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DEVELOPMENT OF VARK LEARNING STYLE-BASED BIOTECHNOLOGY E-LKPD USING THE PJBL-STEAM MODEL TO ENHANCE GRADE IX STUDENTS' SCIENCE LITERACY

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ABSTRACT

Scientific literacy is an essential competence that must be mastered by students in science education, yet its achievement in Indonesia remains relatively low. One strategy to address this issue is developing contextual learning media aligned with students' diverse learning styles. This study aimed to develop a biotechnology e-LKPD oriented to VARK learning styles using the PjBL-STEAM model and to examine its effectiveness in improving junior high school students' scientific literacy. The research employed a Research and Development approach using the 4D model. Participants were Grade IX students of SMP Negeri 1 Tahunan, consisting of 32 students in the experimental class and 32 in the control class. The intervention was conducted over six meetings. Data were collected through expert validation sheets, media readability questionnaires, and scientific literacy tests administered as pretests and posttests. Results showed that the developed e-LKPD achieved high validity and very good readability. The experimental class showed a greater improvement, with mean scores increasing from 50,8 to 86,8 and an N-gain of 0,72, compared to the control class, which improved from 41.34 to 75.2 with an N-gain of 0.58. These findings indicate that integrating PjBL-STEAM with a VARK-based approach effectively enhances students' scientific literacy.

Keyword: E-LKPD; VARK; PjBL-STEAM; scientific literacy

INTRODUCTION

Education plays a strategic role in developing individual potential, making it one of the key indicators of a nation's progress. Education in Indonesia has undergone various developments, alongside ongoing efforts to improve the quality and relevance of learning processes in schools. These changes reflect innovations in education designed to address the challenges posed by advances in science and technology (Jumriani *et al*., 2024). In response to these developments, students are expected to develop mastery of four essential skills. These skills include literacy, creative thinking, effective communication skills, and high levels of productivity (Bagasta *et al*., 2018). Literacy is an individual's ability to manage and understand information through reading and writing (Kumar *et al*., 2024). Individuals with strong literacy skills can objectively and critically analyze facts, evidence, observations, and arguments to draw rational conclusions (Limiansih *et al*., 2024).

One form of literacy that is important for students to possess in science education is scientific literacy. Students with an adequate understanding of science will be able to understand the role of science and

technology in their personal lives, discuss science in the media, examine the potential disadvantages and advantages of scientific advancements, and make choices based on evidence (Kamelia *et al*., 2022). Scientific literacy is intended to equip students with an understanding of science and technology so that they have the ability to make rational and accountable decisions based on empirical evidence, which is obtained through mastery of scientific content and critical thinking skills (Limiansih *et al*., 2024; Valladares, 2021). Empirical findings indicate that the level of scientific literacy of students in Indonesia is still below the expected standard. This was shown in the results of the Programme for International Student Assessment (PISA) conducted by the Organisation for Economic Co-operation and Development (OECD), which evaluated student literacy skills in various countries. Based on the assessment results, Indonesia ranked 67th out of 81 countries with an average score of 383 in students' scientific literacy skills. The majority of students were classified at Level 2, indicating that their scientific competency had reached the stage of applying scientific knowledge in everyday life contexts. At this level, students are able to use basic procedures appropriately to recognize and understand the right scientific explanations (OECD, 2023).

Biotechnology is one of science topics that is closely related to everyday life. This material not only discusses theoretical concepts regarding the use of organisms to produce products but also emphasizes skills in applying the knowledge. Practical learning, oriented toward hands-on experience, can be an effective alternative to help students construct a more concrete understanding of abstract concepts (Akbar *et al*., 2024). The development of scientific literacy skills through practical learning can be optimized by implementing the Project-Based Learning (PjBL) model with a STEAM approach that is oriented towards student's active participation in project-based activities. The STEAM approach is a meta-discipline that integrates science, technology, engineering, art, and mathematics, which is able to evolve students' thinking skills and creativity in solving problems (Nuraini *et al*., 2023). The implementation of learning with the PjBL-STEAM model is inseparable from the use of learning media. The use of textbooks as the learning media in schools is less contextual and is considered too textual. Textbooks with a STEAM-like approach are needed to provide active and engaging learning, which enables students to gain a comprehensive understanding of the material and develop their skills (Dalifa *et al*., 2024). In addition to textbooks, Student Worksheets (LKPD) are needed for project-based learning. Field observations revealed that teachers use printed LKPDs without an appropriate format of the implemented learning model. They only provide tables and questions for students to complete after completing the practicum. This can lead to miscommunication and a lack of understanding in practicing scientific literacy.

