



Assimilation: Indonesian Journal of Biology Education

ISSN 2621-7260 (Online)

Journal homepage: <https://ejournal.upi.edu/index.php/asimilasi>



Development of an augmented reality-assisted e-module on the virus topic to improve students' conceptual understanding and learning independence

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ARTICLE HISTORY

Received: 10 October 2025

First Revised: 10 November 2025

Accepted: 23 November 2025

First Available Online: 23 November 2025

Publication Date: 23 November 2025

KEYWORDS

Augmented reality

Conceptual understanding

E-module

Learning independence

Learning resources

ABSTRACT

The research and development aims to produce learning resources in the form of augmented reality-assisted e-modules on virus concepts that are: (1) suitable for use, (2) practical, and (3) effective for improving concept understanding and learning independence of high school grade X students. This type of research was research and development, using the development model ADDIE (Analysis, Design, Development, Implementation, and Evaluation). The data analysis technique used was the MANOVA test with a significance level of 0.05. The results of this research and development are the product of an assisted e-module learning resource augmented reality on virus concept for high school class X, with the following results: (1) feasible based on the results of the validity test by concept experts, media experts, and trials with students, (2) effective based on concept understanding test data, and student learning independence questionnaire, and (3) practical based on practicality questionnaire data. The data from the test results obtained a significance value of 0.013. This value shows the value obtained < 0.05 . Therefore, it can be stated that there is a significant influence of the use of assisted e-modules augmented reality on viral concept to increase concept understanding and student learning independence.



INTRODUCTION

Learning objectives can be achieved well and efficiently, namely through strong internal factors and supporting external factors. One of the internal factors that becomes a problem in learning and can influence the achievement of learning objectives is understanding the concept being studied. Understanding the concept is part of the cognitive aspect. According to W.J.S Poerwodarminto in Rahayuningsih (2018), the word "understand" comes from the word "understanding", which means "to know or comprehend something correctly". Conceptual understanding is a key factor in successfully achieving learning objectives. However, difficulties in conceptual understanding still frequently arise in the context of biology learning. The challenges faced by students in understanding the concept in biology learning are found in abstract concept, according to the results of research by Fazira et al. (2022) conducted at MAS AL MANAR Pulo Raja, where most students still have a low understanding of biology concepts, especially regarding the scope of biology. One of the factors is the existence of obstacles in understanding the concept, because teachers only provide abstract information without showing real-life examples of what is being taught. Topic about viruses is one of the most challenging topics in the complex field of biology (Augustine et al., 2020). In Indonesia, virus material is taught in the tenth grade. The results of interviews and field observations indicate that students' understanding of biology is still relatively low. This is evident in the fact that some students are unable to explain biology concept that has been previously studied, provide examples, or classify subtopics within previous concept.

This condition may affect their understanding of viruses, as students not only lack prior knowledge but also feel that learning about viruses is not particularly important. Of the 30 students interviewed, 65% felt that it was difficult to understand viruses because there were so many names or types of viruses and the structure of viruses could not be visualised using only images or videos, as the structure of viruses is invisible or abstract. This problem was caused by the limitations of visual media in providing interesting and interactive learning. The problems that arise in the field can have an impact on the suboptimal understanding of the concept by students, as well as influencing low learning achievement in the cognitive domain. This condition is reinforced by the results of research by Widyaningrum & Anggaraini (2023) and Parani et al., (2023), who stated that the most challenging aspects of virus-related concept in Grade X biology lessons were the types of viruses and the virus life cycle, specifically the difficulty in memorising virus names and structures, as well as the concept of viruses transforming into particles containing living components within host cells, which are often abstract and challenging for students to grasp. Therefore, Anderson and Krathwohl as examined in Larsen et al. (2022), classify Bloom's taxonomy of understanding into several cognitive processes that serve as tools for measuring students' conceptual understanding, including the ability to interpret, provide examples, classify, summarize, infer, compare, and explain.

Achieving the learning objectives of virus material is not only influenced by understanding the concept as a cognitive aspect, but also involves affective and psychomotor aspects, one of which is learning independence. The term "learning independence" is related to things such as self-regulated learning, self-directed learning, and self-determined learning. In this study, learning independence refers to self-regulated learning. Zimmerman (2002) defines self-regulated learning as the level of an individual's metacognitive, motivational, and behavioural involvement in managing their own learning process. Learning independence can be measured by applying self-regulation strategies in the form of processes and activities aimed at acquiring information and skills involving perception, goals, and the use of instruments by students. Furthermore Zimmerman (2002) explains that there are 14 categories of strategies commonly used by students to improve learning independence, including: self-evaluation, organisation and transformation, goal setting and planning, seeking information (friends, teachers, other people), recording or monitoring (reading notes, previous exam questions, textbooks), learning environment

arrangement, self-reinforcement, practice and memorisation, seeking social assistance, reviewing notes, and other parties.

