be improved and added to the teaching materials, such as more complete and detailed reference sources and additional explanations for some parts of the material that still need clarification.

The development and implementation analysis results show that WIV-S can help Physics Education students develop inquiry abilities and digital literacy effectively. During implementation, students feel more involved in learning, and the teaching materials presented are more interactive and attract attention (Fig. 2).

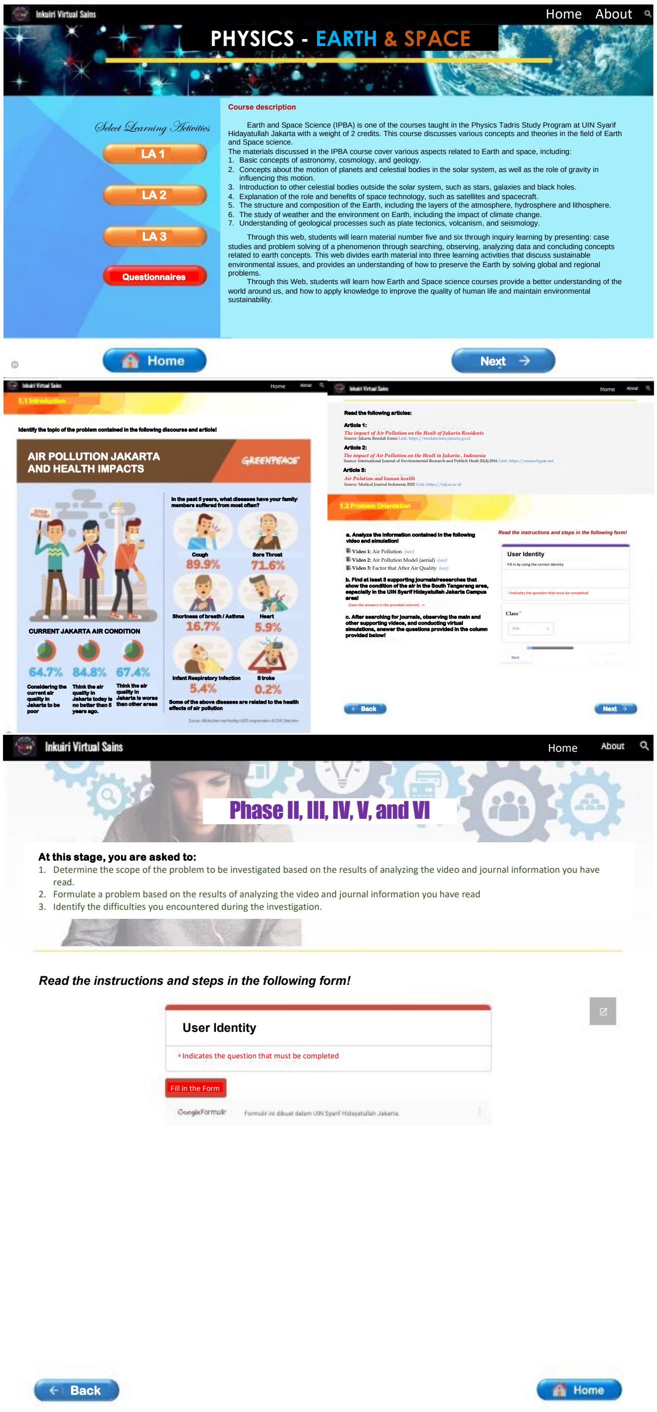

Fig. 2. WIV-S physics e-learning (course description).

In addition, the learning tasks provided at WIV-S also help students develop inquiry abilities and digital literacy independently. These assignments are designed with different difficulty levels so they can be adapted to students' abilities and levels of understanding. WIV provides a learning experience in line with the online Community of Inquiry theoretical framework introduced by Garrison *et al.* [34]. Their framework is essential for this task because the active presence of the teacher, who is involved in the active cognitive process, and the presence of all participants' social interactions are significant. The role of lecturers is to transmit knowledge usually received in face-to-face interactions, as well as teachers involved in distance education and teachers in blended environments who are collaboratively present in designing, facilitating, and directing educational experiences. This is consistent with the work of Vaughan *et al.* [35], who emphasize the significance of research into the factors that influence the success of online education, as it has significant implications for the design of productive online communities. Blended learning involves collaborative work interactions within the context of communities [36, 37] that leverage digital technology [38].

Several obstacles were found in its implementation, such as limited internet access, which could affect the learning process. However, these obstacles can be overcome by providing alternative access, such as using the campus WIFI network. Thus, developing and implementing WIV-S can help Physics Education students develop inquiry abilities and digital literacy effectively and efficiently. In addition, the development of WIV-S can also become a model for developing technology-based teaching materials that other degree programs can adopt.

