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Guided Inquiry Module Based on Augmented Reality to Improve Cognitive Learning Outcomes and Science Process Skills in Biology Technology Innovation

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ABSTRACT
Biology learning, particularly in biological technology innovation such as genetic engineering, often encounters challenges due to the complex and abstract nature of the material and limited school practicum facilities. These factors lead to low cognitive learning outcomes and weak science process skills. To address this, innovative learning media that can visualize abstract concepts interactively and support independent learning are needed. This study aims to develop a guided inquiry module based on Augmented Reality (AR) to enhance students' cognitive learning outcomes and science process skills on the topic of biological technology innovation. Using the ADDIE development model—Analyze, Design, Develop, Implement, and Evaluate—the research involved a systematic process. The analysis stage used interviews, observations, and questionnaires to identify learning challenges. The design and development stages integrated interactive AR visualizations, guided inquiry activities, and Higher Order Thinking Skills (HOTS)-based exercises. The module was validated by material, media, and learning experts to ensure content accuracy and instructional feasibility. Implementation employed a quasi-experimental design with control and experimental groups given pre-tests and post-tests to measure learning gains. Evaluation included formative and summative assessments. Findings show that the AR-based guided inquiry module is feasible, practical, and effective in improving cognitive achievement and science process skills, while also increasing engagement and motivation in biology learning.

Keywords: Guided Inquiry, Augmented Reality, Cognitive Learning Outcomes, Science Process Skills, Biology Innovation

INTRODUCTION

Major changes in various sectors of life have occurred, especially after the Covid-19 pandemic, which paralyzed almost all social and economic aspects. According to Chonsawat and Sopadang (2021), the social sector has entered the era of social revolution 5.0, while the technology sector is now in the era of industrial revolution 4.0. These changes have had a broad impact on the lives of the global community (Agyeman, Schlosberg, Craven, & Matthews, 2016; Díaz et al., 2019). People who can adapt will benefit, while those who struggle to adapt will be left behind. This condition requires every country to be agile in facing challenges arising from social and technological changes (Neumann et al., 2021).

Responding to the social and technological revolution requires a well-prepared strategy, especially in the field of education, which is the main foundation for preparing quality human resources (Shahroom & Hussin, 2018). Education is viewed as a key sector that can produce a competent generation capable of optimizing technology for the welfare of society (Kipper et al., 2021). The Law of the Republic of Indonesia No. 20 of 2003 concerning the National Education System emphasizes that learning must involve the interaction of teachers, students,

and learning resources within a learning environment. According to Aripin (2019), this communication process involves teachers as senders, students as receivers of messages, and subject matter as the core content of the message.

Learning media are vital components in supporting educational success. Effective media can convey information appropriately and enhance student learning outcomes (Ramli, 2015). Conversely, inappropriate media may cause differences in perception between teachers and students, making comprehension difficult. According to Haddoud (2021), media that provide direct experiences make knowledge more concrete because they engage all the senses. Furthermore, media suited to students' characteristics encourage independent learning and foster student-centered approaches (Halimovna et al., 2021).

One of the technologies resulting from the industrial revolution 4.0 that is relevant to education is Augmented Reality (AR) (Salam et al., 2018; Septian, Susilowati, & Zulkarnain, 2021). AR technology integrates digital elements in the form of text, images, audio, and video into real environments, making them appear as though they are physically present before the students (Fernandez-Garcia, 2021; Hammer et al., 2021). According to Mubai et al. (2020), AR uses objects as markers to display 3D content, simulations, and practicum videos. Research by Tasrif et al. (2020) and Djati (2022) shows that AR has been proven to improve higher-order thinking skills and student learning outcomes. This aligns with the characteristics of Generation Z, who possess strong technological abilities and tend to prefer independent learning (Kusumaningtyas, 2019).

To support independent learning, one of the teaching materials frequently used is the module. Modules are structured learning materials that contain content, methods, and evaluations designed for independent study (Ertikanto, 2017). The use of modules has been shown to improve students' understanding (Hamsu, 2017) as well as learning outcomes, as evidenced by Chasanah (2019) and Gemuruh et al. (2022). Nevertheless, the limitations of conventional modules remain apparent, particularly in modern biotechnology topics such as genetic engineering, which require authentic practicum experience, high costs, and advanced equipment (How, Ta, Thanh, & Ping, 2025; Modupe & Abass, n.d.; Schmitt, Golüke, & Budisa, 2024; Tasnim, 2024).

The effectiveness of modules or learning media increases when combined with an appropriate learning model. In biotechnology materials, the guided inquiry model is one suitable alternative (Yolida, 2021). This model emphasizes students' analytical processes in discovering solutions to problems under teachers' guidance (Lovisia, 2018). Inquiry-based characteristics, which demand active student engagement, foster confidence, and develop science process skills (PPP) (Al-Tabany, 2017; Karim et al., 2021), align with the objectives of biotechnology learning.

