Biosfer: Jurnal Pendidikan Biologi

Journal homepage: http://journal.unj.ac.id/unj/index.php/biosfer

ARMOD e-module for pre-service teachers: Boosting analytical thinking skills and digital literacy of bioinformatics

Reza Dino Mahardika*, **Hanum Isfaeni, Rusdi**

Magister of Biology Education, Faculty of Mathematics and Natural Science, Universitas Negeri Jakarta, Indonesia

*Corresponding author: rezadino15@gmail.com

ARTICLE INFO

Article history
Received: 19 January 2025
Revised: 04 March 2025
Accepted: 14 March 2025

Keywords:
E-Module
Learning Material
Project Based Learning

ABSTRACT

The rapid development of data and technology in science encourages the collaboration of various disciplines to produce new branches of science, one of which is Bioinformatics, which studies molecular biology data stored in digital databases. The process of studying digital data requires special skills, such as analytical thinking skills and digital literacy. Efforts are needed to improve these two skills, one of which is by applying innovative teaching materials in project-based learning (PjBL). This study aims to determine the effect of the application of ARMOD E-Module teaching materials in PjBL on these two skills. Research with quasi-experimental methods and pretest-posttest control group design was conducted on students of the UNJ biology education study programme. The results showed that the application of ARMOD E-Module in PjBL can increase the average post-test in the aspects of segmentation ability, ability to connect system functions, ability to compare, ability to evaluate which are aspects of analytical thinking. The average post-test increases also occurred in the aspects of information and data literacy, communication and collaboration, digital content creation, security, and problem solving which are all aspects of digital literacy. The results of the one-way MANOVA test between the experimental class and the control class were 0.026, indicating a significant difference. The significant difference is thought to be due to the innovative features of teaching materials used in learning bioinformatics.

INTRODUCTION

The industrial era 4.0 makes almost every aspect of life able to be integrated with technological advances, such as artificial intelligence (AI), internet of things (IoT), 5G, cloud computing, data analysis, and robotics (Moreira et al., 2017; Muktiarni et al., 2019). Technological advances also have an impact on the ease of access and the massive amount of information available on the internet. A large amount of information and data (big data) is stored in the database (Moreira et al., 2017). Big data can be in the form of scientific research results, one example is the Protein Data Base (PDB), which contains research results related to protein structure and function. The information and scientific data available in the database can be utilised in the aspects of industry, education and further research.

The massive archive of research data in databases has led to the formation of new disciplines, such as bioinformatics. It is a multidisciplinary discipline representing a new field of science that develops by using computational approaches to answer biological questions utilizing large and complex data sets (big data) to reach valid biological conclusions (Baxevanis & Ouellette, 2001). Bioinformatics is also known as a dry laboratory (in silico) by using computer algorithms to analyze the sequences of genetic material such as DNA and RNA, analyze a protein, and even test molecules from secondary metabolites of an organism to be used as drug candidates using computer algorithms (Lin et al., 2021).

Bioinformatics requires good analytical thinking skills and digital literacy to process and analyze digital data scattered in databases. Analytical thinking skills are used in determining the information and data stored in the database in the application of bioinformatics in the aspect of new drug design (Qin, 2009). Digital literacy skills play a role in optimally and safely using the three bioinformatics tools, which are the database, web server, and software (Roy, 2019). They are also part of the 21st-century skills that are in high demand (Trilling & Fadel, 2009). Improving both skills in learning is urgently needed. The results of several studies show that both students' analytical thinking skills and digital literacy are relatively low (Hafiza et al., 2022; Prawita et al., 2019). The lack of learning concept construction that can train both skills is one of the causes (Hafiza et al., 2022).

Efforts to improve analytical thinking skills and digital literacy can be done by the implementation of project-based learning (PjBL) models with the implementation of innovative teaching materials, such as the ARMOD E-Module. ARMOD E-Module can display augmented reality technology and innovative features by optimizing multimedia principles in education so that it can comprehensively visualize bioinformatics material and its application in the design of new drugs in silico through molecular docking methods. The PjBL model has a syntax consisting of six stages, namely: Starting with an essential question; Designing a project; Creating a schedule; Monitoring the students and the progress of the project; Assessing the outcome; and Evaluation. Each of these stages is interrelated and can help improve students' thinking skills (Wicaksana et al., 2020). The application of innovative teaching materials in PjBL has a positive effect on learning (Fadhilah & Thahir, 2023). E-modules can display material concepts in the form of images, animations, and videos (Kismiati, 2020). ARMOD E-Module contains material on basic concepts of bioinformatics that is packaged attractively by applying the stages of analytical thinking and is equipped with images, videos, and scientific articles. The teaching material has an Augmented Reality feature that can display the 3D structure of protein molecules and small compounds. Visualization in the form of images and videos assists in understanding process-based (Ristanto et al., 2021)concepts. How can the implementation of the ARMOD E-Module in project-based learning improve analytical thinking skills and digital literacy?