The results of interviews and observations of students in the field show that students' learning independence is still low. Students still depend on teachers as a source of learning and only carry out tasks based on teachers' instructions. This indicates that students' learning attitudes are still dependent on others. Furthermore, students are not active in learning. Based on observations in the classroom, only 30% to 40% of the 31 students present were active, either asking questions or discussing the lesson. This is related to students' confidence and belief in their ability to achieve their learning objectives. Furthermore, regarding student motivation in learning, especially in biology, independent students must be able to explore learning independently. Therefore, low independence needs to be encouraged through appropriate teaching concepts or learning media. These so that learning independence becomes a factor that motivates students to master the taught concept issues must be addressed, according to research conducted by Albana & Sujarwo (2021) it was found that increased understanding is not gained from knowledge and skills alone, but from mastery of the learning process carried out during the learning period.

Limitations in teaching methods and concepts are one of the external factors that influence the achievement of learning objectives of virus material. In fact, based on student interviews and observations in the field, the use of learning resources and teaching concepts in schools is still limited, particularly in biology education. The learning resources used primarily rely on printed modules provided by the education department as the main source, combined with student worksheets (LKS) for practical activities, and occasionally using PowerPoint presentations or educational videos. Meanwhile, 100% of students use gadgets in their daily lives, so this should be an opportunity that must be utilized, considering that complex and abstract virus material requires teaching materials that can visualize abstract virus concepts. As a result, students lack enthusiasm and motivation in participating in biology lessons, leading to suboptimal learning activities in the classroom. This contrasts with the findings of Serevina *et al.* (2018), who stated that the use of e-modules as a learning resource by teachers aims to stimulate critical thinking, emotions, interest, and enhance student motivation.

The explanation of the problem above shows the need for a solution in the form of appropriate learning guidelines so that students can be served and achieve the learning objectives that have been set. One alternative learning resource that is appropriate and effective is electronic modules. Electronic modules are considered important for students to understand concepts well, and are also important for encouraging students to develop good independent learning skills (Lathifah *et al.*, 2021). Printed modules tend to be monotonous and less appealing to students, resulting in low enthusiasm for learning and suboptimal mastery of concepts (Herawati & Muhtadi, 2018). One effort to increase the appeal of modules is to design them in an interactive digital format, as interactive digital modules have been shown to enhance students' interest in learning (Fitriani *et al.*, 2025; Hanatan *et al.*, 2023). This electronic format allows for the integration of various features, not only text, images, and videos, but also multimedia elements such as animations, quizzes, and simulations, which enrich the learning process, especially in the study of virus-related concepts. According to Mayer's (2017) multimedia learning principles, the combination of words and dynamic visual elements presented in an interactive format can significantly improve learners' engagement and understanding, thereby strengthening the rationale for using interactive e-modules in complex scientific topics. In addition, e-modules are able to train students to evaluate ideas based on predetermined criteria (Larasati, 2020). Student characteristics, varying learning abilities, and the nature of the subject matter are factors that must be considered in the development of interactive electronic modules, given that viruses are microscopic (very small) organisms and their form is abstract, they cannot be seen with the naked eye. Furthermore, to ensure that students can understand scientific terms in virus-related concepts, the presentation and delivery of content in learning activities should not rely solely on illustrations in the form of images or videos. A solution that can be applied is the use of augmented

reality (AR) technology, which can display visualisations of subject matter objects in a more realistic and interactive manner, thereby providing a more interactive and in-depth learning experience, especially for abstract subject matter such as viruses.

AR-assisted electronic modules on viruses can be used as an alternative and solution for implementing the teaching and learning process on virus concept, providing students with access to learning resources that can be used independently outside the classroom. The presentation of virus-related concept is not limited to images and videos; it also includes 3D visuals that realistically depict the objects being studied, enabling augmented reality technology to help visualise abstract concepts and significantly enhance students' understanding. As previous research conducted by Sholikha et al. (2024) showed that AR-based PBL products are a new and efficient way to improve students' understanding of complex and microscopic biology concept, particularly viruses. This was further supported by the research results of Puspita et al. (2024), who stated that AR-assisted design thinking-based e-modules can improve mathematical creative thinking skills. The use of AR which can visualise abstract objects in a real, interactive, and multimedia manner using smartphones, and the use of non-marker AR can also support flexible learning that can be accessed anywhere and anytime. Therefore, AR-assisted e-modules can also enhance students' learning independence, as stated by Belanisa et al. (2022) that interactive e-modules also help teachers and students learn more easily, enhance student independence, and improve enjoyable learning experiences. Based on the previous research, which only focused on understanding the concept or on independence, and the developed products were only based on augmented reality and on mathematics concept or subjects, there are AR assisted e-modules but their focus is on improving mathematical creative thinking skills. This development research aims to develop an AR-assisted e-module as an innovative solution to overcome students' learning problems related to concept comprehension and to improve students' learning independence in learning about viruses. This development is expected to help students understand the concept of viruses comprehensively while improving their independent learning attitudes