Based on interviews with biology teachers at SMAN 1 Kedunggalar, students tend to easily understand conventional biotechnology because they are accustomed to simple practicums, such as making tempeh. However, they face difficulties in genetic engineering topics due to limited facilities and high costs. Observations show that learning is still teacher-

centered, students rarely conduct independent investigations, and science process skills have not been fully optimized (Goldschmidt, Scharfenberg, & Bogner, 2016; Ndaimehafo Asilevi, Kärkkäinen, Sormunen, & Havu-Nuutinen, 2024; Tang, 2023). This underscores the urgency of implementing AR-based modules integrated with a guided inquiry model to bridge the gap in practicum facilities.

Biotechnology was selected as the research focus due to its high complexity, its importance in the development of science and technology, and the practical skills it demands. With the limited laboratory facilities available in schools, developing an AR-based guided inquiry module is expected to be a solution for improving students' cognitive learning outcomes and science process skills. This innovation is also relevant to implementing the Independent Curriculum, which encourages active, creative, and student-centered learning. Therefore, this research aims to develop an AR-based guided inquiry module on biotechnology materials as an innovative effort to enhance the quality of biology education.

The benefits of this research encompass both theoretical and practical aspects. Theoretically, developing an Augmented Reality (AR)-based guided inquiry module enriches learning theory by supporting constructivism, reinforcing experiential learning, and contributing to academic studies on the effectiveness of AR in science education. Practically, this module assists teachers in improving the quality of abstract and complex biology learning, making lessons more interactive and engaging, increasing student motivation, and cultivating critical and scientific thinking skills through a structured inquiry process.

METHOD

The type of research used is development research or what is often called Research and Development (R&D). Development research is research that is carried out by developing a product or developing a product that has existed before (Sugiyono, 2017). This development research aims to produce an Augmented Reality-based guided inquiry module that can improve students' cognitive learning outcomes and science process skills on biological technology innovation materials. The development model used in this study is ADDIE (Analyze, Design, Develop, Implement, and Evaluate) developed by Robert Maribe Branch (Branch, 2019). The ADDIE model consists of five stages of development, namely: 1) Analysis, 2) Design, 3) Development, 4) Implementation, and 5) Evaluation. Each stage in this model is designed to ensure that the resulting product is not only relevant to the needs of students but also effective in improving their understanding and skills (Branch, 2019). The research on the development of an Augmented Reality-based guided inquiry module will be carried out at SMA Negeri 1 Kedunggalar. The research population used was students of class X, who would be the subjects to test the effectiveness of the modules in improving cognitive learning outcomes and science process skills.

This research was carried out at SMA Negeri 1 Kedunggalar, which is located in Ngawi Regency, East Java Province. The selection of this school is based on the consideration that

the school has implemented the Independent Curriculum and has students who are in accordance with the module development target, namely class X students.

The population in this study is all students of class X of SMA Negeri 1 Kedunggalar for the 2024/2025 school year. This population was chosen because it is in accordance with the purpose of developing modules focused on Biological Technology Innovation materials taught in class X according to the Independent Curriculum. The research sample consisted of two classes taken using cluster random sampling techniques from the class X population. One class was designated as an experimental class using an AR-based guided inquiry module, and the other class was a control class using conventional learning. Each class consists of 30 students, so the total sample is 60 students.

The data collection techniques in this study were carried out through interviews, observations, questionnaires, and tests. The interview was used to obtain information on the development needs of Augmented Reality (AR)-based guided inquiry modules, including curriculum, biology materials that are difficult to understand, learning strategies, media used, learning constraints, and the availability of technology facilities in schools. Observations are carried out to assess the implementation of each learning step in accordance with the design of the developed module. Meanwhile, the questionnaire was used to explore students' responses regarding the biology learning experience, the feasibility and practicality of the module, and its effectiveness in improving learning outcomes. Tests are given in the form of pre-tests and post-tests to measure the improvement of students' cognitive learning outcomes and science process skills after the use of the module.

The data collection instruments used include various forms of questionnaires and tests. The questionnaire consists of initial observation (need assessment) for students, teacher interview guides, material aspect assessment questionnaires by material experts, media aspect assessment questionnaires by media experts, and product assessment questionnaires by teachers and students. In addition, a learning interest questionnaire was also provided that measured changes in students' motivation and involvement in biology learning using AR-based modules. Each questionnaire is validated by experts before being used so that the results obtained are in accordance with the research objectives.

The test instrument consists of a science process skill test and a cognitive learning outcome test. The science process skills test is in the form of essay questions that assess students' ability to make observations, analyze data, and draw scientific conclusions. Meanwhile, the cognitive learning outcome test is in the form of multiple choice and essays to measure understanding of biological concepts, especially technological innovation materials. These two tests are administered in the control and experimental classes in the form of pre-tests and post-tests, and are validated by experts before implementation, so that the resulting data can be used to objectively assess the effectiveness of AR-based guided inquiry modules.