METHODS

Research Design

This research was conducted at Universitas Negeri Jakarta (UNJ), Indonesia. This research used a quasi-experiment method with a pretest-posttest control group design. The research was conducted in the biotechnology course of bioinformatics material in two classes of the Biology Education class of 2022. Both classes were conducted using the PjBL model. In the experimental class, learning uses ARMOD E-Module teaching materials, while in the control class, the teaching materials used are PowerPoint slides.

Learning was conducted for 4x50 minutes of classroom learning and 2 x 50 minutes of online self-learning. Before learning, each respondent was asked to take a pretest consisting of analytical thinking instruments and bioinformatics digital literacy. After the learning is complete, respondents are asked to take a post-test with the same instrument to determine changes in these results. Pretests and post-tests were done on the form provided. The results of the pre-test and post-test became data and were analysed to determine the average difference between the experimental class and the control class.

Population and Samples

The population in this study were all students at universities in Jakarta, Indonesia. The sample determination was carried out by multi-stage random sampling. The administrative city of East Jakarta was selected by personal judgement with a note that the area has 18 universities. The administrative city of East Jakarta has six sub-districts, and Pulo Gadung sub-district, Indonesia was selected by cluster random sampling, and Universitas Negeri Jakarta (UNJ) was chosen as the research location. UNJ was chosen because it has a Biology Education study programme, and one of the lecture materials in it is bioinformatics. Biology Education Class A 2022 and Biology Education Class B 2022 were selected as respondents because both took biotechnology courses with bioinformatics material. The two classes were each selected to be the control class and the experimental class. The selection of samples from the two classes was carried out by simple random sampling, so that 30 samples were selected in each class.

Instrument

This study used two instruments, namely the analytical thinking instrument and the digital literacy instrument. Both instruments were tested for content validity by three expert validators and empirical validity by 20 student samples. Expert validators were selected with the criteria of state university lecturers who are competent in developing test instruments and bioinformatics materials. The following is the lattice of analytical thinking and digital literacy bioinformatics instruments.

Table 1
Bioinformatics analytical thinking instrument framework

Numb.	Basic Analytical Thinking Skills	Bioinformatics Materials		Total
		Basic Concept	Application	
1.	Segmentation capability	7	3	2
2.	Ability to associate system functions	6, 8	9	3
3.	Comparison ability	10	2	2
4.	Evaluation ability	1	4, 5	3
	Total	5	5	10

Table 2
Bioinformatics digital literacy instrument framework

Numb.	Components of Digital Literacy	Bioinformatics Materials		Total
		Basic Concept	Application	
1.	Information and data literacy	1, 2, 35,	8, 9, 14,	**6**
2.	Communication and collaboration	3, 4, 5,	10, 11,	**5**
3.	Digital content creation	6, 7, 17, 18	12, 13, 16, 19, 20,	**9**
4.	Safety	22, 23, 24, 27, 28	21, 25, 26,	**8**
5.	Problem solving	29, 30, 33, 34	15, 31, 32,	**7**
	Total	**19**	**16**	**35**

Procedure

The stages of this research began with the development of analytical thinking instruments and bioinformatics digital literacy. Both instruments were tested for content validity by three expert validators and tested for empirical validation on 20 student samples. The valid instruments will be used in the pre-test before learning and the post-test after learning. Before learning, lecturers and students were conditioned. Lecturer conditioning is carried out by adjusting the model used, namely in the experimental class the implementation of the ARMOD E-Module in the PjBL model, while the control class uses PPT slides in the PjBL model. Student conditioning was carried out by informing each student to bring a laptop for bioinformatics learning.

The learning process is carried out by the PjBL syntax, namely: (1) Starting with an essential question; (2) Designing a project; (3) Creating a schedule; (4) Monitoring the students and the progress of the project; (5) Assessing the outcome; and (6) Evaluation. The final result of the project is a scientific article with a format from a reputable journal. Learning with the PjBL model begins with an essential question: "Indonesia has a lot of medicinal plants with a variety of bioactive compounds, how is a relatively fast and theoretically accurate way to show the potential of these medicinal plants against a disease?" Then, the lecturer, as an educator, divides students into groups of 3 to 5 students. Each group makes a project design and schedule. Each group's progress is displayed on a google doc that can be accessed by the lecturer. The project results are discussed together in class. Each input becomes a project evaluation for each group. The final result of the project is a draft scientific article. Learning was conducted for 4 x 50 minutes of classroom learning and 2 x 50 minutes of online self-learning. Learning begins with a pre-test and ends with a post-test.