METHODS

The type of research used in this study is research and development (R&D). The purpose of R&D is to create a specific product and evaluate its effectiveness. The main objective of this research is to develop a product in the form of an augmented reality-assisted e-module using the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) development model according to Branch (2009). The product developed is a three-dimensional (3D) augmented reality-assisted e-module designed using the Unity Engine application. This product is used as teaching concept for Biology lessons in grade X at SMAN 1 Seyegan, Yogyakarta. Observations, interviews, questionnaires, and tests were used to collect data in this study. The instruments used include a media expert questionnaire to assess validity, a concept expert questionnaire to assess validity, a student feedback or practicality questionnaire, a questionnaire to measure the effectiveness of student learning independence, and a test to assess student understanding of the concept before and after participating in learning using AR-assisted e-modules on virus concept.

Data analysis in this study includes product validation data analysis, instrument validity and reliability, product practicality analysis, and effectiveness analysis. Product validation and practicality analysis were measured using a Likert scale. The analysis of the validation data for the e-module product currently under development can be assessed as valid or non-valid based on a scale determined in accordance with the guidelines in Table 1, adapted from Argubhy & Sumbawati (2017).

Instrument validity analysis for item testing used the Corrected Item Total Correlation technique, and reliability testing used the Cronbach's Alpha test with the SPSS application. The instrument for assessing concept comprehension consisted of 20 questions, with a significance level of (<0.05). The reliability test results showed that the Alpha value of the item reliability test

for concept understanding was 0.936, indicating that the reliability of the items for measuring students' understanding of the concept in virus learning using AR-assisted e-modules is highly reliable with an Alpha value above 0.70 (Cho & Kim, 2014). Then, the item test of the learning independence instrument, the number of items tested was 25 items. Based on the minimum correlation coefficient limit that can be seen in the r-Product Moment table for 30 respondents, which is 0.361, all items tested can be declared valid or feasible because the Corrected Item-Total Correlation value is above 0.361. The reliability test results showed that the Alpha value of the learning independence test items was 0.984, indicating that the reliability of the test items for measuring students' learning independence in virus learning using AR-assisted e-modules was very reliable with an Alpha value above 0.70 (Cho & Kim, 2014). The concept validity test was conducted a teacher and education practitioner in the field of biology.

Table 1. Likert scale validity test

Percentage	Criteria	Description of Achievements
85.01–100.00	Highly valid	e-Module can use without revision
70.01–85.00	Valid	Usable but minor revisions
50.01–70.00	Less valid	It is recommended not to use
01.00–50.00	Invalid	Must not be used

Product practicality analysis, conducted through questionnaires filled out by students and teachers, with the aim of determining the practicality level of the developed e-module. This practicality level can be measured using a modified Likert scale, as shown in Table 2 (Riduwan, 2018).

Table 2. Likert scale product practicality

Achievement Level	Categories
$80\% < x \leq 100\%$	Very practical
$60\% < x \leq 80\%$	Practical
$40\% < x \leq 60\%$	Sufficiently practical
$20\% < x \leq 40\%$	Less practical
$0\% < x \leq 20\%$	Not practical

Data analysis to assess effectiveness using the SPSS application includes prerequisite tests (normality and homogeneity tests), as well as limited MANOVA to measure the significance of X to Y1 and Y2, with a significance level of 0.05.

RESULTS AND DISCUSSION

The results of research and development are e-modules assisted by augmented reality (AR) technology. The e-modules were developed in the form of an Android-based application using Unity 3D and Vuforia software. The e-module focuses on virus-related concept in the biology curriculum for Grade X students. The use of AR technology in this e-module aims to serve as an alternative learning resource in the form of three-dimensional instructional concepts that can be used as supplementary learning concepts to support the learning process effectively and efficiently, particularly in understanding virus-related concept, as well as a flexible learning resource that can be accessed anytime and anywhere to support students' independence in learning. The development of the e-module product was carried out using the ADDIE model, with each step implemented systematically. The description of the results of the AR-assisted e-module product development can be presented as follows.

