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DIGITALWIV-S: ENHANCING STUDENTS' INQUIRY SKILLS AND DIGITAL LITERACY IN PCR AND ELECTROPHORESIS FOR SUSTAINABLE EDUCATION

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ABSTRACT

Digital-based learning can mediate technical barriers and create a support system that enhances the effectiveness of education. This study aims to develop biology learning media, DigitalWIV-S, to enhance the inquiry skills and digital literacy of prospective science teachers. The development method follows Hannafin & Peck's model, which includes the phases of Needs Assessment, Design, Development, Implementation, and Evaluation. The research findings indicate that DigitalWIV-S, as a biology learning media, is deemed appropriate and received positive feedback from students. The evaluation of digital literacy is excellent across cognitive, affective, and conative aspects. Students' inquiry skills are very good in problem orientation and data collection; however, abilities in problem formulation, hypothesis structuring, data analysis, and summarizing are categorized as moderate among the students. The developed media for the PCR and Electrophoresis concepts help students understand these topics better, thereby enhancing their inquiry skills and digital literacy. Additionally, the media addresses the limitations of equipment and materials in modern biotechnology practicums.

Keywords: Biology learning media; biotechnology; prospective science teachers; virtual inquiry web

INTRODUCTION

The teaching of biotechnology, especially at the higher education level for prospective science teachers, faces challenges in terms of equipment, materials, and support for modern biotechnology practicum activities, particularly in PCR and Gel Electrophoresis. This aligns with Ndikumana et al. (2024), who identify similar obstacles in Rwanda's higher education system, such as inadequate facilities, limited connectivity, and weak coordination between academic and administrative bodies, all of which hinder the effective teaching and learning of biotechnology. Zulfiani et al. (2024) found that learning activities on these topics in biotechnology often rely on assignments such as reviewing relevant journals, summarizing, and presenting in class. Survey results reveal that concepts complex for students to understand include PCR (56.6%), Gel Electrophoresis (66.7%), Tissue Culture (11.1%), Stem Cells, Transgenic Animals, and Cloning (22.2%). All students agree (100%) that these topics require practical activities or inquiry-based learning. Interviews with biotechnology course lecturers indicate that the teaching materials used consist of textbooks and articles from national

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and international journals, without enriched materials from lecturers' research. The analysis of teaching material needs among students who have taken the biotechnology course shows that the recommended materials do not fully provide students with practical or research-based experience in biotechnology. Survey results from these students who have completed the biotechnology course indicate a desire for teaching materials that include biotechnology research, particularly PCR and gel electrophoresis, which are fundamental techniques in modern biotechnology research (Aydın & Bedizel, 2023- Alghamdi et al., 2024).

Further research has found that students' ability to analyze and critique phenomena has improved. However, their understanding remains limited in terms of comprehensive procedural knowledge, particularly regarding how these techniques function. Furthermore, the direct use of tools such as PCR and gel electrophoresis requires proper preparation to ensure accurate results, with PCR testing in particular demanding skilled and quick operators, although it remains time-consuming (Babu et al., 2018). Given the large number of students who lack understanding, efforts to improve the quality of learning are necessary, one of which is the development of effective teaching materials. Research indicates that the incorporation of practical methods in teaching can motivate students, teach laboratory skills, support conceptual understanding, and foster scientific attitudes. Therefore, adequate laboratory facilities are needed to support laboratory-based teaching (Hamidu et al., 2014).

The development of science learning materials based on inquiry learning is expected to improve problem-solving skills and scientific attitudes. Widowati et al. (2017) have developed guided inquiry-based teaching materials that are valid, practical, and effective in improving the scientific literacy skills of prospective MI/SD (Madrasa Ibtidaiah) teachers. Sari et al. (2022) analyzed Computational Inquiry-based Teaching (CIbT), demonstrating its significant effect on improving high school students' computational thinking skills. Both studies highlight the effectiveness of inquiry-based approaches in developing critical scientific competencies across different educational levels.

Amid the widespread use of technology in learning, there has been a strong impetus for teachers to present material digitally. This effort aligns with the digital transformation that enables internet access, facilitating limitless learning. Learning spaces have shifted from face-to-face to virtual interactions. The implementation of learning adopts these two modes, often referred to as blended learning, which has become a trend issue among academics (Zhang et al., 2025), and enhances students' digital literacy. Teachers using a blended learning approach can meet the diverse learning needs of students from various generations, personality types, and learning styles (Caravias, 2018). This experience indirectly provides students with the opportunity to adapt to the dynamics of technology quickly. The presence of videos and intelligent tutoring systems has enhanced teaching and learning activities by providing access to a broader range of students and facilitating independent online learning. Blended learning offers a flexible and personalized approach that is effective in enhancing student engagement, academic performance, and satisfaction, while addressing diverse learning needs, ultimately improving learning outcomes in a digital environment (Mushtaq & Iqbal, 2024).

Researchers have developed a virtual inquiry web called DigitalWIV-S Biology Learning Media (BLM) for the concepts of PCR and Gel Electrophoresis. DigitalWIV-S BLM was developed in line with the WIV-S media for Physics Courses in the Physics Education Program at UIN Syarif Hidayatullah Jakarta (Suwarna & Zulfiani, 2024). The prototype models of these two media integrate inquiry learning activities into a web-based design, aiming to enhance students' Inquiry skills and digital literacy (Figure 1).

DigitalWIV-S Biology Learning Media (DigitalWIV-S BLM) is implemented through a combination of synchronous and asynchronous blended learning, which remains a challenge in higher education in terms of building a learning community (Garrison & Kanuka, 2004; Sareen & Mandal, 2024). Moreover, in asynchronous mode, the online community may face potential misunderstandings among its members. Research related to collaborative inquiry design has been developed by Gunstone, presenting an inquiry-based learning (IBL) virtual resource. The IBL framework is based on a community of inquiry, which includes social presence, cognitive presence, and teaching presence (Garrison, 2016). IBL involves students' participation inductively, encouraging them to take responsibility for learning and information exchange.