Student's individual characteristics can cause suboptimal learning (Yuspa & Azizah, 2022). Therefore, it needs to be adjusted and integrated into the Student Worksheet (LKPD). Adapting the Visual-Auditory-Read/Write-Kinesthetic (VARK) learning style can support hands-on learning activities (Chayono & Nuriyatin, 2023). The

visual style includes images, models, and printed information. The auditory style focuses on audio delivered by the teacher and MP3 recordings. The reading/writing style encourages students to take detailed notes by carefully reading and writing the learning materials. The kinesthetic style leans more towards practical sessions and applications to gain real-life experience (El-Saftawy *et al*., 2024). Referring to research on the scientific literacy profile based on the learning style tendencies of junior high school students, 61% of them have a multimodal style, which means they can learn through various sensory channels, compared to only 39% students who have unimodal styles that heavily rely on a particular style (Pratiwi *et al*., 2025). Identifying students' VARK learning styles is considered as a way to adapt learning approaches to their learning preferences. Based on the research on junior high school students, it was concluded that 35% of them are kinesthetic learners, 30% visual, 21% auditory, and 14% read/write (Subagja & Rubini, 2023). These results can vary in each class and junior high school. Therefore, a flexible LKPD is required to accommodate all student learning styles and maximize their learning potential.

Integrating PjBL-STEAM and VARK learning styles creates a more adaptive instructional process that supports contextual learning and promotes the development of 21st century competencies. PjBL provides opportunities for students to investigate complex, real-world problems, test alternative, and reflect on their learning processes, which fosters deeper understanding of problem-solbing strategies (Zayyinah *et al*., 2022). The implementation of PjBL model has also been shown to produce significant positive effects on studenys' critical thingking, skills, scientific literacy, and overall learning outcame (Karmana, 2024). When applied within a PjBL-STEAM framework, students collaboratively construct knowledge, generate ideas, and apply critical thinking to analyze authentic situations before transforming their solutions into meaningful projects (Chistyakov *et al*., 2023). The inclusion of VARK learning preferences further strengthens on learning media by accomodating diverse ways of processing information, therby making learning expericences more relevant, personalized, and contextually grounded (Kusworo *et al*., 2021).

Along with the development of educational technology that has driven the transformation of printed learning methods to digital, LKPD can now be created in electronic or digital form (e-LKPD) by presenting superior features such as interactivity, multimedia, and direct feedback that support learning optimization. Previous studies from Silfiyani *et al*. (2024) have reported that e-LKPD PjBL-STEM can enhance students' scientific literacy at SMPN 1 Tanjung Bintang. The implementation of the developed e-LKPD directs students to apply their prior knowledge in solving real-world problems through project-based activities that are adjusted to visual, auditory, and kinesthetic learning styles. This research was designed to provide a more comprehensive contribution by developing a VARK-oriented in e-LKPD integrated with the PjBL-STEAM model, an approach that has not been widely investigated, particularly in terms of its application for enhance students' scientific literacy. Based on this background,

the development of this e-LKPD can be used as an alternative instructional delivery to foster students' scientific literacy.

METHOD

This study applies a 4D model development design that includes the define, design, development, and dissemination stages. The model selection is intended to produce a biotechnology VARK learning style-oriented e-LKPD product and integrated with the PjBL-STEAM learning model. The developed product is then evaluated for its feasibility through validity tests and product trials to identify students' scientific literacy levels after using the e-LKPD on biotechnology material. The sample for the product trial was selected using purposive sampling involving one class consist of 30 students who were chosen based on predetermined criteria relevant to the study objective.