Analysis

During the analysis stage, a preliminary study was conducted to identify the problems faced by students in learning about viruses. The methods or approaches used included interviews with biology teachers of Grade X and several Grade X students, followed by document analysis and direct interaction with students. The analysis stage consisted of needs analysis, curriculum analysis, environmental analysis, and student characteristics analysis. Needs analysis consists of a gap between the current situation and the results of the analysis, namely teaching materials that only use specified printed modules, and virus material that requires teaching materials that contain material and present information, visualisation, and evaluation, which are expected to help students understand the material and attract them to study independently, as well as to assist teachers in facilitating learning with 3D visualisation so that abstract material can be easily understood and students are interested in learning more. The appropriate form of activity is to develop AR-assisted e-modules as learning guides. The target of this research and development is Grade X students at SMAN 1 Seyegan.

Curriculum analysis aims to ensure that the AR-assisted e-module teaching materials developed are in accordance with the requirements of the curriculum used. Biology learning in schools has implemented an independent curriculum in the learning process, along with the established learning outcomes and learning objectives. The third analysis is an analysis of the environment and student characteristics. The identification of the initial behaviour and characteristics of prospective students is based on the judgement that the students are aged between 16 and 17 years old, use kinesthetic and visual learning styles, and have a low level of understanding of the material and independence in learning about viruses, due to the limited use of teaching materials and learning media in the teaching of virus material.

Design

After conducting a needs analysis at SMAN 1 Seyegan, the next stage is to design the product to be developed, namely an AR-assisted e-module on viruses. The design stages and results are explained in Table 3.

Table 3. Design stage and results

Design Stage	Results
a. Determining the Evaluation	The evaluation is divided into two parts, namely evaluation of research products and evaluation of products (assignments) in learning. Product evaluation is carried out through product validation, including: instrument validation, expert validation (material and media), and product testing (practicality and effectiveness). Evaluation of learning in products is divided into three parts, namely: individual assignments, practice questions, and self-reflection. Individual assignments and exercises in this e-module are based on predetermined learning outcomes and objectives, as well as Bloom's taxonomy of learning levels (comprehension), and self-reflection related to students' responses to the product.
b. Compiling Learning Objectives	Compiling learning objectives based on predetermined learning outcomes. Among other things, students will be able to correctly identify the characteristics of viruses, provide examples and correctly classify virus types, correctly compare the harmful and beneficial roles of viruses, correctly explain the structure of viruses, the virus replication cycle, and the prevention and treatment of viral infections, and correctly summarise the material on viruses.
c. Compiling Concepts	E-modules present material based on learning objectives. The material is taken from reliable sources.

Design Stage	Results
d. Selecting Formats	The format of the e-modules developed includes: The material is divided into two learning activities, the material is presented with theory, images, 3D, and colour combinations to make students more interested in learning, applications used in product development include Canva for editing materials and design, Blender for creating 3D animations, and Unity 3D, Android Studio, and Vuforia to create a fully AR-assisted e-module in the form of an application. The AR-assisted e-module is presented in the form of an application (APK) for Android-based mobile phones. The background colour used is light green, and the font colour used is Lato with a dark brown hue.
e. Designing the Product Display	Consisting of content outline, flowchart, screen design and storyboard. The content outline consists of cover, home page, introduction, instructions for use, preface, CP & TP, concept map, materials, bibliography, glossary, evaluation, developer profiles. Some of the results of the screen design and storyboard development can be seen in Figure 1.

Development

The development stage involves the creation of an AR-assisted e-module on viruses for X grade high school students based on the results of the previous stages, starting from analysis and design. In the product development stage, the e-module is built from scratch using the software specified in the previous stage. The development stage consists of the preparation and development of the initial e-module product, conducting formative evaluation consisting of instrument and e-module product validation by experts, individual testing, revising the results of the revisions by experts and individual testing, and small group testing. The product display is as follows.