Data Analysis Techniques

Pretest and post-test data of analytical thinking and digital literacy of experimental and control classes. These data were subjected to several tests, including descriptive test and hypothesis testing. Descriptive tests were conducted to facilitate understanding of the data consisting of the number of samples, mean, median, highest value, lowest value, and standard deviation. Statistical testing was carried out on pretest and post-test data using the one-way MANOVA test and a level of error (α) of 0.05. One-way MANOVA hypothesis testing can only be done if it fulfils the following nine assumptions.

The increase needs to be done in a one-way MANOVA test to prove the significance of the difference in the improvement of pretest-posttest results in experimental and control classes. Before the test is carried out, first prove the nine assumptions of the one-way MANOVA test, including:

1. Two or more dependent variables must be measured at the interval or ratio level. The dependent variables used in this study are analytical thinking skills and digital literacy. The data for both dependent variables are the post-test results of the experimental class and control class.
2. One or more independent variables consisting of two or more categorical and independent groups. This study used two independent variables, namely the application of ARMOD E-Module in the experimental class and the control class used general teaching materials in the form of PowerPoint slides.
3. Independence of observation or sample data is not related between groups or classes. Students sampled in the experimental and control classes were from different classes, namely biology education classes A (control) and B (experimental).
4. The number of samples is adequate, and the more samples, the better. The number of samples in 30 samples in the experimental class and 30 samples in the control class. The total sample in the two classes used as dependent and independent variables is 60 samples.
5. There are no univariate or multivariate extreme outliers. The Box Plot visualization results show that the data is generally spread around the whisker lines in the analytical thinking and digital literacy post-test results. The dots indicate the respective post-test scores. The dots located in the whisker line region indicate the outliers are still within the normal distribution and there are no extreme outliers. (Fitrianto et al., 2022).

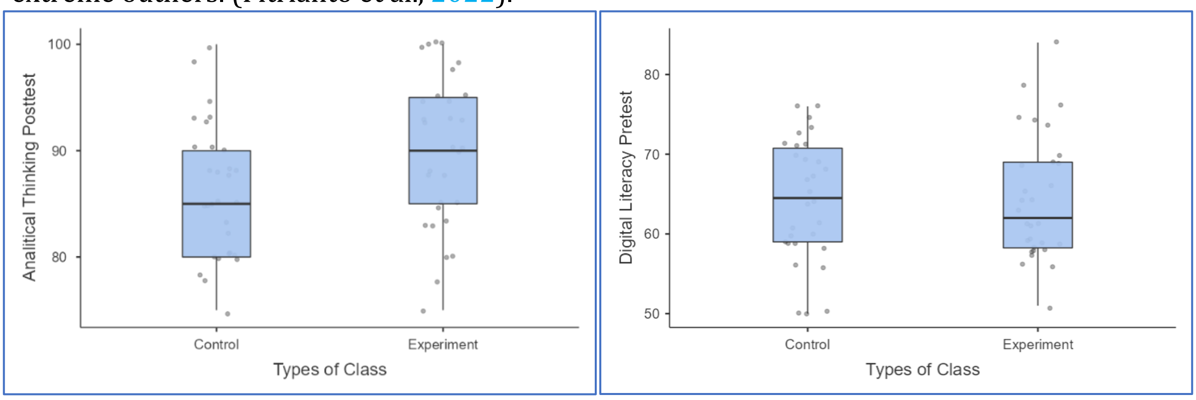

Figure 3. Result of Box Plot test

6. Data is multivariate and normally distributed. This assumption test can be done with the Shapiro-Wilk test. The normality results show a significance value (p) of 0.333. These results are greater than α = 0.05, so it can be said that the data is multivariate normally distributed.

7. There is a linear relationship between each pair of dependent variables for each group of independent variables. This assumption test is shown by the results of the scatterplot matrix. Each point on the plot represents one observation or data. The regression line shows that there is a tendency for the 'Digital Literacy Post-test' score to increase along with the 'Analytical Thinking Post-test' score. This means that, in general, students who have higher 'Analytical Thinking Post-test' scores tend to also have higher 'Digital Literacy Post-test' scores.