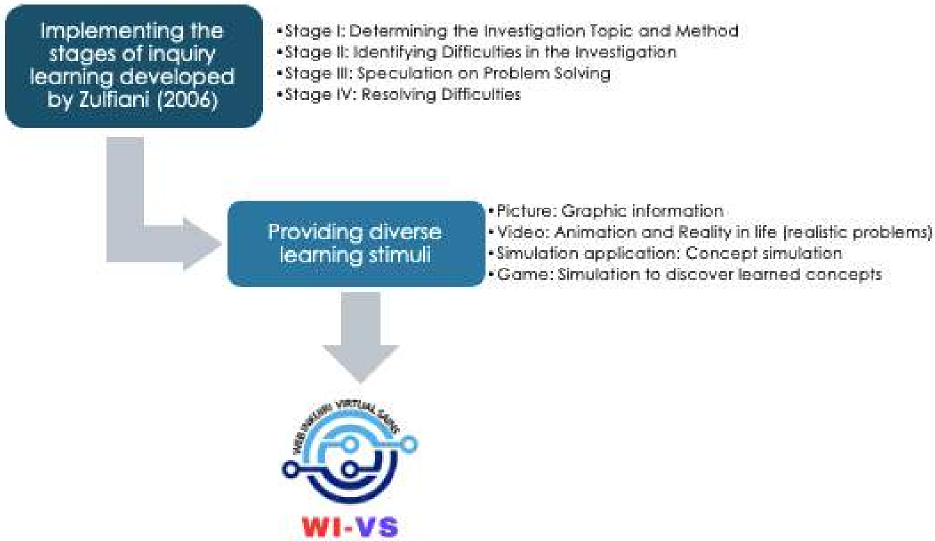

Figure 1. WIVS Procedure Model (Suwarna & Zulfiani, 2024)

DigitalWIV-S fosters a learning community while offering learning experiences that enhance inquiry skills and digital literacy. Inquiry skills focus on the ability to formulate problems, construct hypotheses, explore and analyze data, and communicate conclusions. Digital literacy encompasses several abilities, including identifying and searching for information through digital devices (Bravo et al., 2021). Digital literacy encompasses a set of knowledge and skills related to using the internet. According to Monggilo et al. (2021), digital literacy is constructed through knowledge of the digital landscape and access to the internet. Lutfi et al. (2024) found that digital literacy is essential for both teachers and students. This was conveyed to the teacher about the importance of digital literacy for the learning process. Digital literacy applied to learning activities can encourage students to stay informed about technological developments (Lutfi et al., 2024). Thus, the development of DigitalWIV-S BLM aligns with the mainstream of 21st-century learning, meeting higher education learning outcomes in the Industry 4.0 era.

Teaching materials are adapted to fulfill information literacy, technology literacy, data literacy, and 21st-century skills that foster HOTS. The 21st-century learning abilities of millennial generation students are very low in the components of creative collaborator and innovation designer (Rahmadi & Hayati, 2020), as well as information and communication technology skills. In the rapidly evolving era of information and communication technology, inquiry skills and digital literacy are crucial in science education, especially in higher education. Therefore, a reorientation of curriculum development is needed to enhance graduates' digital literacy. Advances in science and technology have driven changes and updates in teaching methods from traditional classrooms to smart classrooms. Smart classrooms combine advanced technology with teacher-delivered instruction (Xiaoyan, 2023).

Inquiry-based learning emphasizes practical activities in biotechnology courses, incorporating concepts such as PCR and Gel Electrophoresis, to enhance students' problem-solving and foster their inquiry skills. Research indicates that technology can maximize the achievement of inquiry and data literacy (Kippers et al., 2018), which are associated with TPACK (Cui & Zhang, 2022). The importance of using inquiry-based pedagogy lies in developing students' capacity to adopt learning strategies that utilize inquiry techniques and tools, enabling them to construct their own knowledge. Therefore, prospective science teachers need the DigitalWIV-S media to enhance digital literacy while providing meaningful inquiry experiences. Rapid advancements in technology and digitalization will influence education and practice in the healthcare field (Frehywot & Vovides, 2023).

This article explores the implementation of DigitalWIV-S in teaching the concepts of PCR and Gel Electrophoresis at the student level through a blended learning approach, an effective method for providing meaningful learning experiences. The study develops Digital Biology Learning Media (DigitalWIV-S) to enhance students' digital literacy and inquiry skills in understanding complex biological concepts. This media also supports the achievement of Sustainable Development Goals (SDGs), particularly SDG 4 and SDG 9, by providing quality education and promoting lifelong learning opportunities. Furthermore, the study demonstrates how digital media can improve educational accessibility and foster scientific curiosity in the digital age. The novelty of DigitalWIV-S lies in its integration with Inquiry-Based Learning (IBL) enhanced by technology, which promotes active student engagement in searching, evaluating, and verifying PCR and Gel Electrophoresis information. This approach helps students deepen their understanding and develop critical thinking and selective skills, particularly when encountering misinformation or disinformation.

METHODS

This study employs the development method by Hannafin and Peck (1988), which includes needs assessment, design, development, implementation, and evaluation. The research subjects consisted of 60 prospective biology teachers and one lecturer from a biotechnology course. The model was selected for its iterative and systematic approach, which is particularly effective in developing technology-based learning media. It emphasizes three interconnected phases, involving continuous evaluation and revision to ensure the accuracy of the information content (Hijriyah et al., 2025; Roseli & Hamzah, 2022). Furthermore, the model's distinct focus on instructional product development, combined with its user-centered, flexible, and iterative nature, facilitates the creation of effective learning programs. This approach ensures that the final product is not only technically sound but also practical and usable by the target audience (Nazliati, 2024; Simamora et al., 2024). A visual of the Hannafin & Peck development model is presented in Figure 2.