The participants of this study included all ninth-grade students at SMP Negeri 1 Tahunan in the 2025/2026 academic year. The research sample was determined as two classes, each playing a role as an experimental class and a control class, with the sample determination being carried out using a purposive sampling technique. The two class samples were obtained through a homogeneity test of the odd semester summative grade data. The intervention was conducted over six meethings, with each session lasting two instructional periods (2x40 minutes). The experimental class engaged in learning activities stucture according to the PjBL framework. These activities integrated with biotechnology material and adapted to accommodate VARK learning styles through the learning process. The teacher acted as a facilitator who guided discussions, provided scaffolding, monitored project progress, and supported students in connecting scientific concept wit real-world applications, while the control class received discovery learning model. The development of the VARK learning style-oriented biotechnology E-LKPD involved data analysis, including:

1. **Validity Analysis of the VARK Learning Style-Oriented Biotechnology E-LKPD Using the PjBL-STEAM Model**

   The validity of the E-LKPD was assessed by five validators, consisting of two lecturers and three teachers, on the media and material aspects of the e-LKPD. The validity analysis used the Aiken V formula as follows:

$$V = \frac{\Sigma S}{n(c-1)}$$

   Information:

   V : validation value
   ΣS : the total of the difference between the scores given by the experts and the lowest importance rating score
   c : number of importance rating score options
   n : number of experts involved

Table 1. Aiken V Criteria Index

Index	Criteria
0,8 ≤ V < 1,0	Highly Valid
0,6 ≤ V < 0,8	Valid
0,4 ≤ V < 0,6	Moderately Valid
0,2 ≤ V < 0,4	Less Valid
V < 0,2	Invalid

2. **Readability Analysis of VARK Learning Styles-Oriented**

Biotechnology E-LKPD Media Using the PjBL-STEAM Model

The readability of the e-LKPD media was conducted in a small-scale trial on 30 students at SMA Negeri 1 Tahunan. The small-scale trial aimed to identify students' level of understanding of the biotechnology e-LKPD and evaluate other aspects including appearance, material suitability, and language use. The assessment was carried out through a questionnaire that was designed using a five-level Likert scale, which included categories from strongly disagree to strongly agree. Data obtained from the questionnaire results were then analyzed using the following percentage formula:

$$Final\ Score = \frac{Total\ student\ scores}{Total\ scores} x100\%$$

Tabel 3. Interval Kriteria Angket Keterbacaan Media

Percentage (%)	Criteria
81 - 100	Very Good
61 - 80	Good
41 - 60	Fair
21 - 40	Poor
< 20	Very Poor

3. Analysis of the Effectiveness of VARK Learning Styles-Oriented Biotechnology E-LKPD with the PjBL-STEAM Model to Foster Scientific Literacy

Students' scientific literacy was analyzed through pretests and posttests during pre-treatment and post-treatment learning using e-LKPD biotechnology. The results of the pretest-posttest data were then analyzed using normality tests, t-tests, and N-Gain tests to determine the effect and improvement of students' scientific literacy. The normality test is used to determine whether the research data is normally distributed. Normally distributed data were then analyzed using t-tests as a parametric statistical test. If the data is not normally distributed, the analysis is carried out using the Mann–Whitney test as a nonparametric statistical test. After obtaining an analysis of whether there is a difference between the conditions before and after the treatment, the next stage is to conduct an N-Gain test to measure the level of improvement in students' scientific literacy.