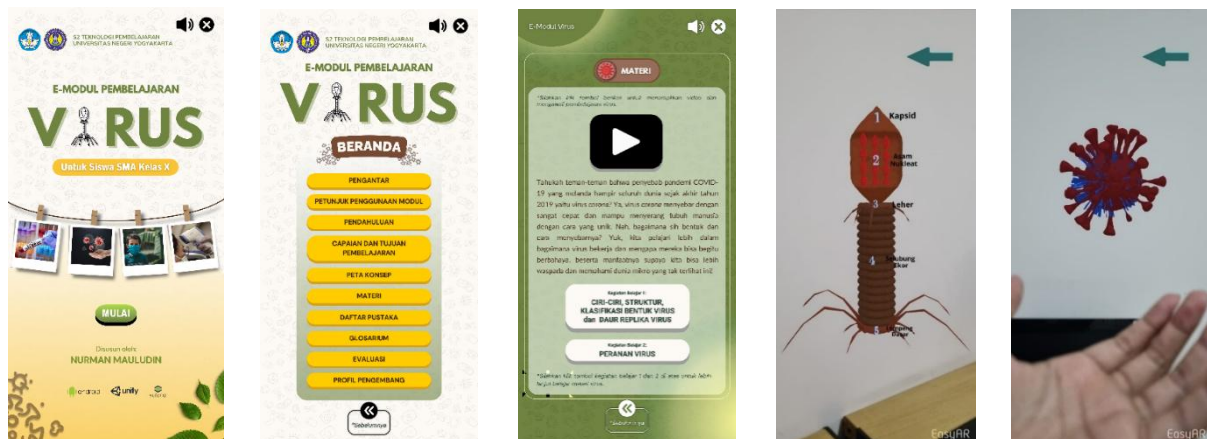


Figure 1. E-Module display

The initial display consists of the e-module cover. Some of the menus include introduction, module usage instructions, overview, learning outcomes and objectives, concept map, concepts, references, glossary, evaluation, and developer profile. The initial concept display includes a learning video as a learning stimulus, and the concept is divided into two learning activities. The 3D object display in the AR-assisted e-module on viruses contains two objects, supported by other concept such as educational videos and quizzes.

Implementation

The implementation or field-testing phase was conducted at SMAN 1 Seyegan, specifically in class X. Students in the experimental class were given the opportunity to use AR-assisted e-modules during lessons and outside of class. Data was then collected by asking students to complete

comprehension tests, independence questionnaires, and responses to the product. The results of the study in Table 7 showed that students responded positively to the use of AR-assisted e-modules. They stated that these modules were more practical and easier to understand than regular textbooks. The AR feature was considered helpful in clarifying concepts that were previously difficult to understand through text or two-dimensional images alone. Furthermore, most students stated that they felt motivated to study independently at home because learning through e-modules was more enjoyable and interactive.

Evaluation

The evaluation stage involves formative and summative evaluations of the effectiveness and efficiency of the initial product. The e-modules that have been created are then implemented to obtain data and findings that indicate the need for evaluation. The purpose of the evaluation is to improve the quality and effectiveness of the product used. This evaluation also includes reflection on technical challenges, such as the limited devices available to some students, as the product was only developed for Android devices and not yet compatible with iOS for iPhone users. Overall, this AR-assisted e-module is considered highly potential for further development and broader implementation. The evaluation results serve as an important foundation for further revisions, ensuring that the AR-assisted e-module can better meet learning needs and enhance the learning experience.

Test results

The product testing results demonstrate the practicality, effectiveness, and validation of the product during the development of the AR-assisted e-module on virus-related concept. The validity test was theoretically evaluated by experts in the field. The validation results indicated that no instruments were categorized as not ready for data collection, and the research instruments were deemed valid in terms of construct and ready for use after revision. The instruments that have been tested by experts were then empirically tested using students from class XI of SMAN 1 Seyegan. The empirical test was conducted using reliability analysis to test the validity of the questions and the reliability of the instruments. This analysis was used to determine the consistency of the instruments when repeated. The validity of the questions assessing concept comprehension was analyzed using SPSS with Pearson's correlation coefficient because the questions were multiple-choice. To verify the validity of the instrument assessing independence, the Corrected Item Total Correlation method was used via SPSS. Reliability was assessed using Cronbach's Alpha to determine the consistency of the measurement tool. The results of the instrument test can be seen in the methods section above.

Concept validity testing was conducted by experts in the field. Concept validity tests are conducted by two experts. The results of the concept suitability assessment for AR-supported e-modules on the topic of viruses, based on evaluation by subject matter experts, can be seen in Table 4 and Table 5 below.

Table 4. Result of the E-module content validity 1

No	Indicator	Maximum Score	Total Score	Percentage	Category
1	Preliminary Aspects	15	13	87	Very Valid
2	Content Aspect	55	48	87	Very Valid
3	Learning Aspects	35	30	86	Very Valid
4	Summary Aspects	10	9	90	Very Valid
5	Task/Exercise and Evaluation Aspects	20	17	85	Very Valid
Average				87	Very Valid

Table 5. Result of the E-module content validity 1

No	Indicator	Maximum Score	Total Score	Percentage	Category
1	Preliminary Aspects	15	13	87	Very Valid
2	Content Aspect	55	49	89	Very Valid
3	Learning Aspects	35	32	91	Very Valid
4	Summary Aspects	10	9	90	Very Valid
5	Task/Exercise and Evaluation Aspects	20	17	85	Very Valid
Average				87	Very Valid

The overall score obtained from all aspects of the evaluated concept is 87% and is categorized as highly suitable. Therefore, based on the results of the concept suitability test above, the AR-assisted e-module on viruses is categorized as highly suitable or very valid.