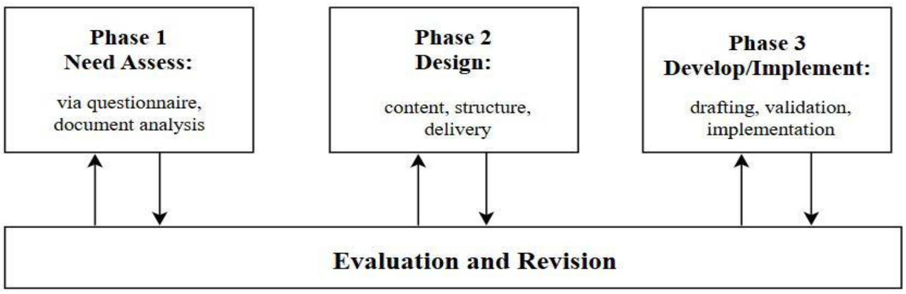

Figure 2. Development Model by Hannafin and Peck (1988)

In the needs assessment phase, the needs and objectives for developing teaching materials are identified. This phase is crucial for understanding the context and needs of students in the science learning process. In the design phase, the content, structure, and delivery of the website are designed, involving the development of storyboards, teaching materials, and learning media. This phase is crucial because good web design can enhance the student learning experience and the effectiveness of online learning. The next phase was development, during which expert validation was conducted. The DigitalWIV-S media was tested in lectures, followed by the distribution of questionnaires. The results included assessments of DigitalWIV-S media, digital literacy, and inquiry skills. The course included three face-to-face and online lectures on PCR and Gel Electrophoresis material. Table 1 shows the stages of virtual inquiry learning for PCR and gel electrophoresis material.

Table 1. Stages of Virtual Inquiry Learning for PCR and Gel Electrophoresis Material

Material	Mode		
	Meeting 1 (In-Person)	**Meeting 2 (Online)**	**Meeting 3 (In-Person)**
PCR	The lecture is conducted in class, providing instruction on using the module and working in groups. Students read articles, formulate problems, and develop hypotheses to address the issues presented. Read practical instructions and prepare for virtual lab practice. The lecturer opens a class discussion and allows each group to present article summaries and problem statements to focus the experiment's objectives. Students perform the practical work. Lecture ends.	Students work in groups to practice in the virtual laboratory and complete lab reports. The lecturer discusses the virtual lab results and selects group representatives.	Students report research findings.
Gel Electrophoresis	The lecturer facilitates group work online. Students read articles. Students discuss problems. Formulate problem statements.	Students take a pre-test on using the gel electrophoresis virtual lab. Students present problems per group in class. The lecturer guides and corrects problem formulations. Students conduct virtual lab practice. Students report experimental results. The lecturer clarifies the results.	Students report research findings.

The lecture follows an inquiry-based structure model, comprising the following stages: formulating problems, developing hypotheses, collecting data, analyzing data, and drawing conclusions. DigitalWIV-S media includes course descriptions, two learning activities, a digital literacy questionnaire, and a Google form for student worksheets. Group work is required for reporting student worksheet results. The results are then analyzed descriptively to assess students' inquiry skills. This study reports the results of a group student worksheet on gel electrophoresis to describe students' inquiry skills. Table 2 presents information regarding the primary data collection elements, including the instruments used and a description of the research subjects.

Table 2. Components, Instruments, and Subjects

Component	Instrument	Subject
Initial needs of lecturers and students for biotechnology learning	Questionnaire	Students and lecturers
Document Analysis	Field Note Observation Sheet	-
Media Prototype Validation	DigitalWIV-S BLM and material validation sheet	Media Expert and Content Expert
Module Assessment	Questionnaire	Students
Inquiry skills	DigitalWIV-S Student Worksheet	Students
Digital Literacy	Questionnaire	Students

The components of the digital literacy instrument include cognitive, affective, and conative aspects (Monggilo et al., 2021). The media validation and content validation instruments were reviewed through expert judgment by evaluation experts. Data analysis techniques include: (1) validation results from media and content experts presented descriptively based on a scale of 1-5 with categories of very poor, fair, good, and very good; (2) module assessment and digital literacy analyzed quantitatively through student response percentages; and (3) inquiry skills analyzed qualitatively from the results of student worksheets.

The module assessment and digital literacy evaluation of students were analyzed using percentages with the following formula (Astuti & Ismail, 2021):

$$P = \frac{S}{N} x\ 100\%$$

Explanation:

P : Percentage sought

S : Number of respondent answers in one item.

N : Ideal value in the item

RESULTS AND DISCUSSION

The DigitalWIV-S interface is accessed through the Biology-Biotechnology menu with personal username and password. The dashboard is the main interface, presenting course options such as Learning Activities and Questionnaires. The following is a view of the DigitalWIV-S Dashboard (Figure 3).

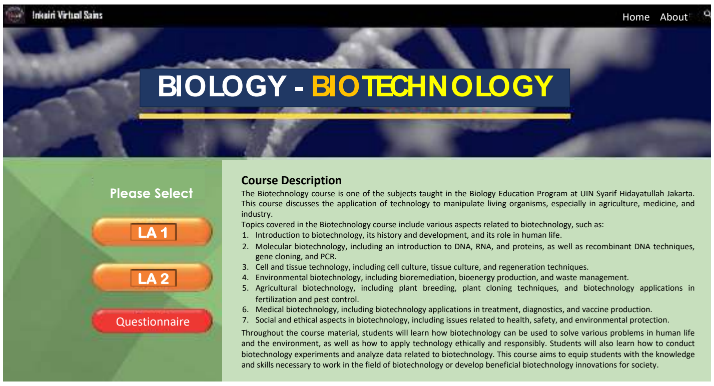

Figure 3. DigitalWIV-S Dashboard (Source: Personal Documentation)

Continuing from the main dashboard, the platform also provides guided tasks for student engagement (Figure 4).