RESULTS AND DISCUSSION

This biotechnology e-LKPD was developed as a digital learning tool to support active, contextual, and student-centered science education for ninth-grade junior high school (SMP/MTs) students. From a pedagogical perspective, this e-LKPD is based on the Project-Based Learning (PjBL) model, which emphasizes student involvement in the learning process through project activities. PjBL enables students to construct knowledge independently through exploring real-world problems, designing solutions, implementing projects, and evaluating learning outcomes (Irene *et al*., 2024). FThe project guide feature in e-LKPD contains the steps of the PjBL model, which consist of (1) determining basic questions; (2) designing project planning; (3) preparing a product creation schedule; (4) monitoring project activities and progress; (5) testing the results; (6) evaluating experience. The research procedures carried out using the 4D model in this study are as follows:

1. Define
   Define is the initial stage of 4D research, the aim of which is to analyze and collect information related to research needs, such as performing these following activities:
   a) Fundamental Problem Analysis
      Conduct direct interviews with teachers and students to identify difficulties experienced in science learning.
   b) Literature Analysis
      Conducting an analysis of scientific journals and articles related to VARK learning styles-oriented e-LKPD with the PjBL-STEAM model.
   c) Curriculum and Material Analysis
      Mapping biotechnology material according to the learning outcomes of the Merdeka curriculum.
   d) Software Selection
      The e-LKPD is prepared interactively by considering software that is easily accessible to students, such as Canva.
2. Design
   In this second stage, the VARK learning style-oriented e-LKPD using the PjBL-STEAM model design was developed. This process began with the preparation of a table of contents, user manual, mapping of STEAM and VARK learning styles, and the selection of supporting technologies that could be integrated into the e-LKPD. The foundation used in the design stage was obtained from previous research. Then, the design was carried out in the form of a storyboard.
3. Development
   Product development and refinement are performed after validation by experts at this stage. After revisions and validation by the validator, an initial product trial is conducted in the form of a media readability test on 10th grade students.
4. Dissemination
   At this stage, e-LKPD media was distributed to the principle of SMP Negeri 1 Tahunan and MGMP IPA throughout Jepara Regency.

This e-LKPD was created using the web-based platform Canva, allowing students to easily click on icons, listen to audio, watch videos, and access simulations through its hyperlink feature. Afifah *et al*. (2019) asserted that the quality of a media is characterized by the ease of use and clarity level in information delivery, making it easily understood by users, including the general public. With the rapid development of technology, the developed learning media is required to support a more dynamic, efficient, and effective learning process (Derta *et al*., 2023). Another characteristic of this e-LKPD is its integration with the STEAM approach, which aims to link biotechnology learning with various disciplines in a complementary manner. Students independently strive to identify STEAM aspects based on conventional biotechnology projects they create with their groups. Beyond the STEAM approach, this e-LKPD was designed to accommodate diverse student learning styles by integrating visual, auditory, read/write, and kinesthetic (VARK) aspects. The material is presented in various formats, including reading text,

images, videos, audio, and modern biotechnology simulation activities.

Based on the observation data, most students demonstrated unimodal learning preferences, accounting for 60 out of 72 students dominated by visual (32%) and auditory (31%) types. In contrast, multimodal learners comprised 12 students in total, distributed across combinations such as VA, VK, AR, or other mixed style. The VARK learning style adjustments in e-LKPD were intended to accommodate differences in student learning preferences, thus optimizing the learning process. Adapting learning styles to students' learning styles can significantly increase student engagement in processing information.

From a cognitive and skills aspect, this e-LKPD is explicitly designed to foster scientific literacy. Students are guided through activities, such as DNA extraction simulations and conventional biotechnology projects in the food sector, as applications of biotechnology in everyday life, which could strengthen their ability to connect scientific concepts to real-world contexts. The characteristics of the developed e-LKPD are shown in Table 3.

Table 3. Characteristics of Biotechnology E-LKPD

No	Characteristics
1	The developed e-LKPD consists of a book cover, home page, introduction, user guide, materials, project guide, reflections, and author profile.
2	E-LKPD is designed using the PjBL-STEAM model as a learning guide when students work on projects.
3	E-LKPD provides project guidelines related to scientific literacy indicators which are contained in student activities.
4	E-LKPD presents biotechnology material in the form of videos, reading materials, audio, and simulations that can be easily accessed by students.
5	E-LKPD is designed to meet the needs of visual, auditory, read/write, and kinesthetic learning through text, images, videos, teacher explanations in audio form, report writing activities, discussions, and project creation so that students can optimize each learning style they have.
6	E-LKPD presents reflections through a padlet and offers digital certificates as a form of appreciation for students after successfully completing a biotechnology project.