The results of testing the AR-supported electronic module on the topic of viruses, according to media experts, can be seen in Table 6 below.

Table 6. Media validity results

No	Indicator	Maximum Score	Total Score	Percentage	Category
1	Aspect Alignment with Competencies	20	17	85	Very Valid
2	Linguistic Aspects	20	17	85	Very Valid
3	Presentation Aspects	35	30	86	Very Valid
4	Graphic Design	65	57	88	Very Valid
5	Usability	10	8	80	Valid
Average				86	Very Valid

The total score obtained from all aspects of the concept assessed is 86% and is categorized as highly suitable.

Practicality tests were conducted as a form of direct evaluation by users, and were carried out during the trial, more precisely after the learning process was completed. The data on the results of the practicality tests according to students on the AR-assisted e-module product on viruses that had been developed can be seen in Table 7 below.

Table 7. Practicality results by students

No	Indicator	Maximum Score	Total Score	Percentage	Category
1	Learning Aspect	1550	1301	84	Very Practical
2	Appearance	1395	1183	85	Very Practical
3	Benefit Aspects	775	672	87	Very Practical
Average				85	Very Practical

The overall average score obtained from all aspects is 85% and is categorized as very practical.

Table 8. Practicality results by teachers

No	Indicator	Maximum Score	Total Score	Percentage	Category
1	Learning Aspect	50	43	86	Very Practical
2	Content Aspects	25	21	84	Very Practical

No	Indicator	Maximum Score	Total Score	Percentage	Category
3	Benefit Aspects	20	17	85	Very Practical
4	Media Display	30	26	86	Very Practical
Average				85	Very Practical

The practicality results according to teachers in Table 8 above also show the total overall score obtained from all aspects, with an average of 85%, categorized as very practical.

The results of testing the effectiveness of the AR-supported e-learning module on the concept of viruses on student understanding and independent learning were obtained from test scores given twice, namely before (pre-test) and after (post-test) learning. After the data was obtained, it was then calculated statistically with prerequisite tests, namely normality and homogeneity, to then test the hypothesis using the MANOVA technique with SPSS.

The test was given to two classes, namely the experimental class and the control class. There was a difference after the treatment was administered to both classes (experimental and control), namely, the experimental class showed a much larger difference in the average score between the pre-test and post-test scores compared to the difference in the average score between the pre-test and post-test scores in the control class. The results of the students' comprehension test on these concepts can be seen in Table 9 and Table 10 below.

Table 9. Results of the effectiveness of concept comprehension in the experimental class

<i>Pretest</i>			<i>Post-test</i>			Difference
Score Obtained	Ideal Score	Average	Score Obtained	Ideal Score	Average	
2200	3100	70.97	2665	3100	85.96	14.99
Category		Good	Category		Very Good	

The average score between the initial and final tests in the experimental class in Table 9 shows an increase from 70.97 to 85.96. This indicates an increase in the average score of 14.9 from the pretest to the posttest.

Table 10. Results of effectiveness on concept understanding in the control class

<i>Pretest</i>			<i>Post-test</i>			Difference
Score Obtained	Ideal Score	Average	Score Obtained	Ideal Score	Average	
2295	3200	71.72	2370	3200	74.06	2,34
Category		Good	Category		Good	

The average score between the pretest and posttest in the control class in Table 10 shows an increase from 71.72 to 74.06. This shows that there was an increase in the average score of only 2.34 from the pretest to the posttest.

The results of the effectiveness test of the AR-assisted e-module on virus concept on student learning independence were obtained from the student learning independence questionnaire scores that had been tested twice, namely before (pre-test) and after (post-test) learning. After the treatment, both classes (experimental and control) showed differences, namely, the experimental class showed a larger difference in the average score between the pre-test and post-test scores compared to the difference in the average score between the pre-test and post-test scores in the control class. The results of the student learning independence questionnaire can be seen in Tables 11 and 12 below.

The average score between the pretest and posttest in the experimental class in Table 11 shows an increase from 64.77 to 74.06. This indicates an increase in the average score of only 9.29 from the pretest to the posttest.