The development procedure in this study uses the ADDIE model proposed by Robert Maribe Branch (2020), which includes the Analyze, Design, Develop, Implement, and

Evaluate stages. In the analysis stage, the researcher identified biology learning problems, especially biological technology innovation materials, through interviews and observations to obtain data related to the needs of teaching materials, student activities, and the availability of learning facilities. Furthermore, at the design stage, the researcher designed an Augmented Reality (AR)-based guided inquiry module by paying attention to the suitability of the material, the selection of AR-based interactive features, the preparation of inquiry-based activities, the practice of HOTS questions, and the design of an attractive and easy-to-use interface. The development stage realizes the design of the module into a learning product that is validated by material experts, media experts, and learning experts; Feedback from the validators is then used to improve the module to make it more usable. After that, the implementation stage was carried out with field trials using pseudo-experiment designs, dividing students into control and experimental groups, and carrying out pre-tests and post-tests to measure the effectiveness of the modules. The last stage is evaluation, both formative at each stage to ensure the feasibility of the product, and summative after all stages are completed to assess the effectiveness of the module in improving students' cognitive learning outcomes and science process skills.

RESULTS AND DISCUSSION

A. Initial Product Development

In the analysis stage of the ADDIE model, the researcher identified the needs and problems that exist related to the learning of biological technology innovation materials in grade X of high school. Based on the results of this analysis, the learning objectives to be achieved can be formulated with clear expertise, and Augmented Reality-based guided inquiry modules can be developed to meet more effective and engaging learning needs.

1.Analysis

1) Preliminary Study

Analysis of the use of learning media in schools shows that the media used so far tends to be conventional and less attractive to students, especially in biology learning. Learning media such as pointers (PowerPoint) and printed books are more widely used as a means of conveying information, which in fact often causes students to feel monotonous and less involved in the learning process. This leads to low interest in learning and active involvement of students in learning. According to Ramli (2015), effective learning media must be able to convey information in a way that facilitates a hands-on learning experience for students, which can increase their understanding and engagement. Meanwhile, Haddoud (2021) stated that students' knowledge will be more concrete if they can interact directly with learning materials through media that involves all human senses.

Biology learning in schools is often focused on texts delivered by teachers, without any innovation in the use of media. This causes learning to seem static, with no opportunity for students to explore and hone their thinking skills independently. For example, observations show that during the biology learning process, the role of the teacher is more dominant, and

students tend to only take notes of explanations delivered through PowerPoint or textbooks, without actively engaging in experiments or discussions. This condition slows down the development of students' science process skills, such as critical thinking and problem-solving, which are crucial in achieving optimal learning outcomes.

To increase the effectiveness of learning, innovation is needed in the use of technology-based media that is more interactive and in accordance with the character of students. The use of technology such as simulations, learning videos, or digital teaching aids can provide a more engaging and immersive learning experience for students, as well as encourage them to learn independently.

2) Student Analysis

The analysis of students was focused on the characteristics of high school class X students who were the subjects of the study. Based on information in the field, students tend to face difficulties in understanding abstract and technical material, such as biological technology innovations. In addition, many students are more interested in learning that involves technology and methods that are interactive. Therefore, a learning approach is needed that can stimulate their interest, one of which is through the use of Augmented Reality (AR) which can provide a more visual and interesting learning experience.

3) Curriculum Analysis

Curriculum analysis on the Independent Curriculum at SMA Negeri 1 Kedunggalar shows that this curriculum emphasizes the development of student competencies that are more holistic and applicative, with the main goal of preparing students to face the challenges of the times. Learning Outcomes (CP) in phase E at the end of high school targets students' ability to create solutions to problems that arise based on local, national, and global issues. The material taught includes the diversity of living things, their role in ecosystems, viruses, biotechnology, as well as interactions between ecosystem components and environmental changes. Although these goals are relevant to the educational needs of the 21st century, the implementation of this curriculum in class X still faces obstacles in the form of limited learning facilities and effective modules, which affect student learning outcomes, especially in cognitive aspects.

The Merdeka Curriculum aims to enable students to understand biological concepts in depth and applicability, as well as to connect the knowledge gained with natural phenomena around them. However, during the learning process, the dominance of the teacher's role in providing explanations and the limitations of learning media make students tend to be passive, so that critical thinking skills and knowledge application skills are hampered. For this reason, this research aims to develop Augmented Reality (AR)-based modules to improve students' cognitive learning outcomes and science process skills, especially in biological technology innovation materials.

The application of AR technology as a learning medium is expected to be able to overcome the limitations of existing facilities and modules, and have a positive impact on student learning outcomes in accordance with the desired outcomes in the Independent

Curriculum. This AR module is designed to support competency-based learning, while improving students' science process skills in the context of biology learning. Thus, the development of AR-based modules is expected to strengthen the implementation of the Independent Curriculum, especially in improving the quality of learning and student learning outcomes at SMA Negeri 1 Kedunggalar.