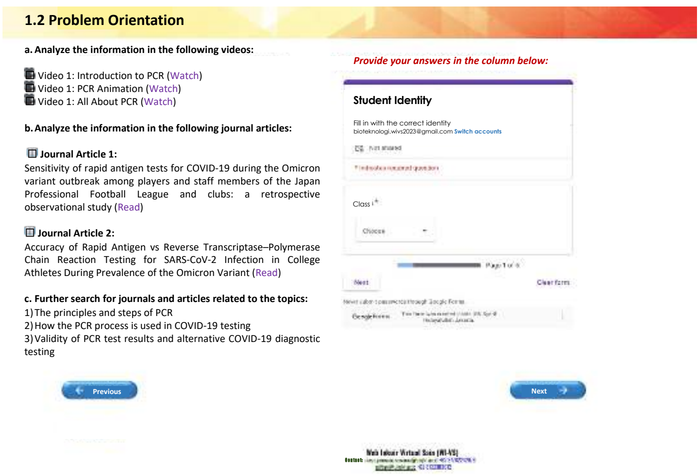

Figure 4. Page of Problem Orientation-First Stage of IBL (Resource: personal documentation)

Figure 4 illustrates the Problem Orientation page, where students are guided through structured activities. These include video analysis, review of journal articles, and independent literature searches. The right section displays a Google Form embedded for student responses, facilitating personalized input and data collection.

This WIV-S media presents biotechnology content digitally, integrated into Inquiry-Based Learning (IBL), allowing students to engage in a blended learning environment. In this way, the WIV-S media tackles the critical challenge faced by prospective science teachers: mastering the material while also developing their inquiry skills and digital competencies—two key abilities for their future careers. Traditional pedagogy, still dominant worldwide, will be integrated with innovative approaches such as e-learning, blended learning, and student-centered technologies, including self-directed learning, project-based learning, and flipped classrooms, to shape the future pedagogical landscape (Tikhonova & Raitskaya, 2023). The flipped classroom model enhances prospective teachers' self-efficacy in organizing field visits and encourages its adoption in their teaching profession (Karaduman, 2025).

The next step is to evaluate the Digital-WIV-S Biology Learning Media in terms of its effectiveness in developing students' inquiry skills and digital literacy. The aspects evaluated include content feasibility and media feasibility. Table 3 presents the evaluation results for the content feasibility of the DigitalWIV-S Biology Learning Media.

Table 3. Feasibility of DigitalWIV-S Media Content on PCR and Gel Electrophoresis Concepts

Aspect	Evaluation Indicator	Concept			
		PCR		Gel Electrophoresis	
		Score	Description	Score	Description
Content Feasibility	Alignment of the material with Learning Outcomes	4	Good	4.3	Good
	Accuracy of the material	4.2	Good	4.6	Good
	Relevance of the material	5	Very good	5	Very good
	Encourages curiosity	5	Very good	4.5	Good
Presentation Feasibility	Presentation technique (Concept coherence)	5	Very good	5	Very good
	Learning presentation (Student-centered and encourages critical thinking)	5	Very good	5	Very good
Language Feasibility	Conformity with rules (word usage and sentence effectiveness)	3.5	Fair	4.2	Good
	Language	4	Good	4	Good

The DigitalWIV-S media received good responses regarding the alignment of the material with Learning Outcomes and the accuracy of the material. The concepts of PCR and gel electrophoresis were rated very well in terms of material relevance. The aspect of encouraging curiosity was rated very well for the PCR concept and well for the gel electrophoresis concept. The language feasibility aspect for the PCR concept received moderate to good responses, while the language feasibility aspect for the gel electrophoresis concept was rated better than that for the PCR concept. The evaluation results of the feasibility of the DigitalWIV-S Biology Learning Media are shown in Table 4.

Table 4. Feasibility of DigitalWIV-S Media on PCR and Gel Electrophoresis Concepts

Assessment Indicator	Assessment Item	Concept			
		PCR		Gel Electrophoresis	
		Score	Description	Score	Description
Display Aspect Screen Design	The selection of font size is in accordance with the standard	5	Very good	4	Good
	The selection of typeface is in accordance with the standard	5	Very good	4	Good
	The accuracy of the composition of the writing color with the background color is correct	3	Fair	4	Good
	Having attractiveness with colors, images, illustrations, letters (bold, italic, underline, etc.)	3	Fair	4	Good
Ease of Use	Web-based electronic modules are easy to operate	5	Very good	5	Very good
	The instructions in the module are easy to understand	4	Good	5	Very good
Consistency and Formatting Aspects	Using consistent words, terms, and sentences	4	Good	4	Good
	Using consistent fonts	4	Good	5	Very good
	Using a consistent display layout	4	Good	5	Very good

In terms of display design, both the PCR and gel electrophoresis concepts received moderate to very good responses, with the gel electrophoresis concept having a more visually appealing display than the PCR concept. The researcher made design enhancements to the PCR concept, particularly in the composition of text and background colors, by implementing higher-contrast colors, which helped enhance readability and provided visual appeal through the color scheme, illustrations, and typography (Figure 5).