Table 11. Results of the effectiveness of learning independence in the experimental class

<i>Pretest</i>			<i>Post-test</i>			Difference
Score Obtained	Ideal Score	Average	Score Obtained	Ideal Score	Average	
2510	3875	64.77	2943	3875	74.06	9.29
Category			Category			
Sufficient			Good			

Table 12. Results of effectiveness on learning independence in the control class

<i>Pretest</i>			<i>Post-test</i>			Difference
Score Obtained	Ideal Score	Average	Score Obtained	Ideal Score	Average	
2595	4000	64.88	2716	4000	67.9	3.02
Category			Category			
Sufficient			Sufficient			

The average score between the pretest and posttest in the control class in Table 12 shows an increase from 64.88 to 67.9. This indicates an increase in the average score of only 3.02 from the pretest to the posttest. Although there was an increase in scores, the scores obtained from the pretest and posttest on the variable of student learning independence in the experimental group or class were 9.29, which was higher than the control class, which only had an average score increase of 3.02.

To calculate the effectiveness of the product, a normality test was conducted using the Shapiro-Wilk test in SPSS software with a significance level of $\alpha = 0.05$. The results of the normality test can be seen in Table 13 below.

Table 13. Test of normality

Tests of Normality							
		Kolmogorov-Smirnov^a			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Understanding the Material	Experiment	.096	31	.200*	.969	31	.493
	Control	.139	31	.134	.964	31	.374
Learning Independence	Experiment	.134	31	.169	.939	31	.077
	Control	.114	31	.200*	.967	31	.431

*.This is a lower bound of the true significance

a. Lilliefors Significance Correction

Based on Table 13, the significance value for the results of students' understanding of the material in both classes (experimental = 0.493 and control = 0.374) is greater than the α value = 0.05, which means it is normally distributed. Then, the significance value for the results of student learning independence in both classes (experimental = 0.077 and control = 0.431) is greater than the value of $\alpha = 0.05$, which means that it is normally distributed.

After the normality test, a homogeneity test was conducted using PSPP software with Levene's Test based on the mean value with a significance level of $\alpha = 0.05$. The results of the normality test can be seen in Table 14 below.

Table 14. Test of homogeneity of variance

Tests of Homogeneity of Variance						
		Levene Statistic	df1	df2	Sig.	
Understanding the Material	Based on Mean	.044	1	60	.834	
Learning Independence	Based on Mean	.126	1	60	.724	

Based on Table 14, the significance value for the students' understanding of the material scores (significance = 0.834) is greater than the α value = 0.05. Then, the significance value for the students' learning independence results obtained (significance = 0.724) is also greater than the α value = 0.05, which means that the data on students' material comprehension scores and learning independence are homogeneous.

After conducting both prerequisite tests, the next step is to test the hypothesis using MANOVA statistical analysis with SPSS software. The results of the MANOVA test on students' material comprehension and learning independence using the SPSS application are presented in Table 15 below.

Table 15. Tests of hypotheses 1&2

Tests of Between-Subjects Effects						
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Group	Understanding the Material	1451.613	1	1451.613	4.393	.040
	Learning Independence	1356.452	1	1356.452	4.661	.035

Based on Table 15 above, the significant value for students' understanding of the material obtained is 0.040. This means that the significance obtained ($0.040 < 0.05$), so H_0 is rejected, and it can be concluded that there is an effect of using AR-assisted e-modules on students' understanding of the material. Then, the significant value for learning independence obtained is 0.035. This means that the significance obtained ($0.035 < 0.05$), so H_0 is rejected, and it can be concluded that there is an effect of using AR-assisted e-modules on virus material on students' learning independence. The third hypothesis test can be seen in Table 16 below.

Table 16. Test of hypothesis 3

Multivariate Tests^a						
Effect		Value	F	Hypothesis df	Error df	Sig.
Group	Wilks' Lambda	.862	4.724 ^b	2.000	59.000	.013

Based on Table 16, the significant value obtained is 0.013. This means that the significance obtained ($0.013 < 0.05$). Therefore, H_0 is rejected, so it can be concluded that there is a simultaneous effect of the use of AR-assisted e-modules on students' understanding of the material and their learning independence.