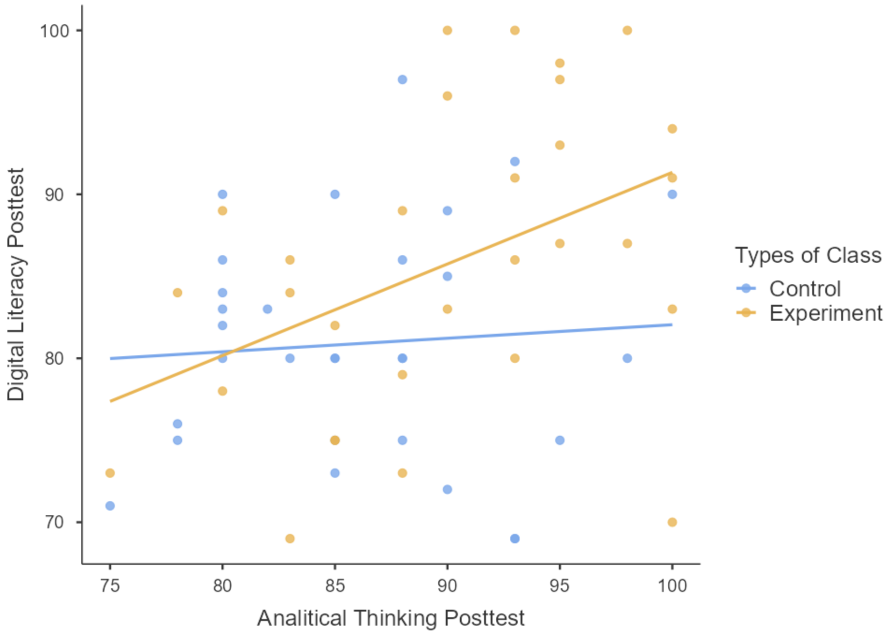

Figure 4. Result of scatterplot analysis

The distribution of data points around the regression line indicates the strength of the relationship between the two variables. The tighter the data points gather around the regression line, the stronger the relationship.

8. Here is the homogeneity of the variance-covariance matrix. This assumption can be shown from the results of Box's M test for covariance equality. A homogeneity test using Box's M test shows a significance value (p) of $0.124 > \alpha = 0.05$, so it can be said that the assumption of homogeneity of the variance-variance matrix is fulfilled.
9. There is no multicollinearity, or independent variables do not affect each other. This assumption test can use the Variance Inflation Factor (VIF) test.

RESULTS AND DISCUSSION

Pretest and post-test data on analytical thinking and digital literacy were taken from 30 samples from each experimental and control class. The data was analyzed using descriptive tests to determine the mean, median, maximum value, minimum value, and standard deviation. Descriptive tests are intended to facilitate understanding of the data collected. The following table shows the descriptive test results.

Table 3 shows the increase in scores from the pre-test and post-test on both dependent variables in the experimental and control classes. The average result of the analytical thinking post-test in the experimental class was 90.0, while in the control class, it was 86.1. The average result between digital literacy post-tests in the experimental class was 85.7.0, while in the control class, it was 80.9. The maximum value in the analytical thinking and digital literacy post-test of the experimental class was 100, while in the control class, it was 100 and 97.0. The increase in post-test scores indicates the positive effect of using the product in learning (Ristanto et al., 2020, 2021). The difference in results shows that there is an increase in the average from before and after learning bioinformatics.

Table 3
Descriptive test results of pretest and post-test of experimental class and control class

Analysis	Types of Class	Analytical Thinking		Digital Literacy	
		Pretest	Post-test	Pretest	Post-test
Mean	Experiment	62.70	90.00	64.40	85.70
	Control	61.10	86.10	64.30	80.90
Median	Experiment	63.00	90.00	62.00	86.00
	Control	60.00	85.00	64.50	80.00
Standard deviation	Experiment	6.88	7.11	7.92	9.19
	Control	7.29	6.24	7.69	7.140
Minimum	Experiment	48.00	75.00	51.00	69.00
	Control	50.00	75.00	50.00	69.00
Maximum	Experiment	75.00	100.00	84.00	100.00
	Control	75.00	100.00	76.00	97.00

These results are supported by the average percentage increase that occurred in all aspects of analytical thinking and digital literacy. The aspects of analytical thinking skills consist of segmentation ability, ability to relate system functions, comparison ability, and evaluation ability. All these aspects have increased after learning. The ARMOD E-Module presents bioinformatics material, which is generally divided into two, namely basic bioinformatics and bioinformatics applications. Basic bioinformatics discusses databases, web servers, and software that become bioinformatics tools. Bioinformatics applications focus on the application of bioinformatics in new drug design. Both sub-materials also showed a percentage increase in the control and experimental classes. The following is a diagram of the percentage increase in analytical thinking skills.