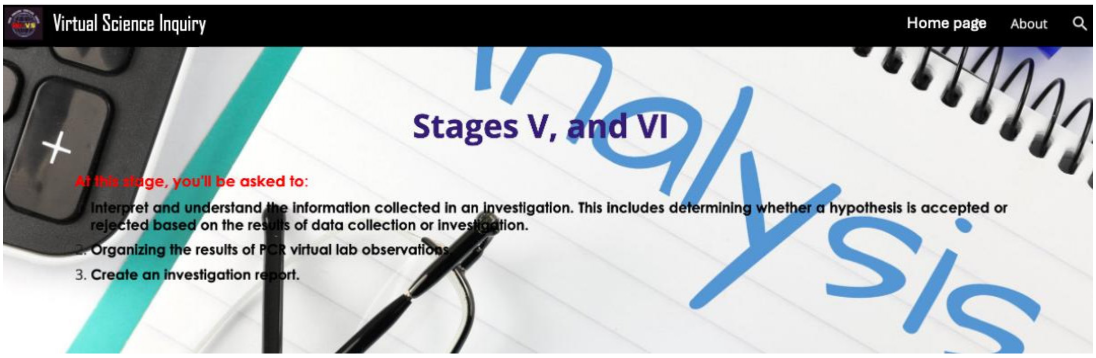

Figure 5. PCR Concept Design Before Media Validation

The revised design following the media validation process is presented in Figure 6.

Figure 6. PCR Concept Design after Media Validation

Based on Figures 5 and 6, the design improvement of the PCR concept can be observed before and after expert media validation.

The ease of use aspect for both the PCR and gel electrophoresis concepts was rated very well, as were the consistency and format aspects. However, the consistency and format of the gel electrophoresis concept were rated better than those of the PCR concept.

Validating the media prototype is a crucial step before testing it with users. Prototype creation can occur throughout the design process, starting with simple sketches that develop into wireframes and gradually become more comprehensive design representations (Bjarnason et al., 2023). The validation results will determine the media's feasibility and may lead to improvements, enhancing the product.

Students assessed four aspects of using DigitalWIV-S: the attractiveness of the module, the systematics of the module, the language, and the usefulness of the module. Figure 7 shows the results of the DigitalWIV-S assessment administered to students in the Tadris Biology program.

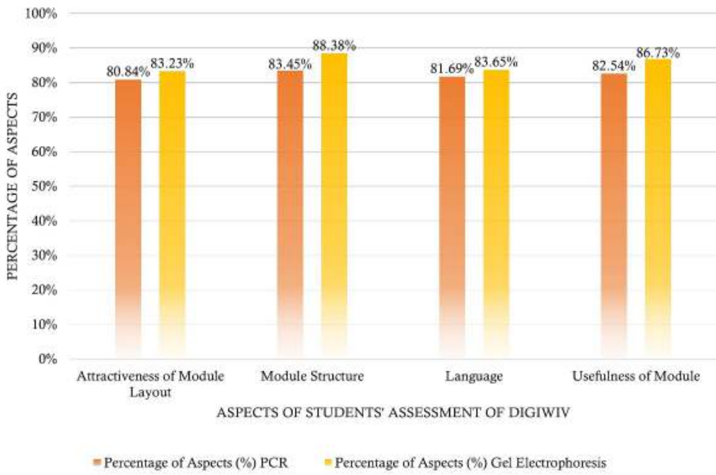

Figure 7. Student Assessment of Tadris Biology Students on PCR and Gel Electrophoresis

The attractiveness of the DigitalWIV-S Module Display received equal ratings of 81% (PCR) vs. 83% (Gel Electrophoresis). This percentage indicates that students found the DigitalWIV-S display quite appealing. An attractive module display can help capture students' attention, increasing their enthusiasm for participating in learning activities. The systematics of the module achieved a score of 83.45% (PCR) and 88.38% (Gel Electrophoresis). This indicates that students rated the DigitalWIV-S module as well-structured and well-organized in its presentation of the material. A well-organized module system helps students follow the learning flow easily, creating order, effective teaching, and a focus on the concepts being studied. The language aspect achieved scores of 82% (PCR) vs. 84% (Gel Electrophoresis). This indicates that students consider the language used in the module to be quite good. The use of appropriate, clear, and effective language can help students understand the instructions or information conveyed, minimize misinterpretation, and increase time efficiency in learning activities. The usefulness aspect of the module achieved scores of 82.54% (PCR) vs. 86.73% (Gel Electrophoresis). These percentages indicate that students find the WIV-S module useful for optimizing learning activities.

The module can help students understand the material and test their comprehension of it. The assessment results show that overall, Tadris Biology students have a positive evaluation of using DigitalWIV-S, as indicated by the good scores in each aspect. Based on these assessments, students believe that DigitalWIV-S has a quite attractive module display, a well-structured and organized module system, appropriate and understandable language, and is useful for optimizing learning activities.

The WIV-S module offers hybrid learning management, supported by a website that provides access to PCR and Electrophoresis materials. Virtual labs are conducted in WIV-S, which addresses the technical barriers often encountered in real-life labs. The development of science and technology has driven innovations in the use of technological products in the field of education (Perdana et al., 2020), aligning with the WIV-S media's goal of enhancing digital literacy. The management of hybrid learning models using web-based media in physics education has shown that students' motivation to learn physics increases, thereby enhancing their interest in the subject (Yani et al., 2021).

Another effect of web-enhanced learning is that it helps introverted students feel comfortable with individual learning and less social interaction. The media will assist introverted students in communicating in front of their screens without direct contact. Modern technologies, including electronic platforms, virtual classrooms, multimedia materials, and communication tools, create a flexible and interactive learning environment. Web-based media supports personalized learning, enabling students to choose the time, pace, and subject development that align with their interests and motivation (Kerimbayev et al., 2023). Additionally, increasing the number of learning resources on websites (internet) provides various learning tools and opportunities (Techataweewan & Prasertsin, 2018).