4) Analysis of Biology Concepts

The analysis of biological concepts in this study focuses on the application of biology learning which is still predominantly teacher-centered and does not actively involve students, especially in developing science process skills (PPP) in biotechnology materials. Based on the results of observations and interviews with Mrs. Suci Rahayu, a biology teacher at SMA Negeri 1 Kedunggalar, it was found that biology learning still relies a lot on lecture methods, recording material from textbooks and presentations using power points, which makes students less involved in the learning process. This hinders the development of critical and creative thinking skills, especially in understanding modern biotechnology materials such as genetic engineering which requires practicums with expensive tools and costs. In addition, the practicum activities carried out are limited to simple experiments, so students have not reached higher stages in science skills, such as formulating hypotheses, conducting experiments independently, and presenting the results. Augmented Reality (AR) technology, which has not been widely applied in biology learning in schools, has great potential to help students understand abstract concepts in biotechnology in a more realistic and interactive way. Therefore, the development of AR-based modules in biotechnology learning is expected to improve students' cognitive understanding and their science process skills, while addressing the limitations that exist in practicum facilities.

b.Design

1) Determining classes and materials

In this study, the selection of classes and materials strongly considered the context and needs of students at SMA Negeri 1 Kedunggalar. Class X was chosen as the subject of the field trial because they are studying modern biotechnology, specifically the sub-material of genetic engineering, which is a major challenge in students' understanding. Meanwhile, the material taught will be adapted to the Independent Curriculum which emphasizes a competency-based and student-centered approach. Using this approach, this research aims to develop science process skills (PPP) through a more interactive and practical method, considering the limitations of existing practicum facilities.

2) Determining the content of the Augmented Reality-Based Guided Inquiry Module

The determination of AR content should be done taking into account the relevance of the material being taught, particularly as it relates to modern biotechnology topics, such as genetic engineering. The AR content developed is expected to facilitate students' understanding of complex concepts through more interactive and realistic visual representations, such as simulations of genetic engineering processes or three-dimensional modeling of DNA molecular structures. This will provide an opportunity for students to better

understand material that is difficult to understand with just static text or images. The language aspect in the presentation of content is also an important concern to ensure that the material presented is easy for students to understand, taking into account their level of scientific language understanding. The assessment of the AR module by biology teachers in class X will be a crucial step to evaluate the feasibility and practicality of the module, both in terms of the suitability of the material with the curriculum, scientific accuracy, and effectiveness in supporting the development of students' science process skills. Thus, the determination of AR content is expected to improve students' cognitive learning outcomes and practical skills in biotechnology materials, as well as provide solutions to the limitations of practicum facilities in schools.

3) Determining the design of the creation of an Augmented Reality-Based Guided Inquiry Module

The design phase of the Augmented Reality (AR)-based guided inquiry module involves several important steps designed to ensure the successful development of modules that are effective and fit the learning objectives.

(a) Content creation process of Augmented Reality-Based Guided Inquiry Module

The process of creating Augmented Reality (AR)-based Guided Inquiry Module content involves several interrelated strategic stages. First, needs analysis and the formulation of learning objectives are carried out to ensure that the modules are in harmony with the curriculum and characteristics of students. Furthermore, a structured inquiry learning scenario is designed with stages such as formulating a problem, designing a hypothesis, conducting a virtual experiment through AR elements, analyzing data, and drawing conclusions.

The development of AR visual content is carried out by integrating 3D objects or interactive simulations that can be accessed through mobile devices. After the digital content is completed, it is validated by material and media experts to ensure its scientific accuracy and technical suitability. The final stage includes a limited trial to learners to evaluate the effectiveness and attractiveness of the modules before being widely applied in the learning environment.

(b) Defining a pipeline in an E-LKPD

Determining the flow in the E-LKPD (Electronic Learner Worksheet) is a crucial step to ensure integration between learning objectives, student activities, and expected outcomes. The next stage is investigation, where students carry out inquiry activities such as formulating hypotheses, collecting and analyzing data, and interpreting results. The E-LKPD is then directed to the stage of reflection and drawing conclusions based on student findings, ending with an evaluation to measure comprehension and competency achievement.

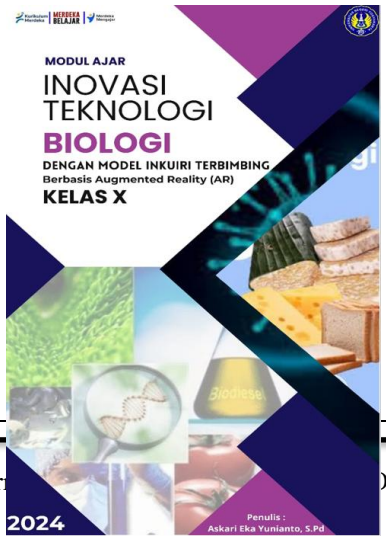
2) Revised Results

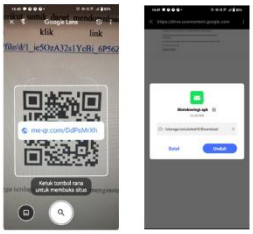
The results of the revision based on input from the validators show that there is an improvement in the quality of the module to be more in line with its development goals as technology-based independent teaching materials. First, the title of the product that was originally written as "teaching module" has been adjusted to "module" only, considering that

this module is intended for direct use by students, not as a teacher's learning tool. Furthermore, in the instructions for use section, documentation in the form of photos has been replaced with screenshots to make the display clearer, more aesthetic, and easier to understand by users. In addition, the part of the assessment criteria that is considered less relevant or not in accordance with the characteristics of the module has been removed, in order to maintain the consistency of the content and focus of the module on the inquiry learning process. This revision is expected to increase the effectiveness and attractiveness of the module in supporting independent Augmented Reality-based learning.