This development research uses the ADDIE (analysis, design, development, implementation, evaluation) development model. This development research uses the ADDIE model (analysis, design, development, implementation, evaluation). Recent studies indicate that the ADDIE model continues to serve as a reliable and validated framework for developing effective digital learning materials, including interactive multimedia Husen et al. (2024) and AR-assisted e-modules designed to enhance students' reasoning skills (Syaharani et al., 2024). This model is also used to implement learning tools systematically (Nichols Hees & Greer, 2016). The validity and practicality of AR-assisted e-modules on viruses can be seen from various aspects, one of which is the validity of the concept, which is largely determined by the relevance of the content to the 3D illustrations of viruses, which help promote students' understanding of the concept and independent learning, coupled with several features such as usage instructions, concept, summaries, evaluations, and reflections. The results of the effectiveness test show that the use of AR-assisted e-modules on virus concept can significantly influence students' understanding of the concept. This aligns with the findings of Chao et al. (2016) who stated that the application of augmented reality in learning can have positive impacts on learning, such as enhancing students' understanding of conceptual concept.

The aspects with the highest scores in the experimental class were presenting examples and nonexamples of a concept, followed by the ability to classify and the ability to conclude. These three aspects were the most influential factors in the students' understanding of the concept in the experimental class. The ability to classify and present examples and non-examples was obtained from questions that presented illustrations based on the concept presented through images, videos, and 3D animations. Therefore, it can be concluded that the use of images, videos, and 3D animations can significantly influence concept comprehension, consistent with Mayer (2009) multimedia learning theory, which outlines principles such as redundancy, coherence, contiguity, segmentation, modality, and multimedia integration in e-modules to enhance students' understanding of the concept. The ability to draw conclusions can be obtained from the presence of summaries and the appropriate organization of concept without excessive information. However, the increase in the difference in scores before and after using the e-module indicates that all aspects of concept comprehension can improve.

The aspects of information search, goal setting and planning, self-evaluation, and active learning were the highest-scoring indicators, indicating that these four aspects had the strongest influence on students' learning independence in the experimental class. The improvement in goal setting and planning was supported by the introductory component of the e-module, which includes the module identity, learning outcomes, learning objectives, and instructions for using the AR-assisted e-module. These elements reflect Simon's constructivist learning theory as presented in Ivers and Barron (2002), which emphasizes goal-oriented learning.

In addition, the inclusion of navigation buttons (such as "Next" and "Back") provides learners with control over pacing and sequencing, enabling them to regulate their learning process more effectively. Empirical studies have shown that such learner-controlled pacing can reduce cognitive load and improve transfer performance Tabbers & de Koeijer (2010), while interactive navigation features in digital learning environments also enhance student engagement and support more meaningful learning experiences (Fauziyah *et al.*, 2024).

The aspects of information search, self-evaluation, and active participation in learning also showed a significant influence. These improvements stem from the use of e-module components such as conceptual explanations and self-evaluation activities, which align with constructivist principles namely that learning should be active, integrative, and reflective. Furthermore, based on Mayer's (2009) multimedia learning theory, the principles of multimedia, interactivity, and personalization encourage students to actively engage with the e-module during learning. This is consistent with the findings of Saprudin *et al.* (2022), who state that AR-assisted e-modules support students' learning independence, reduce their reliance on teachers, and accommodate differences in learning levels and learning pace.

CONCLUSION

The research and development conducted involved the development of augmented reality-assisted e-modules on virus concept using the ADDIE development model (analysis, design, development, implementation, evaluation). The augmented reality-assisted e-modules on virus concept to improve students' understanding of the concept and independence in learning were declared suitable for use. Feasibility was based on the results of validation by subject matter experts, with a score of 87% in the highly feasible category, and by media experts, with a score of 86% in the highly feasible category. The augmented reality-assisted e-module product on virus concept to improve students' understanding of the concept and independent learning was declared practical for use. The practicality is based on the results of practicality tests by students with a score of 85% in the very practical category and practicality tests by teachers with a score of 85% in the very practical category. There is a difference in concept comprehension and student learning independence between those who use augmented reality-assisted e-modules on virus concept and those who do not. The differences in concept comprehension and learning

independence were analyzed based on a MANOVA test with a significant value of 0.040 for students' understanding of material, then obtained a value of 0.035 for students' learning independence, and obtained a value of 0.013 for students' concept comprehension and learning independence. These values indicate that the obtained values are < 0.05 , which means that H_0 is rejected and H_a is accepted. It can be stated that there is a significant effect of the use of AR-assisted e-modules on virus concept on improving students' understanding of virus concept and learning independence.

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Acknowledgment

Researcher would like to thank the university which funded this research and the participants who were involved in this research.

Authors' Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

How to Cite this Article

Mauludin, N., Ismaniati, C., & Rassyi, S. F., (2025). Development of an augmented reality-assisted e-module on the virus topic to improve students' conceptual understanding and learning independence. *Assimilation: Indonesian Journal of Biology Education*, 8(2), 241-256. <https://doi.org/10.17509/aijbe.v8i2.91025>