Blended learning integrates online learning, structured face-to-face activities, and real-world practice, while maintaining the importance of in-person instruction. This approach allows students to learn independently through online platforms before class meetings, which are then used to deepen understanding and facilitate collaborative reflection (Huizinga et al., 2022).

With its new teaching advantages and new style, smart classrooms are gradually entering the public vision and gaining attention and support from most educators. One example is the Grand Wisdom Classroom, which utilizes "Internet +" thinking and new-generation information technologies, such as big data and cloud computing, to create an intelligent and efficient classroom, enabling the entire implementation process to be realized before, during, and after class (Xiaoyan, 2023).

The evaluation of digital literacy comprises 16 questions, grouped into three aspects: cognitive, affective, and conative (Monggilo et al., 2021). The results of the digital literacy evaluation for students on the topics of PCR and gel electrophoresis are presented in Table 5.

Table 5. Evaluation Results of Digital literacy for Tadris Biology Students

Aspects of Digital Literacy	Concept	
	PCR	**Gel Electrophoresis**
Cognitive	82%	84%
Affective	92%	96%
Conative	100%	97%

The digital literacy aspects of students, from highest to lowest, are conative, affective, and cognitive (Table 5). The evaluation results for the affective aspect of digital literacy show that students have a very positive attitude towards using official digital devices, recognize the importance of verifying the information they obtain, and are aware of the potential consequences of not ensuring the accuracy of the information.

The evaluation results for the conative aspect of digital literacy also show excellent results. Students can verify information and compare it with other sources. The cognitive aspect of digital literacy shows the lowest achievement compared to the other two aspects. Figure 8 illustrates the cognitive aspects of digital literacy for students in relation to both concepts.

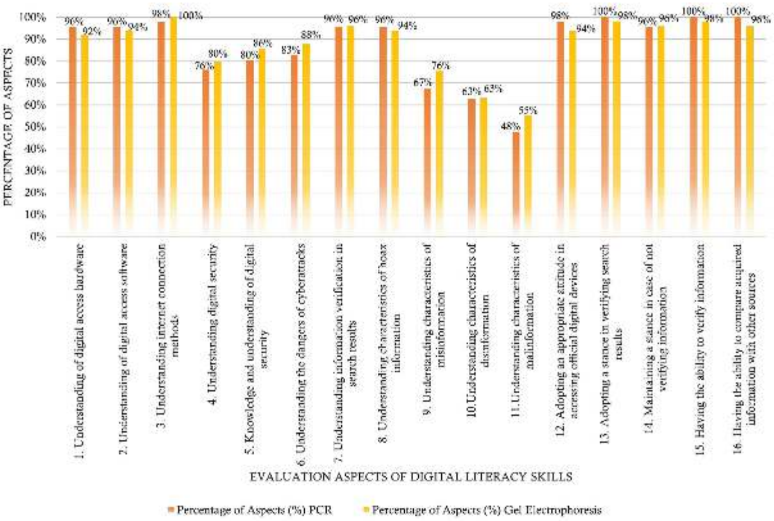

Figure 8. Cognitive Aspect of Students' Digital Literacy

The overall evaluation results for the cognitive aspect of digital literacy show good outcomes. Students can access, select, understand, and analyze various hardware and software used for digital media. They can also connect to the internet, understand digital security, cyber-attack risks, information verification, and recognize characteristics of hoax information. Meanwhile, the evaluation of students' digital literacy regarding information disorder characteristics, including misinformation, disinformation, and malinformation, shows less satisfactory results (aspects 9, 10, 11) (45%-70%). Students need to evaluate their information literacy and critically analyze information to enhance their understanding of information disorders.

All indicators of the affective and conative aspects of digital literacy, in relation to the concepts of PCR and Gel Electrophoresis, achieved excellent results. However, not all indicators in the cognitive aspect of digital literacy achieved excellent results. Three indicators, namely the characteristics of information disorder, including misinformation, disinformation, and malinformation, showed less satisfactory results.

Modern technology, particularly the internet, has expanded education beyond the classroom, enabling students to access and interact with educational content independently and at their own pace (Hamzah et al., 2018). While offering these conveniences, technological advancements also bring new challenges, particularly regarding the spread of inaccurate information. The dissemination of false and/or inaccurate information is not a new phenomenon; in fact, misinformation and disinformation have become increasingly widespread (Pérez et al., 2025). The emergence of new social technologies, which facilitate the rapid dissemination and large-scale flow of information, has further enabled the proliferation of misinformation—defined as information that is inaccurate or misleading (Vosoughi et al., 2018). Additionally, Yesmin (2024) reported that in the digital era, there has been an increase in infodemic (i.e., a pandemic of information disorder). An infodemic involves disinformation (i.e., false information shared by the sender despite knowing the truth—such as fabricated or manipulated content), misinformation (i.e., false information shared by the sender believed to be true—such as misleading content), and malinformation (i.e., real information shared by the sender with malicious intent—such as defamatory or hateful content).

Therefore, media and information literacy are significant factors in avoiding fake content (Rapp & Salovich, 2018). Prior knowledge is important in handling inaccurate information encountered in daily life. Critically verifying information to avoid misinformation is crucial.

The novelty of the WIV-S media lies in its integration of Inquiry-Based Learning (IBL) and technology. This media facilitates active student engagement in the inquiry process, which involves searching for, evaluating, and verifying information related to PCR and Gel Electrophoresis before completing their tasks. Through this approach, students not only gain an understanding of the material but are also trained to think critically and selectively about information, particularly when dealing with misinformation, disinformation, and malinformation. In this context, training in digital literacy or media and information literacy is highly recommended for the public

(Adriani, 2019). Such training provides essential knowledge, attitudes, and competencies to obtain authentic and credible information, critically evaluate the authenticity of news, and understand how and when to use information effectively.