b. Implementation

The implementation began in the even semester by involving high school class X students in biological technology innovation materials, especially biotechnology. The subjects in the field trial were high school class X students from five classes. Of the five classes, two classes were randomly selected through a lottery process to be used as a control class and an experimental class. The experimental class will use a guided inquiry module equipped with augmented reality technology, while the control class will undergo learning using conventional methods. At this stage, the inquiry module is guided by using the Augmented Reality (AR) method which is used as the main learning medium. The types of questions presented include essay-style questions that focus on learning outcomes such as understanding biological technology innovations, analyzing the application of biotechnology, and evaluating impacts in various aspects of life. In this implementation, students are invited to get to know AR modules and applications through a brief introduction. Implementation steps start from material orientation, the use of AR applications to visualize concepts, to guidance in answering questions based on an inquiry approach. Participants conduct virtual experiments, analyze data, and present results in report or presentation format. This module is designed to improve science process (PPP) skills such as observation, planning, data analysis, and communication of results using modern technology, so that learning becomes more interactive and effective.

Before validation	Validator's Advice	After repairs
	Product Title is not a teaching module, but only a module	

2. Download aplikasi hingga terdapat notifikasi untuk menginstall aplikasi 	In the instructions for use, do not use the photos, replace them with screenshots to make them better	2. Download aplikasi hingga terdapat notifikasi untuk menginstall aplikasi 
B. PERMASALAHAN Tempe merupakan bahan makanan yang sangat popular di Indonesia yang dibuat dengan cara fermentasi kedelai. Jamur yang digunakan dalam proses fermentasi tempe adalah *Rhizopus oligosporus* dan *Rhizopus oryzae*. Tahapan pembuatan tempe meliputi perendaman, penggilingan, pencucian, perebusan, pendinginan, penambahan ragi, pengemasan, dan fermentasi.  **Gambar 1.** Tempe MODUL INOVASI TEKNOLOGI BIOLOGI	In the module, add appropriate images2 to make it interesting (remember, the main purpose of module development is to facilitate students to learn independently → must be interesting)	**B. PERMASALAHAN** Tempe merupakan bahan makanan yang sangat popular di Indonesia yang dibuat dengan cara fermentasi kedelai. Jamur yang digunakan dalam proses fermentasi tempe adalah *Rhizopus oligosporus* dan *Rhizopus oryzae*. Tahapan pembuatan tempe meliputi perendaman, penggilingan, pencucian, perebusan, pendinginan, penambahan ragi, pengemasan, dan fermentasi.  **Gambar 1.** Tempe MODUL INOVASI TEKNOLOGI BIOLOGI
Rubrik Penilaian Soal Pilihan Ganda No Soal / Kunci Jawaban / Kriteria Penilaian / Skor Soal Kognitif 1 Jawaban : c) Penerapan prinsip biologi untuk menghasilkan produk yang bermanfaat 1 2 Jawaban : b) Bioteknologi konvensional menggunakan teknologi sederhana, sedangkan bioteknologi modern menggunakan rekayasa genetika. 1 3 Jawaban : a) Energi dari senyawa sederhana menjadi senyawa kompleks 1 4 Jawaban : a) Tempe 1 5 Jawaban : b) Kehadiran mikroorganisme lain yang tidak diinginkan 1 6 Jawaban : a) Tidak memerlukan teknologi canggih 1 7 Jawaban : b) Teknologi yang menambahkan elemen virtual ke dunia nyata melalui perangkat tertentu 1 8 Jawaban : b) Penggunaan AR untuk visualisasi mikroskopis struktur sel atau molekul 1 9 Jawaban : a) Penggunaan mikroorganisme untuk menghasilkan vaksin 1 10 Jawaban : e) Produksi tanaman obat secara komersial dengan teknik kultur jaringan 1 11 Jawaban : b) Melibatkan prinsip rekayasa genetika dan teknologi canggih lainnya. 1	Assessment Criteria Removed	**RUBRIK PENILAIAN** No Soal / Kunci Jawaban / Skor 1 Jawaban : c) Penerapan prinsip biologi untuk menghasilkan produk yang bermanfaat 2 2 Jawaban : b) Bioteknologi konvensional menggunakan teknologi sederhana, sedangkan bioteknologi modern menggunakan rekayasa genetika. 2 3 Jawaban : a) Energi dari senyawa sederhana menjadi senyawa kompleks 2 4 Jawaban : a) Tempe 2 5 Jawaban : b) Kehadiran mikroorganisme lain yang tidak diinginkan 2 6 Jawaban : a) Tidak memerlukan teknologi canggih 2 7 Jawaban : b) Teknologi yang menambahkan elemen virtual ke dunia nyata melalui perangkat tertentu 2 8 Jawaban : b) Penggunaan AR untuk visualisasi mikroskopis struktur sel atau molekul 2 9 Jawaban : a) Penggunaan mikroorganisme untuk menghasilkan vaksin 2 10 Jawaban : e) Produksi tanaman obat secara komersial dengan teknik kultur jaringan 2 11 Jawaban : b) Melibatkan prinsip rekayasa genetika dan teknologi canggih lainnya. 2 12 Jawaban : b) Perbaikan genetik dapat dilakukan secara terarah dan efektif. 2 13 Jawaban : c) Modifikasi genetik dengan memasukkan gen dari bakteri seperti *Bacillus thuringiensis* (Bt) untuk ketahanan hama. 2 14 Jawaban : c) Membantu memproduksi protein penting, seperti insulin, melalui teknologi DNA rekombinan. 2 15 Jawaban : c) Mengatasi infeksi akibat bakteri patogen dengan cara menghambat pertumbuhan atau membunuh bakteri tersebut. 2