1) Validity Analysis of VARK Learning Styles-Oriented Biotechnology E-LKPD with the PjBL-STEAM Model

The validity assessment of the VARK learning style-oriented biotechnology e-LKPD using the PjBL-STEAM model was conducted using a feasibility questionnaire by media experts and material experts. The validity of learning products is an essential component that must be ensured before they are widely implemented in learning activities. Therefore, validation by material experts was performed to evaluate the level of alignment of the material content with learning objectives, established learning outcomes, and student characteristics. Furthermore, this validation also aimed to ensure conceptual accuracy, depth and breadth of the material, and the appropriate use of terms and examples presented. Meanwhile, validation by media experts

focused more on the technical and visual aspects, such as display design, text readability, use of color and illustrations, layout consistency, and ease of use of the media in supporting the learning process. The media and material experts consisted of two expert lecturers and three science teachers at SMP Negeri 1 Tahunan. The results of the media experts' e-LKPD feasibility assessment can be seen in Table 4.

Table 4. Media Expert Validation Results

Indicator	Validity	Criteria
Media Display	0,98	Valid
Use of Letters	1,00	Valid
Physical Criteria and Consistency	0,98	Valid
Media Practicality	1,00	Valid
Mean	**0,99**	**Valid**

Based on Table 4, the assessment results from media experts showed that the VARK learning style-oriented biotechnology e-LKPD with the PjBL-STEAM model obtained a validity score of 0.99, which is in the valid category for use. This assessment implied that the developed e-LKPD is good and met the indicators for learning design development. This is reinforced by Dewi & Meilina (2022) statement that e-LKPD designs created using Canva software can improve the usability for students, and their attractive appearance increases students' interest in using the e-LKPD. Furthermore, the assessment of media experts requires consideration of the material included in the e-LKPD creation. The assessment of material experts on the biotechnology e-LKPD is shown in Table 5.

Table 5. Material Expert Validity Results

Indicator	Validity	Criteria
Content eligibility	0,95	Valid
Presentation eligibility	0,89	Valid
Language eligibility	0,95	Valid
VARK learning styles	0,90	Valid
PjBL-STEAM	0,87	Valid
Scientific literacy	0,95	Valid
Mean	**0,91**	**Valid**

The validation results by material experts, as presented in Table 5, displayed an average value of 0.91, which is included in the valid or feasible category. This indicated that the developed material has met the suitability of student characteristics and is aligned with the applicable curriculum. This is reinforced by Dewi & Meilina (2022), that the material included in the e-LKPD must be accurate to avoid misconceptions by students. The VARK learning style-oriented biotechnology e-LKPD with the PjBL-STEAM model has a systematic presentation structure, attractive presentation, and is easy for students to use. The presentation aspect of teaching materials can be considered valid if the material is arranged systematically and sequentially

according to the level of difficulty and learning objectives, so that students can easily learn the concepts gradually (Bashir *et al*., 2024). Furthermore, the validity of the presentation is also reflected in the strong integration between learning components, such as the relationship between objectives, materials, methods, media, and evaluation. This integration ensures the interrelationship between components in forming a coherent and harmonious learning, so that its implementation can be effective and meaningful (Billa *et al*., 2025)..

2) Readability Analysis of VARK Learning Styles-Oriented Biotechnology E-LKPD Media Using the PjBL-STEAM Model

The biotechnology e-LKPD obtained eligible results from the assessment of media and material experts, which then allowed it to perform a small-scale trial. The purpose of the small-scale trial was to determine students' understanding of the biotechnology e-LKPD and other aspects such as appearance, material, and language. Data from the small-scale trial was obtained from student feedback through a media readability questionnaire. The questionnaire data was used as a basis for revisions before the e-LKPD was distributed and used in the large-scale trial. The results of the media readability questionnaire, done by ninth-grade students at SMA Negeri 1 Tahunan, are shown in Table 6.