This study was conducted as a limited trial on biology education students, consisting of three meetings using blended learning. Inquiry skills are described based on group student worksheets and are summarized in the following table. The data were processed from the worksheets on the concept of gel electrophoresis completed by student groups, as shown in Table 6.

Table 6. DigitalWIV-S Trial Notes – Student Ability on the Concept of Gel Electrophoresis

No.	Inquiry Skills	Percentage	Inquiry Skills Description	Example Student Responses
1.	Problem Orientation	100%	Students have good abilities at the problem orientation stage. Through the problems and questions presented at the beginning of the learning activities, students can identify and establish the scope of the issues related to the working principles and applications of gel electrophoresis.	"Electrophoresis is a technique for separating charged molecules based on their differing migration rates in an electric field. It is mainly used to observe the results of amplified DNA (deoxyribonucleic acid). The visible result of electrophoresis is the formation of bands, which are the amplified DNA fragments showing the number of base pairs."
2.	Formulating Problems	50%	Students show strong skills in formulating problems. The problem statements they propose are relevant to the investigation topic, clear, focused, and analytical.	"What is the relationship between the length of DNA base pairs and their mobility rate?"
		50%	Students' inquiry skills in formulating problems need enhancement. The problem statements they propose consist of definitions, functions, and work steps already present in the lab guide, without containing questions that can be answered through research or investigation.	"What is electrophoresis?" or "What is the function of electrophoresis?" or "What are the steps for using agarose gel electrophoresis?"
3.	Developing Hypotheses	50%	Students demonstrate good skills in formulating hypotheses. The hypotheses they propose include predictions that address the problem statements and provide expected insights, which can be proven through investigation and data analysis.	"The longer the DNA base pairs, the slower their mobility, and vice versa."
		50%	Students' ability to formulate hypotheses needs enhancement. The hypotheses they propose only describe or provide information without containing predictions, making them untestable through investigation.	"Electrophoresis is the separation of electrically charged components based on their differing migration rates in an electric field."
4.	Collecting Data	100%	Students perform well in conducting investigative activities, gathering, and collecting relevant information to address or solve the formulated problem statements.	

No.	Inquiry Skills	Per-centage	Inquiry Skills Description	Example Student Responses
5.	Data Analysis	62.5%	Students demonstrate good skills in interpreting investigative data, answering questions or problem statements, and testing hypotheses.	"... Strongly charged molecules move faster than weakly charged ones. Smaller molecules travel faster than larger ones. Thus, strong charge and small size increase a molecule's electrophoretic mobility, while weak charge and large size decrease a molecule's mobility ..."
		37.5%	Students' data analysis skills need enhancement. The analysis results do not focus on the obtained data but instead discuss the gel electrophoresis work steps that are already in the lab guide or investigation instructions.	"... The stages of gel electrophoresis include preparing the agarose gel, mixing the gel, setting up the electrophoresis chamber, loading samples into the gel, visualizing nucleic acids, and observing the gel. The agarose gel percentage required for electrophoresis is typically around 0.7-1%. Before adding the dye, agarose is heated in a microwave oven. Optimal electrophoresis conditions, achieved at 30 minutes, produce good separation results. The gel poured into the casting mold or well is mixed with the sample loading dye. Using a power supply at 100 volts will cause DNA fragment samples to migrate. Once most of the sample runs to the front of the gel, the dye makes it visible. The agarose gel is then ready for visualization under a UV transilluminator, which illuminates the gel from below ..."
6.	Drawing Conclusions	87.5%	Students demonstrate good abilities in concluding. The conclusions they present are concise, clear, related to the data findings, and relevant to the formulated problem statements and proposed hypotheses.	"Based on the practical work conducted, it can be concluded that electrophoresis separates electrically charged components based on the shape and size of molecules, such as DNA, RNA, and proteins. Factors that can affect gel electrophoresis include the use of DNA markers, DNA molecule size, agarose gel concentration, DNA base composition, temperature, the presence of DNA dyes, and the application of voltage. The brighter the band color, the shorter the DNA fragment size, and vice versa. Additionally, the longer the DNA base pairs, the slower their mobility, and vice versa."
		12.5%	Students' ability to conclude needs enhancement, as some conclusions are not related to the formulated problem statements and proposed hypotheses.	"Based on the practical work conducted, it can be concluded that electrophoresis is a chemical analysis method based on the movement of charged protein molecules in an electric field. The speed of the DNA molecule movement during electrophoresis is influenced by several factors, including size, shape, volume, and the electrical current applied. Gel electrophoresis is used to determine the size of DNA fragments from PCR products, which are then separated based on the size of each fragment."

The inquiry skills of students are described based on the results of their worksheets during biotechnology lectures using the DigitalWIV-S media. According to Table 6, 100% of students possess good problem orientation and data collection abilities. However, only 50% of students possess good problem formulation skills and the ability to structure hypotheses. Additionally, 62.5% of students have fairly good data analysis skills, while 37.5% are less proficient. Furthermore, 87.5% of students have good summarizing skills, while 12.5% are less proficient.

In the gel electrophoresis lecture, which utilized a structured inquiry learning design conducted offline, students demonstrated two inquiry skills: formulating and hypothesizing problems. The ability to formulate problems is fundamental in identifying the variables to be investigated. Correct identification of variables will lead to a hypothesis statement, which serves as a temporary answer or solution to the problem, and can be tested with data. Students are responsible for testing the formulated hypotheses by analyzing the data collected. If the hypothesis is rejected, students can explain their findings based on the inquiry they conducted. This study shows that the students' inquiry skills performance is lacking, particularly in problem formulation, hypothesis structuring, and data analysis.