c. Evaluation

The results of the validation of the material experts showed that the Augmented Reality (AR)-based guided inquiry module had met the curriculum criteria for class X biotechnology

materials, where the materials presented included conventional and modern biotechnology, as well as their applications in various fields, such as food, agriculture, and medicine. This module is also relevant to the latest technological developments, as it utilizes AR to provide an interactive and immersive learning experience. Based on the assessment of material experts, the module was declared feasible for trial without significant revisions, because it was in accordance with the learning objectives and needs of students.

Media expert validation confirms that the design of the interactive module manages to grab students' attention with attractive visual elements and simple navigation. The AR technology in the module helps students understand abstract concepts visually and interactively. However, it is recommended to add more relevant images and replace the photo results with screenshots for better quality visualizations. The module was rated suitable for use in the trial, with some minor revisions to improve visual quality and instructions for use. A limited-scale experiment involving teachers and students of class X who showed a positive response. Teachers can state that this module helps students understand modern biotechnology material, especially practicum aspects that were previously difficult to do due to limited facilities. Student feedback shows an increase in their interest and engagement in learning, thanks to the integration of AR technology and inquiry models that encourage self-exploration. Trials with an all-experimental design, using pre-tests and post-tests, showed significant improvements in students' cognitive learning outcomes and science process skills.

Overall, AR-based guided inquiry modules were considered effective in supporting interactive learning, improving learning outcomes, and training students' science process skills. With some minor revisions to the visual elements and learning structure, the module is ready to be implemented on a wider scale.

Feasibility of Augmented Reality-based guided inquiry module on biological technology innovation material for grade X high school students

The feasibility of the Augmented Reality-based guided inquiry module on biological technology innovation materials for grade X high school students has been assessed through the validation of material experts, media, and teaching modules, which overall showed excellent results with a success rate ranging from 98.67% to 100%, reflecting the suitability of the material with the curriculum, ease of understanding, and effectiveness in increasing student motivation and involvement in learning. These results are in line with research conducted by Wulandari & Hendriana (2021), which found that the use of Augmented Reality in biotechnology learning can improve students' conceptual understanding by up to 98.67% compared to conventional methods, mainly due to the support of interactive visualization that allows students to more easily understand abstract concepts such as genetic engineering and recombinant DNA technology.

The subject matter expert validation also confirmed that the modules have met academic standards with a wide range of conventional and modern biotechnology coverage, from tissue culture to the utilization of genetic engineering, as well as being presented with clear language and interactive illustration support to facilitate student understanding, while the validation of media experts showed that the Augmented Reality-based module design successfully created an innovative and interactive learning experience, with simple navigation and visualization of complex concepts that are able to increase students' absorption of biotechnology materials.

In addition, the expert validation of the teaching module shows that the systematic presentation structure as well as the integration of a guided inquiry approach in this module have successfully encouraged students' active engagement in learning, allowing them to explore biotechnology concepts in greater depth through Augmented Reality-based experiments and interactive discussions, which are in line with the findings of the research by Febrita et al. (2022), who concluded that the application of learning inquiry-based with AR technology can improve students' critical thinking and problem-solving skills by up to 78% compared to conventional methods, as students are encouraged to find solutions to given problems through more real and in-depth digital exploration; Thus, the entire module is declared to be very suitable for use without revision, in the hope that its use can not only improve students' understanding of biotechnology, but also encourage their interest in delving into this field.