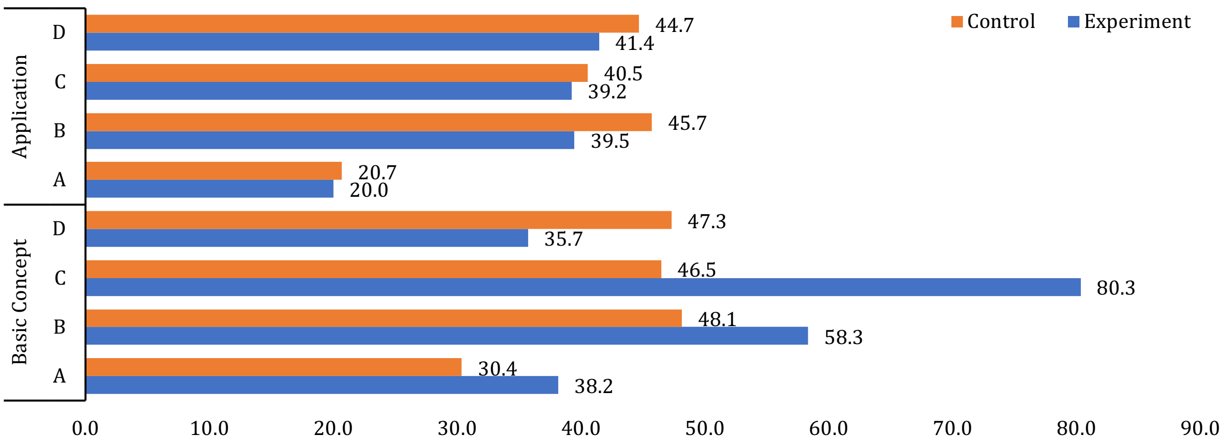

Figure 1. Diagram of the percentage increase in the average analytical thinking skills for each aspect: (A) Segmentation ability; (B) Ability to relate system functions; (C) Comparison ability; & (D) Evaluation ability.

In the basic concepts of bioinformatics, the highest average percentage increase was in the aspect of comparison ability in the experimental class by 80.3%. In general, in the sub-material of the basic concepts of bioinformatics, the improvement in the experimental class was higher than in the control class. Different results were shown in the bioinformatics application sub material. The highest percentage was shown in the aspect of the ability to relate system functions in the control class by 45.7%, and in general, the increase in the control class was higher than the experimental class. The results of the comparative analysis of the two classes in each aspect of analytical thinking skills showed that only aspects of segmentation ability, ability to relate system functions, and ability to compare on the basic concepts of bioinformatics had a greater percentage increase than the control class. Whereas in the bioinformatics application sub material, the percentage increase in analytical thinking of the experimental class was only superior in the aspect of segmentation ability. One possible cause is that the exploration of scientific articles and video tutorials on bioinformatics application sub materials in the control class is broader than the experimental class. Materials that are applications of relevance and dynamic information are in accordance with the development of bioinformatics (Engelberger et al., 2021).

An increase in the average percentage also occurred in the digital literacy variable. Digital literacy consists of aspects of information and data literacy, communication and collaboration, digital content creation, safety, and problem solving. The following is a diagram of the percentage increase in digital literacy skills.

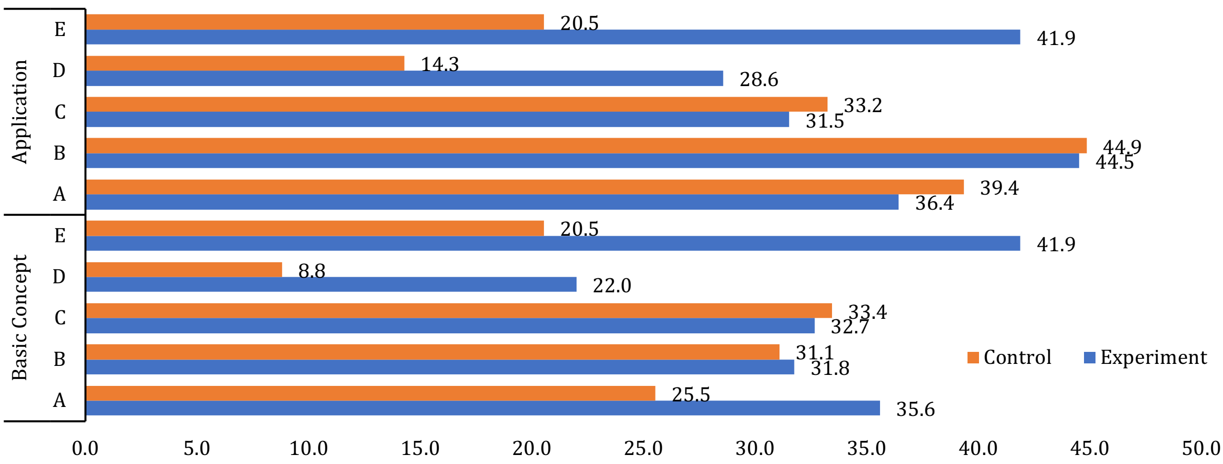

Figure 2. Diagram of the percentage increase in the average digital literacy skills per aspect: (A) Information and data literacy; (B) Communication and collaboration; (C) Digital content creation; (D) Safety; & (E) Problem solving