According to Aydoğdu (2015), prospective science teachers still struggle even with defining hypotheses, formulating hypotheses based on a problem, providing examples of ideal hypotheses, and defining, identifying, and controlling variables. One of the primary reasons why prospective science teachers struggle to identify variables accurately is that they often confuse one variable with another.

Abddulsalam and Mabrook (2020) revealed that pre-service science teachers possess inadequate knowledge and skills regarding scientific research hypotheses (SRHs). Although the results indicated that participants performed better on the SRHUT post-test compared to their pre-test performance, this achievement was still considered insufficient, particularly in terms of hypothesis formulation skills. Scientific research skills are an essential goal in science education. Therefore, both in-service and pre-service science teachers need to be well-prepared in these skills. This can only be achieved if they receive adequate training through preparation programs within faculties of education.

Higher education for prospective teachers plays a crucial role in developing inquiry skills, particularly through their integration into the curriculum. The WIV-S media integrates Inquiry-Based Learning in the context of technology by providing teaching materials on PCR and Electrophoresis, including articles, videos, and integrated task management. The dissemination of the impact of media development on inquiry skills and digital competencies must be continually enhanced, considering the significant role that the learning environment plays in developing students' potential. This aligns with Delgado-Iglesias et al. (2023), who demonstrated that three years of inquiry-based scientific training could enhance the abilities of prospective primary school teachers. However, further strengthening of training is still needed, particularly in the areas of problem formulation, hypothesis development, and scientific argumentation, to prepare prospective teachers better to teach inquiry-based science in primary schools.

Preliminary findings from a survey of pre-service teachers conducted before and after the implementation of the inquiry model showed increased engagement and enhanced learning outcomes (Preston et al., 2015). Therefore, efforts are needed for educators to integrate these scientific skills into the transfer of knowledge at higher education levels. In other words, the inquiry-based learning model, which trains scientific skills in its process, can provide both inquiry experiences and understanding. Additionally, integrating inquiry-based learning into the curriculum has been shown to enhance overall educational outcomes (Kotsis, 2024). This initiative has led to a more student-centered and coherent approach to enhancing scientific literacy and related skills, such as 21st-century skills, namely the 4Cs (Cebrero, 2025; Nahar & Machado, 2025), while also providing greater clarity and transparency for students and implementing an inquiry-oriented approach at all levels.

Inquiry skills are a transferable skill that enables pre-service science teachers to apply their knowledge in everyday life and professional teaching careers. Inquiry-based teaching has garnered increasing attention and has become a crucial component of curriculum reform in higher education (San-gen et al., 2024; Wahyudi et al., 2024). The application of the Inquiry Model can enhance transferable skills, such as critical thinking and collaboration, which foster innovation and prepare students for real-world challenges (Andrini, 2016; Muthoifin et al., 2024; Hariyanto et al., 2025). Courses that utilize small-group inquiry-based learning activities in an interactive, constructive, and cooperative classroom format have been shown to develop and practice transferable skills highly valued in the future workplace (Canelas et al., 2017). The inquiry approach can effectively explore the oral communication skills of pre-service biology teachers, particularly in two key aspects of oral communication skills: the ability to listen and the ability to convey messages (Sari et al., 2019).

DigitalWIV-S Media has developed a virtual web-based Inquiry media with criteria deemed appropriate and positive student responses on the concepts of PCR and gel electrophoresis to address the urgency of practical experience. Several digital skills of students are represented with excellent performance, highlighting the need for reinforcement in cognitive aspects, particularly in identifying misinformation and disinformation. The digitization of education has provided a strong signal for everyone to be sensitive and critical in processing information, thus emphasizing the importance of digital literacy that needs to be educated in the world of education. The inquiry skills of pre-service science teachers still need to be enhanced, and this is a recommendation for redesigning the science teacher education curriculum to integrate inquiry into both content and pedagogy courses.

DigitalWIV-S, as a learning media, emphasizes the importance of developing digital skills in education and provides in-depth inquiry-based learning experiences. It also plays a crucial role in developing transferable skills essential for the modern workforce. This initiative aligns with the Sustainable Development Goals (SDGs), particularly SDG 4: Quality Education and SDG 9: Industry, Innovation, and Infrastructure (United Nations, 2025). By facilitating the development of 21st-century skills and enhancing digital literacy, DigitalWIV-S makes a significant contribution to addressing global challenges and promoting societal well-being. The educational innovation offered by this media holds great potential to strengthen the global education system and drive progress in industry and infrastructure.

CONCLUSION

The Digital Biology Learning Media (DigitalWIV-S) for teaching PCR and Gel Electrophoresis is deemed highly suitable in terms of both content and media, with positive student feedback regarding its design, structure, and ease of understanding. While the evaluation of students' digital literacy shows favorable results in the cognitive aspect, there is a need for enhancement in addressing information disorders such as misinformation, disinformation, and malinformation. Students' inquiry skills are notably strong in problem orientation and data collection, though further development is required in problem formulation, hypothesis development, and data analysis. The implementation of DigitalWIV-S BLM has a positive impact, enhancing students' digital literacy and inquiry skills, and aligning with the principles of digitalization in 21st-century education. Limitations of this study include a small sample size, which limits the generalizability of the findings, and a focus on students' cognitive and inquiry skills without exploring other aspects of digital literacy, such as critical thinking about information disorders. Future research should involve larger and more diverse samples and explore the long-term effects on students' ability to critically evaluate information. Additionally, this study opens opportunities for prospective science teachers to develop relevant teaching competencies, with potential for broader application in larger classrooms through a quasi-experimental design.

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