Table 6. Media Readability Questionnaire Results

Aspect	Response Results (%)	Criteria
Appearance	87%	Very Good
Material	87%	Very Good
Language	88%	Very Good
Mean	**88%**	**Very Good**

Student responses obtained through completing the e-LKPD media readability questionnaire showed positive results with an average of 88%, which fell in the very-good category. Student responses are an essential component in developing learning media because they directly reflect the level of media suitability with students' needs and preferences (Putri & Zulyusri, 2025). The existence of a media readability questionnaire supports the validation assessment of material experts and media experts, so that the VARK learning style-oriented biotechnology e-LKPD with the PjBL-STEAM model is eligible for use in large-scale testing.

3) Analysis of the Effectiveness of VARK Learning Styles-Oriented Biotechnology E-LKPD with the PjBL-STEAM Model to Foster Scientific Literacy

Students' scientific literacy levels after using the biotechnology e-LKPD were measured through pretest and posttest scores. The effectiveness of the biotechnology e-LKPD in improving scientific literacy refers to the N-Gain obtained and is supported by t-test data.

The e-LKPD is considered effective if it obtains an N-Gain score of at least 0.3 and is in the moderate category. The results of the N-gain score analysis on students' pretest-posttest are shown in Table 7.

Table 7. Mean Score and N-gain of Science Literacy

Mean Score		N-gain	
Pre	**Post**	**Score**	**Criteria**
Experimental Class			
50,84	86,83	0,72	High
Control Class			
41,34	75,19	0,58	Moderate

The average pretest-posttest score of the experimental class based on Table 7 obtained a pretest score of 50.84 and increased significantly to 86.83 in the posttest score. The N-gain analysis for the experimental class was 0.72 with a high category. The average pretest-posttest score of the control class was not as high as the experimental class with a pretest score of 41.34 and increased to 75.19 in the posttest score. The N-gain analysis for the control class was 0.58 with a moderate category. The comparison of scores between the experimental and control classes showed that the VARK learning style-oriented biotechnology e-LKPD with the PjBL-STEAM model used in the experimental class was more effective than the LKPD used in the control class. In line with Putri & Zulyusri (2025), the integration of PjBL-STEAM in e-LKPD allowed teachers to use the device as a learning medium to facilitate students' a better understanding of science material. The implementation of the PjBL-STEAM model directed students to play an active role in learning by encouraging them to be involved directly in contextual and collaborative activities. Project-based learning facilitated collaboration between students in groups, encouraged discussion, and allowed them to reflect on the learning process and achievements that have been implemented (Maulida & Yulianti, 2025).

This approach aligns with Anjli *et al.* (2023)'s research which argues that the PjBL model is effective in improving students' scientific literacy because PjBL is considered capable of integrating aspects of scientific knowledge, skills, and attitudes simultaneously, thus supporting the formation of students who can understand scientific concepts, have scientific thinking skills and are ready to face real challenges in everyday life. The increase in scientific literacy in the experimental and control classes needs to undergo a t-test to see the significant differences. The initial step in conducting a t-test is to pass a prerequisite test in the form of a normality test for data. The results of the normality test for scientific literacy data can be seen in Table 8.

Table 8. Results of the Normality Test of Science Literacy Data

Class	Sig Level	Sig Score	Criteria
Pretest			
Experimental	0,05	0,20	Normally Distributed
Control		0,20	
Posttest			
Experimental	0,05	0,09	Normally Distributed
Control		0,20	

The pretest-posttest questions based on Table 4.7 obtained the criteria

for normal distribution with a significance value > 0.05 for both the experimental and control classes. This can be concluded that the posttest data is normally distributed. The pretest-posttest data met the prerequisite test so that it can be continued with a t-test. The results of the t-test analysis are shown in Table 4.9.