The practicality of the Augmented Reality-based guided inquiry module in its application to increase student involvement in learning biological technology innovation material in class X of high school

The practicality of Augmented Reality-based guided inquiry modules in increasing student engagement in learning biological technology innovation in high school class X is highly dependent on the accuracy of AR content relevant to modern biotechnology, such as genetic engineering and recombinant DNA technology. Evaluation of the effectiveness of the module by the biology teacher is an important step in assessing the feasibility of the content, scientific accuracy, and contribution of the module to students' science process skills.

a. Description of Biotechnology Module Practicality Data by Biology Teachers

This assessment is based on the perspective of teachers who observe the application of modules in teaching, as well as evaluate aspects such as the material's relationship to the curriculum, clarity of presentation, and its impact on student understanding.

It can be seen that the score obtained indicates a very positive response. On the effectiveness aspect, both statements obtained a score of 5, which indicates that the teacher feels that this module is very effective in delivering the material and achieving the expected learning objectives. Similarly, in the interactive aspect, most of the statements (3 out of 4) obtained a score of 5, indicating that this module was very successful in creating good interaction between students and the material, as well as increasing student involvement in the learning process.

Although there are two statements with a score of 4, it still shows that the interaction that occurs is quite adequate, although there may be some elements that can be improved to further maximize interactivity. In terms of efficiency, all statements received a score of 5, indicating that teachers rated this module as very efficient in terms of using time and resources to achieve optimal learning outcomes. Finally, on the creative aspect, the entire statement also received a score of 5, which shows that teachers feel that this module is very creative in the presentation of the material, which helps to make the learning process more interesting and innovative. Overall, the teacher's responses showed that the biotechnology module was very effective, interactive, efficient, and creative, although there was little room for improvement in improving more optimal interactivity.

b. Description of Biotechnology Module Effectiveness Data by Students

The description of the data on the effectiveness of biotechnology modules by students aims to provide an overview of the extent to which the developed modules can affect students' understanding and skills in biotechnology materials.

It can be seen that the average score for each statement shows a relatively positive result. The score for the first statement was 3.43, which indicates that the students quite agreed with the presentation of the given module. The score in the second statement, which is 3.57, is slightly higher, indicating that students feel that the module is quite effective in its presentation. The third statement obtained a score of 3.47, which is still in the good category, indicating that the presentation of the module also managed to attract attention and facilitate student understanding. The score for the fourth statement was slightly lower, at 3.40, which still showed a positive response although there were possible aspects of the presentation that needed improvement. Overall, the results showed that students felt that the modules presented were effective and well received.

Based on the results of students' responses to the presentation aspect of the module, it can be analyzed that overall, students gave a positive response. The score on the first statement was 3.53, which shows that students quite agreed with the way the module was presented, although there are some aspects that can still be improved. The second statement obtained a score of 3.40, which is slightly lower, indicating that there are some parts of the presentation that may be less effective or need to be improved to improve student understanding. The score on the third statement was 3.43, which indicates that most learners felt the material was presented quite clearly, although there was room for improvement. In the fourth statement, a score of 3.47 indicates that the module is able to convey information well, but there may be some aspects that are not fully adequate. The highest score was obtained in the fifth statement, which was 3.67, which showed that most students were very satisfied with the aspect of the presentation of the module, indicating that there was a match between students' expectations and the way the material was presented. Overall, although there are several aspects that can be improved, the students' responses to the presentation aspect of the module showed positive results and the module was considered quite effective in delivering learning materials.

Based on the results of the students' responses, the score in the first statement (3.47) shows a fairly good presentation of the module, although there is still room for improvement. The second statement score (3.37) was slightly lower, indicating that some aspects of presentation needed to be improved to be more effective and engaging for students. Overall, even though the modules are quite effective, there is still an opportunity to improve the quality of the presentation to make it more optimal.

Based on the data of students' responses to the aspect of module presentation, overall, the responses given showed positive results even though there was still room for improvement. The score for the first statement is 3.47, which indicates that the presentation of the module is quite good, although it can still be further improved. The score in the second statement, 3.37, is slightly lower, indicating that there are some aspects of presentation that are less effective and need to be improved to improve student appeal and understanding. Scores on the third (3.43) and fourth (3.47) statements indicated that most students felt the material was presented fairly clearly and effectively, although there was still room for improvement. The highest rating in the fifth statement (3.67) indicates a higher level of satisfaction with the presentation of the module. Overall, although there are some aspects that need improvement, the module is well received by students and is considered quite effective in delivering learning materials.

Research by Utama et al. (2024) shows that the use of AR in biology learning increases student engagement with more real learning experiences, while the study of Einstendhi et al. (2024) reveals that the integration of AR in guided inquiry not only deepens conceptual understanding, but also encourages exploration of material through interactive visual experiments, so that this module can overcome the limitations of practicum facilities and improve student learning outcomes. Furthermore, a study by Windrayanti & Astawan (2022) shows that AR-based guided inquiry strengthens students' conceptual understanding through technology-based exploration, while Ashari's (2023) research confirms that learning module designs that combine AR with inquiry methods can improve critical thinking and analytical skills in understanding biotechnology.