Different results are shown in the percentage of improvement in digital literacy skills. Overall, the experimental class showed a higher percentage of improvement compared to the control class. In the basic concept of bioinformatics, the highest result was shown by the problem-solving aspect of 41.9% in the experimental class, while in the bioinformatics application sub-material, the result in the communication and collaboration aspect of 44.9% in the control class was the highest. The introduction of the use of digital technology in learning helps learners gain new, purposeful experiences and prepares them for the digital era in the future (Batyrkanovna, 2023). The increase is thought to be due to the ARMOD E-Module encouraging students to gain new digital experiences by exploring digital pages that have good credibility. E-Modules facilitate the explanation and direction of bioinformatics tools that are easy and safe to access and provide procedures for use in writing and in video form. This can help users in getting new digital experiences while still paying attention to user safety so that it can stimulate the improvement of analytical thinking skills.

Table 4
Result of Variance Inflation Factor (VIF) test

	VIF
Pretest Critical thinking	1.00
Pretest Digital literacy	1.00

The VIF analysis results were <5 and showed no multicollinearity. All assumptions are met, so we can proceed to the one-way MANOVA test. The results of the one-way MANOVA test using Jamovi are as follows.

Table 5
Result of one-way MANOVA test

	value	**F**	**df1**	**df2**	**p**
Experiment & Control	0.120	3.89	2	57	0.026

The table shows the results of the one-way MANOVA test based on several types of statistical tests. The purpose of the one-way MANOVA test is to determine the significant difference of one or more independent variables on two or more dependent variables (Hair et al., 2010). The analysis results show a significant value (p) <0.05. These results indicate that there is a difference between the average post-test results of the experimental class and the control class on students' analytical thinking skills and digital literacy. A significant value (p) < α indicates a significant difference between one or two independent variables on more than one dependent variable (Perdana et al., 2019).

The application of digital teaching materials in the PjBL model facilitates students in completing the learning projects they have designed, as well as assisting with practice questions and assessments (Buroidah et al., 2023). The application of ARMOD E-Module helps guide the process of completing the learning project. ARMOD E-Modules have innovative features, namely:

1. Keep Going Literate

Contains material concepts that are packaged concisely. This feature is also equipped with several supporting scientific articles to find out the latest developments regarding bioinformatics and new drug design.

2. *ANTINK TIME* (Analytical Thinking Time)

A page to train analytical thinking skills based on bioinformatics concepts that have been learnt. Contains eight stages that must be filled in according to the concept of analytical thinking.

3. Digital let's try it

An independent practicum page equipped with images, videos, and directions that aim to train digital literacy skills. Users are directed to search and explore bioinformatics tools that have been previously learnt.

4. Quiz Zone

A collection of multiple-choice questions and short fill-in questions about the material presented by ARMOD as a means of practicing understanding the material that has been learned. Quizzes can be done with the educator or independently. Quizzes are also presented through the Quizizz website to make it easier and interesting to display each item.

5. Augmented Reality

An application that must be downloaded and installed on a smartphone. Applications that show 3D images of proteins and ligands with Augmented Reality markerless technology. 3D images can appear on a flat area to help understand the shape of the ligand and target protein thoroughly.

ARMOD E-Module is also equipped with a google docs link to collect assignments to assist lecturers in monitoring project progress in real time. So that the assessment and evaluation process can run without being limited to time and place. Utilizing google docs makes it easier for learners to work together to complete their work in teams and helps educators assess their work in real time (ÓBroin & Raftery, 2011).

Teaching materials in the form of E-Modules provide easy access and interesting presentation of material, and the use of interactive language makes students comfortable in learning the subject matter (Pramana et al., 2020). The application of the latest technology, such as AR in modules also helps in learning. The application of AR technology can effectively combine space, technology, people, and knowledge systems so that they are transformed and connected at any time (Zhao et al., 2020). The availability of AR in the ARMOD E-Module can stimulate users in analytical thinking and digital literacy. AR users can interact with various animated 3D models that represent phenomena and processes originating from the real world without space, time, or security restrictions (Christopoulos & Pellas, 2020). AR technology facilitates the presentation of 3D images of protein structures with a perspective as if they are appearing. The appearance of the 3D image helps present the protein structure as a whole so that users can analyze the entire protein surface and attached molecules. The current AR technology stimulates users to analyze the material and encourages the visual use of digital technology, and perhaps in the future, AR technology can stimulate other senses to facilitate comprehensive learning.