Table 4. 9 T-test Analysis Results

	t	df	Sig (2-tailed)	Description
Posttest	4,92	62	0,001	There is a difference

Based on the results of the t-test analysis of the posttest data of students in the experimental and control classes as shown in Table 4.9, a sig (2-tailed) value of 0.001 was obtained, which is smaller than the significance level of 0.05, and a t_{count} value of 4.92, which is greater than the t_{table} of 1.69. The test results showed that there is a significant difference in the posttest results between the experimental and control classes. This indicated a significant difference in the increase in scientific literacy between the two groups. Penggunaan LKPD yang berbeda antara kelas eksperimen dan kontrol menjadikan literasi sains siswa memiliki perbedaan. The use of different worksheets (LKPD) between the experimental and control classes resulted in differences in students' scientific literacy. This difference reinforces the positive impact of PjBL-STEAM learning on improving students' scientific literacy. This finding is reinforced by Izzania *et al*. (2025) who found that learning activities using the STEAM approach provide students opportunities to improve their scientific literacy skills holistically. Students explained STEAM aspects in groups after completing a conventional biotechnology project, thus enhancing their scientific literacy skills. Moreover, the VARK feature, which adapts to students' learning styles, can optimize their learning process towards higher scientific literacy skills. In line with what Maulida & Yulianti (2025) argues, e-LKPD created by considering students' learning styles can accommodate their learning needs well. This study shows that the innovation of developing e-LKPD oriented to VARK learning styles with the PjBL-STEAM model can be an effective solution in training students' scientific literacy.

This study demonstrates the overall effectivness of e-LKPD oriented to VARK learning styles with the PjBL-STEAM model in enhancing students' scientific literacy. However, the statistical interaction between the instructional model and learn'rs' preferred learning styles was not specifically analyzed after learning process. A more detailed analysis incorporating interaction testing is therefore recommended for future research in order to determine the extent to which variations in learning preferences moderate the effectivness of the intervention.

This study has limitations related to the population size and characteristics of the sample used. The study subjects only involved a small number of students from a single educational institution, thus, variations in student

characteristics, learning environments, and institutional conditions were not adequately accommodated. This condition results in the research findings remaining contextual and cannot be generalized to a broader population. Therefore, it is recommended to involve a larger sample size and draw from several schools with diverse backgrounds for future research. This expanded population coverage is expected to increase the power of the analysis, enrich the data variety, and produce more accurate, representative, and generalizable findings.

CONCLUSION

The VARK learning style-oriented biotechnology e-LKPD with the PjBL-STEAM model developed through the 4D model was considered eligible and effective for training junior high school students' scientific literacy. The validation analysis of media experts and material experts provided high validity level results with a valid category, while the media readability test received a very good response from students. This means that the e-LKPD met the aspects of content, presentation, language, and appearance eligibility. The implementation of e-LKPD in biotechnology learning was proven to be able to significantly improve students' scientific literacy, which was indicated by the N-gain value in the experimental class with a high category, was superior to the control class, and was strengthened by the results of the t-test which showed that there were significant differences between the two classes. The integration of the contextual PjBL-STEAM model with the VARK learning style adaptation allowed students to engage directly during the learning process, connect science concepts to real-life situations, and optimize diverse learning potential. The findings provide practical implications for classroom implementation, suggesting that teachers can integrate the developed e-LKPD during project exploration and product development phases to facilitate differentiated learning based on students' VARK preferences. Effective implementation requires teachers to possess competencies in digital pedagogy, project facilitation, and multimodal instructional design. From a curriculum perspective, the e-LKPD can be incorporated as a supplementary digital learning resource aligned with competency-based science instruction. Successful adoption also depends on technical readiness, including access to digital devices, stable internet connectivity, and sufficient instructional time allocation. Thus, e-LKPD has the potential to be an alternative, innovative and effective medium in science education, particularly in supporting students' scientific literacy. However, further research with a broader sample size is needed to strengthen the validity and generalizability of the research findings.

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