The effectiveness of Augmented Reality-based guided inquiry modules in improving the cognitive learning outcomes of high school grade X students on biological technology innovation materials

The use of Augmented Reality (AR)-based guided inquiry modules has proven to be effective in improving the cognitive learning outcomes of high school grade X students on biological technology innovation materials. Teachers rated this module as excellent in terms of effectiveness, interactivity, efficiency, and creativity, which contributed to a clearer delivery of the material as well as increased student involvement in learning. Students also responded positively to the module, especially in helping to understand biotechnology concepts more deeply. Nonetheless, some aspects, such as visual presentation and relevance to real-life contexts, can still be optimized to maximize student absorption. Previous research

by Purba et al. (2024) and Cita (2017) also showed that interactive technology-based learning can increase students' motivation and conceptual understanding in the field of science, in line with the results of this study which affirms the importance of innovation in learning media. Based on the data from the results of the study, it can be seen that in the control group, the average cognitive learning outcomes increased from 44.97 (pre-test) to 60.00 (post-test), with a wide range of scores from 32–64 to 48–75. Despite the improvement, the contribution of conventional methods to improving students' cognitive learning outcomes is relatively limited and less significant.

Experimental groups using Augmented Reality-based guided inquiry modules showed higher improvements in cognitive learning outcomes. The average pre-test score was 47.133 with a score range of 32–69 and a standard deviation of 10.064. After treatment, the average increased to 68.233, with a score range of 51–87 and a standard deviation of 8.295. This improvement shows that the use of AR-based modules is effective in aiding material comprehension, thereby contributing to improved learning outcomes.

Furthermore, when compared, the experimental group experienced an average increase of 21.1 points from pre-test to post-test, while the control group only increased by 15,033 points. The post-test score range in the experimental group was also higher, indicating that Augmented Reality-based modules not only improved the average score, but also allowed for higher learning outcomes than conventional methods.

Based on the data from the statistical test results stated above, it can be seen that the experimental group that uses AR-based modules experiences a more significant increase in learning outcomes than the control group that uses conventional methods. The average pre-test and post-test scores in the experimental group increased substantially, demonstrating the effectiveness of the modules in deepening students' understanding of biotechnology concepts. The Kolmogorov-Smirnov normality test ensures that the data has a normal distribution, while through the data the results of the balance test are used to ensure that the initial ability between the two groups before treatment is the same, so that the improvement that occurs really reflects the influence of the AR-based module. These findings support the study of Sri Handini (2020), who stated that interactive technology-based learning is able to improve students' science process skills and cognitive understanding.

The effectiveness of the Augmented Reality-based guided inquiry module in improving the science process skills of high school grade X students on biological technology innovation materials.

The use of Augmented Reality (AR)-based guided inquiry modules has been proven to be effective in improving the Science Process Skills of high school grade X students on biological technology innovation materials. Based on data analysis, it can be seen that the increase in the value of Science Process Skills (PPP) from an average of 56.1 to 75.0, the increase occurred in a relatively narrow range of scores (59–92), which indicates improvement, but not as optimal as the experimental group. These findings support the results

of previous research by Purba et al. (2024) and Cita (2017) and also show that interactive technology-based learning can increase students' motivation and conceptual understanding in the field of science, in line with the results of this study which affirms the importance of innovation in learning media.

In the experimental group using Augmented Reality (AR)-based modules, there was a more significant increase in the value of Science Process Skills (PPP). The average score increased from 57.03 in the pre-test to 84.3 in the post-test, with a wider range of scores (65–103). This shows that the use of AR not only improves average student achievement, but also supports the development of students with diverse abilities.

The results of the research revealed above show that Augmented Reality (AR)-based guided inquiry modules are more effective in improving science process skills than conventional methods. AR technology encourages active interaction and helps students understand complex concepts visually and interestingly, while the inquiry approach provides room for deeper exploration and understanding and is able to make solutions in overcoming problems such as limitations in conducting practicums for example in genetic engineering topics that require advanced tools and expensive fees. These findings support the study of Sri Handini (2020), who stated that interactive technology-based learning is able to improve students' science process skills and cognitive understanding. Therefore, the implementation of AR-based modules in science learning can be an innovative strategy to increase educational effectiveness and student readiness in facing the challenges of 21st century learning.

CONCLUSION

The Augmented Reality (AR)-based guided inquiry module on biological technology innovation for grade X high school students was found to be feasible, practical, and effective, with expert validation results ranging from 80%–100%. The module successfully addressed laboratory limitations through AR-based digital experiment simulations that allowed students to interactively explore biotechnology concepts, enhancing motivation and engagement in inquiry-driven learning. It effectively improved cognitive learning outcomes and Science Process Skills (KPS), as evidenced by higher post-test scores in the experimental group and students' improved ability to identify problems, design experiments, and analyze data critically. This innovation demonstrates a promising approach to strengthening 21st-century biology education. Future research could expand the implementation to other complex biology topics and assess the long-term impact of AR-integrated guided inquiry learning on students' creativity, collaboration, and problem-solving skills.

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