The availability of images, videos, and scientific articles also helps train students in analyzing material (Maulidya et al., 2021). Presentation of material that encourages users to practice material in the digital world, such as hyperlinks and QR-codes, stimulates the development of users' digital skills (Nurlinah et al., 2023). These features and advantages are contained in the ARMOD E-Module. The keep going literate and digital let's try it features are equipped with images, videos, and hyperlinks containing scientific articles or webservers and software related to bioinformatics material. ARMOD E-Module is also equipped with practice questions in the Quiz Zone feature that can be used independently or when studying in class with a lecturer. Interactive digital quizzes can help users measure their understanding of the material they have learned (Noor, 2020).

CONCLUSION

The implementation of the ARMOD E-Module in PjBL proved to have a positive effect on improving analytical thinking skills and digital literacy. ARMOD E-Module is equipped with augmented reality technology and innovative features to facilitate students in completing project stages in the PjBL model. The application of the ARMOD E-Module improves every aspect of analytical thinking skills and digital literacy. There was a significant difference between the class that used the ARMOD E-Module in PjBL and the class that used PPT slides in PjBL. Improvement occurred in every aspect of analytical thinking skills and bioinformatics digital literacy.

ACKNOWLEDGMENT

Thanks are due to the three expert validators who were willing to assess the analytical thinking and digital literacy instruments. Acknowledgements are also addressed to the UNJ biology clusters for their willingness to be the site of this research.

REFERENCES

Batyrkanovna, N. F. (2023). Digital literacy in biology education through mobile learning technologies. *AT-TAWASSUTH: Jurnal Ekonomi Islam*, *VIII*(I), 1–19. https://doi.org/10.63034/esr-14

Baxevanis, A. D., & Ouellette, B. F. F. (2001). Bioinformatics: A Practical Guide to the Analysis of Genes and Proteins (Methods of Biochemical Analysis, 43). In *A John Wiley & Sons, inc., Publication* (Vol. 2, Issue 4). A John Wiley & Sons, inc., Publication. https://doi.org/10.1093/bib/2.4.407

Buroidah, H., Zubaidah, S., & Mahanal, S. (2023). Effects of Project-Based Learning with Project Guide E-book on Critical Thinking and Metacognitive Skills: A Case from Undergraduate Biology Students in Genetic 1 Course. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *11*(2), 240. https://doi.org/10.33394/j-ps.v11i2.6727

Christopoulos, A., & Pellas, N. (2020). Theoretical Foundations of Virtual and Augmented Reality-Supported Learning Analytics. *11th International Conference on Information, Intelligence, Systems and Applications, IISA 2020*. https://doi.org/10.1109/IISA50023.2020.9284410

Cintamulya, I., Warli, & Mawartiningsih, L. (2024). The Development of Project-Based Learning Models That Accommodate the Reflective and Impulsive Cognitive Style. *Studies in Learning and Teaching*, *5*(1), 59–72. https://doi.org/10.46627/silet.v5i1.279

Engelberger, F., Galaz-Davison, P., Bravo, G., Rivera, M., & Ramírez-Sarmiento, C. A. (2021). Developing and Implementing Cloud-Based Tutorials That Combine Bioinformatics Software, Interactive Coding, and Visualization Exercises for Distance Learning on Structural Bioinformatics. *Journal of Chemical Education*, *98*(5), 1801–1807. https://doi.org/10.1021/acs.jchemed.1c00022

Fadhilah, N., & Thahir, R. (2023). Development of Electronic Module with Project based Learning. *Bioeduscience*, *7*(3), 350–357. https://doi.org/10.22236/jbes/11817

Fitrianto, A., Wan Muhamad, W. Z. A., Kriswan, S., & Susetyo, B. (2022). Comparing Outlier Detection Methods using Boxplot Generalized Extreme Studentized Deviate and Sequential Fences. *Aceh International Journal of Science and Technology*, *11*(1), 38–45. https://doi.org/10.13170/aijst.11.1.23809

Hafiza, N., Rahayu, H. M., & Pasah Kahar, A. (2022). The Relationship Between Digital Literacy and Learning Outcomes in Biology Learning for Students. *Jurnal Penelitian Pendidikan IPA*, *8*(1), 171–176. https://doi.org/10.29303/jppipa.v8i1.1067

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). Multivariate Data Analysis.pdf. In *Prentice-Hall: Vol. 7 edition*. Prentice-Hall. https://www.drnishikantjha.com/papersCollection/Multivariate Data Analysis.pdf

Kismiati, D. A. (2020). Implementasi E-Modul Pengayaan Isolasi dan Karakterisasi Bakteri dalam Meningkatkan Kemandirian Belajar Siswa SMA. *ALVEOLI: Jurnal Pendidikan Biologi, 1*(1), 1–10. https://doi.org/10.35719/alveoli.v1i1.1

Lin, Y. F., Lin, C. H., Tsai, S. H., & Lin, M. F. (2021). Application of Bioinformatics in the Internet of Things-Construction of Mushroom Cloud Digital Learning Platform. *Journal of Physics: Conference Series*, *1873*(1). https://doi.org/10.1088/1742-6596/1873/1/012057