Combining inquiry-based learning and virtual lab activities can create a more engaging and meaningful science learning process in online education [39]. Efforts to engage in appropriate science-related learning activities to gain Internet access and participate in this scenario are also crucial. Therefore, they can also learn independently, enabling them to work at their place.

D. User Ratings of WIV-S

Students assess four aspects of using WIV-S, namely the module's attractiveness, systematic, language, and usefulness aspects. Student assessments in the Physics Education Study program regarding WIV-S on the aspects attractiveness of the display of the web module, systematics of the web module, the language used, and usefulness of the module on the web are presented in the following Fig. 3:

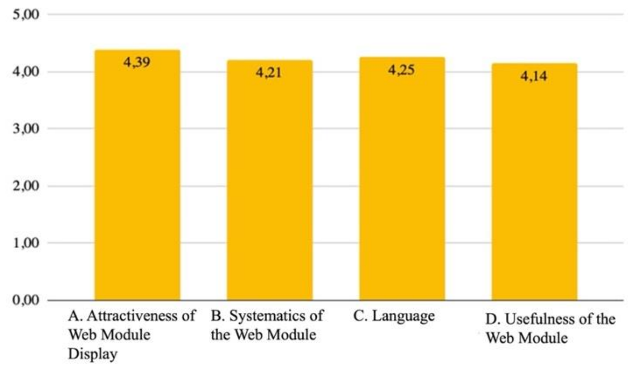

Fig. 3. Physics education student assessment graph on WIV-S.

The maximum score for each aspect assessed is 5. Overall, the Physics Education student assessment for the Physics web module is 4.25 out of a maximum score of 5 or with an achievement of 84.91%.

The assessment results show that Physics Education students highly assess WIV-S use in the attractive aspect of web module displays. Physics Education students responded positively to WIV-S, especially in aesthetic quality, with an average score of 4.39. The WIV-S web module display proved to be exciting and able to motivate their learning process. The systematicity of the web module also received appreciation, with an average score of 4.21, indicating that the module was presented logically and structured, making it easier for students to follow the content. The language chosen in the WIV-S web module also received praise with a score of 4.25, confirming that the language is comprehensive and enhances students' understanding capacity in physics. Finally, from a utility perspective, the WIV-S web module achieved a score of 4.14, showing how significant the contribution of this module is in increasing students' understanding of physics material.

Regarding language use, the WIV-S web module received high appreciation from Physics Education students, who had an average score of 4.25. This shows that the language in the module is communicated clearly and is appropriate to the academic context of the physics they study in the physics course. Finally, regarding the usefulness of the web module, students gave an average rating of 4.14. This shows that students feel the benefits of using the WIV-S web module in improving their understanding of physics.

Overall, the Physics Education students' assessment of using WIV-S in the physics web module showed positive results. From a maximum score of 5, the average assessment reached 4.25 or an achievement of 84.91%. This shows that students generally consider using WIV-S in physics web modules valuable and effective in supporting their learning. These results indicate the success of implementing WIV-S as a learning tool to increase Physics Education students' understanding of physics.

In line with the findings of Schnieder *et al.* [40], students reported greater confidence in comprehending theory in virtual labs compared to face-to-face labs. In addition, they praised the flexibility of completing virtual labs whenever, wherever, and at their tempo, as well as the benefits of interactivity. The average class exam results of students who completed some or all virtual lab experiments were higher than those who did not (83–89% vs. 67%). It is apparent that equipping inquiry abilities and digital skills has become a critical issue in 21st-century competencies for both students and teachers, attained through traditional teacher training and e-learning [41]. The practical implications of this study suggest that integrating tools like WIV-S into science curricula can significantly bridge the digital literacy gap among prospective educators in Indonesia, providing a scalable model for broader educational reform.

V. Conclusion

WIV-S Physics e-Learning was developed based on a need analysis of the importance of digital-based teaching materials, especially in virtual lab activities. This development involves inquiry abilities and digital literacy competencies as two 21st-century competencies. WIV was designed by considering various aspects of web design and learning technology, which was tested on several students after receiving expert validation. WIV-S was proven valid and suitable for use with improvements to the display and ease of submitting assignments. User responses are positive that WIV-S certainly provides experiences with inquiry-based learning that can be considered an alternative for meaningful online learning activities, especially in science education. From observations during implementation, WIV-S helped students develop inquiry abilities and digital literacy. Students feel more involved in learning, and the teaching materials presented are more interactive and attract attention. In addition, the learning tasks provided in WIV-S Physics E-Learning also help students develop inquiry abilities and digital literacy independently. Future research recommendations include optimizing content clarity, and reading material will be expanded, sequenced, and made more relevant.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Iwan Permana Suwarna served as the researcher, data analyst, manuscript writer, designer and developer of the WIV-S application in the Physics and Biology study program. Zulfiani contributed as a researcher and manuscript writer. All authors have approved the final version of the manuscript.

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