Maulidya, H. Z., Aprilia, N., & Hanafi, Y. (2021). Studi Literatur Peningkatan Kemampuan Analisis Siswa

Melalui Model PBL Pada Pembelajaran IPA Biologi. *Journal of Biology Learning*, *3*(2), 55. https://doi.org/10.32585/jbl.v3i2.1526
Moreira, F., Ferreira, M. J., & Cardoso, A. (2017). Higher Education Disruption Through IoT and Big Data : *Springer International Publishing AG 2017*, *1*, 389–405. https://doi.org/10.1007/978-3-319-58509-3
Muktiarni, M., Widiaty, I., Abdullah, A. G., Ana, A., & Yulia, C. (2019). Digitalisation trend in education during industry 4.0. *Journal of Physics: Conference Series*, *1402*(7), 0–6. https://doi.org/10.1088/1742-6596/1402/7/077070
Noor, S. (2020). Penggunaan Quizizz Dalam Penilaian Pembelajaran Pada Materi Ruang Lingkup Biologi Untuk Meningkatkan Hasil Belajar Siswa Kelas X.6 SMA 7 Banjarmasin. *Jurnal Pendidikan Hayati*, *6*(1), 1–7. https://doi.org/10.33654/jph.v1i1.927
Nurlinah, Hartono, & Murnihati. (2023). Integrasi Teknologi Pembelajaran dalam Upaya untuk Meningkatkan Literasi Digital Siswa SMA Kelas XI SMA Negeri 1 Pangkep. *Jurnal Pemikiran Dan Pengembangan Pembelajaran*, *5*(2), 1131–1136. https://doi.org/10.31970/pendidikan.v5i2.746
ÓBroin, D., & Raftery, D. (2011). Using Google Docs To Support Project-Based Learning. *AISHE-J: The All Ireland Journal of Teaching & Learning in Higher Education*, *3*(1), 35.1-35.11. https://doi.org/10.62707/aishej.v3i1.35
Perdana, R., Jumadi, J., & Rosana, D. (2019). Relationship between Analytical Thinking Skill and Scientific Argumentation Using PBL with Interactive CK 12 Simulation. *International Journal on Social and Education Sciences*, *1*(1), 16–23. https://interactives.ck12.org/simulations/physics.html.
Pramana, M. W. A., Jampel, I. N., & Pudjawan, K. (2020). Meningkatkan Hasil Belajar Biologi Melalui E-Modul Berbasis Problem Based Learning. *Jurnal Edutech Undiksha*, *8*(2), 17. https://doi.org/10.23887/jeu.v8i2.28921
Prawita, W., Prayitno, B. A., & Sugiyarto. (2019). Effectiveness of a generative learning-based biology module to improve the analytical thinking skills of the students with high and low reading motivation. *International Journal of Instruction*, *12*(1), 1459–1476. https://doi.org/10.29333/iji.2019.12193a
Qin, H. (2009). Teaching computational thinking through bioinformatics to biology students. *SIGCSE'09 - Proceedings of the 40th ACM Technical Symposium on Computer Science Education*, *March 2009*, 188–191. https://doi.org/10.1145/1508865.1508932
Ristanto, R. H., Mahardika, R. D., & Rusdi. (2021). Digital flipbook immunopedia (DFI): A learning media to improve conceptual of immune system. *IOP Conference Series: Earth and Environmental Science*, *1796*(1), 1–11. https://doi.org/10.1088/1742-6596/1796/1/012066
Ristanto, R. H., Rusdi, Mahardika, R. D., Darmawan, E., & Ismirawati, N. (2020). Digital Flipbook Imunopedia (DFI) A Development in Immune System e-Learning Media. *International Journal of Interactive Mobile Technologies*, *14*(19), 140–162. https://doi.org/10.3991/ijim.v14i19.16795
Roy, K. (2019). *Multi-Target Drug Design Using Chem-Bioinformatic Approaches*. Springer Science.
Trilling, B., & Fadel, C. (2009). *21st Century Skills, Enhanced Edition: Learning for Life in Our Times*. Jossey-Bass.
Wicaksana, E. J., Atmaja, P., & Muthia, G. A. (2020). Jurnal Pendidikan Biologi. *Jurnal Pendidikan Biologi*, *12*(1), 22–29. https://doi.org/10.21009/biosferjpb.v13n2.230-249
Zhao, X., Li, X., Wang, J., & Shi, C. (2020). Augmented Reality (AR) Learning Application Based on the Perspective of Situational Learning: High Efficiency Study of Combination of Virtual and Real. *Psychology*, *11*(09), 1340–1348. https://doi.org/10.4236/psych.2020.119086