Proceedings Series of Educational Studies

**The 4th International Conference on Educational Management and Technology (ICEMT) 2025**

# DEVELOPMENT OF GEOLOCATED GAMES AUDIO AUGMENTED REALITY ON THE BACTERIA MATERIAL FOR GRADE X

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**Abstract**

This research developed a geolocated game using audio augmented reality (AAR) to teach Grade X students at Nasional Senior High School Malang about beneficial bacteria. The development followed the five-stage Lee & Owen model and aimed to assess the media's feasibility for classroom learning. Prior to implementation, the product was validated. It received an average score of 94.67% from media validators and a 100% score from a material expert, confirming both the technology and the content were valid for field testing. The game was then tested with Grade X students during their biology lessons. The results were highly positive, with all students demonstrating an increase in their post-test scores. To measure the learning impact, an N-Gain analysis was performed, yielding an average score of 83.98%, which falls into the "effective" category. While individual N-Gain scores ranged from 29% to 100%, the overall findings led to a clear conclusion. The use of the AAR-based geolocated game is an effective learning tool for improving student outcomes in biology regarding the role of beneficial bacteria.

**Keywords:** *Geolocated Games; Audio Augmented Reality; Biology*

## Introduction

The evolution of technology in education has become an inescapable transformative force, fundamentally changing the paradigm of how knowledge is accessed, processed and experienced by learners. In Indonesia, technology integration is no longer a discourse, but an evolving reality, aiming to create a more dynamic, inclusive and effective learning ecosystem. This context of educational technology refers to the systematic utilization of various innovative tools and techniques-from audio-visual devices, recording media, to advanced computers and software-to facilitate and optimize the achievement of educational goals. The role of technology is significant; it breaks down the barriers of time and space, making education more accessible to a wide range of people, while increasing the efficiency and effectiveness of the teaching and learning process. Within this framework, one innovation that shows tremendous potential in revolutionizing the learning experience is Augmented Reality (AR).

Augmented Reality is a technological bridge that combines the virtual world with the real world in a direct and interactive way. Unlike Virtual Reality (VR) which fully immerses the user in a digital environment, AR overlays virtual information or objects on top of the user's view of the real world. The integration of AR technology in education has attracted enormous attention due to its unique ability to create immersive and interactive learning experiences. Its main potential lies in its ability to transform abstract and hard-to-imagine concepts into concrete and manipulable three-dimensional (3D) visualizations. Imagine a biology student who doesn't just read about cell structure, but can see a 3D cell model hovering over his desk, rotate it, and virtually dissect its parts. This not only increases conceptual understanding in depth but has also been shown to significantly increase student interest and engagement in learning. By providing opportunities for learners to learn through direct interaction, AR makes learning

more than just a transfer of information, but rather an exciting and memorable process of discovery.

However, amidst the rapid development of AR media, there is a significant limitation: the majority of its development focuses too much on the visual component. Existing AR learning media mostly only meet the needs of learners with visual learning modalities, i.e. those who learn most effectively through the stimulation of pictures, diagrams, colors, and videos. This reliance on visuals indirectly neglects the potential of other learning modalities, especially auditory modalities. To address this gap, a more specific branch of AR emerged, namely Audio Augmented Reality (AAR). AAR is a technology that places layers of audio information into the user's three-dimensional physical environment. The goal is to provide contextual information, direct attention, or guide actions through sound, without having to interfere with the user's visual field of view. In Indonesia, the potential of AAR is relatively unexplored, even though it offers an ideal solution for learners with auditory learning modalities, who more easily absorb knowledge through sound, discussion, or music. A common implementation of AAR is as an automated tour guide in museums or historical sites, where headphones connected to a smartphone will play an audio narration automatically when the user approaches a particular object or location.

Effective AAR implementation relies heavily on accurate positioning technology, and this is where the Location-Based AR model plays a crucial role. This technology uses a combination of inertial sensors and Global Positioning System (GPS) receivers that are already embedded in almost all modern smartphones, just like those used by map applications such as Google Maps. The advantages of this tracking method are its relatively low cost, high performance, and low latency, making it a reliable platform for outdoor applications. One platform that facilitates the creation of location-based AAR content is Echoes.xyz, which allows creators to place various Points of Interest (PoIs) on a digital map. Users can then interact with this content by physically walking to the PoI location, which automatically triggers the playback of the prepared audio content.

This concept can then be further developed into a very interesting learning model: geolocated games. This model utilizes Location-Based AR technology to transform real-world environments into a giant playground. Players interact with the game by physically moving around in their environment, tracked via GPS. The most phenomenal example of geolocated games is Pokémon GO, which successfully motivated millions of people to get out and explore their surroundings. The pedagogical advantages of this model are immense. Besides the fun factor, the game inherently increases players' knowledge of their physical environment and local geography. Studies show that gaining knowledge about the local environment is one of the most favorable outcomes for players. Such games can be a means to teach players about their own regional space and have even been shown to increase a sense of place.

By understanding all the potential of this technology, an innovative learning media development project was designed to address the specific problems faced at SMA Nasional Malang. Based on observations, teaching and learning activities in biology subjects at the school still tend to use conventional media which is considered less effective and monotonous. As a result, students are often less enthusiastic, passive, and do not get a memorable learning experience. To overcome this, an AAR-based geolocated games learning media was developed. This project specifically takes the material about the role of beneficial bacteria found in the environment around the school. Thus, learning is no longer confined to the classroom, but rather brings students directly to the real world context.

This learning media is intelligently designed to be a holistic solution that can fulfill various learning modalities of students simultaneously. First, for the visual modality, students will use the digital map on the app on their smartphones to navigate and locate the marked PoIs. Second, for the auditory modality, which is at the core of the AAR experience, students will listen to an informative and engaging narration that will play automatically every time they reach a PoI. Third, for the kinesthetic modality, the concept of geolocated games itself requires students to be physically active-walking, searching, and exploring the school environment to complete missions in the game. This multi-modal approach ensures that every student, with any learning style, can be fully engaged. The use of the game format also adds an element of challenge and fun, which can intrinsically increase students' motivation to learn. Hopefully, through the development of this media, students' understanding of abstract biology material can be significantly improved, and most importantly, they can feel that learning is an active, relevant and fun adventure.

## Method

This research uses the development method (Research & Development). According to Sugiyono (2020), Research and Development is a research method that aims to create certain products and evaluate the effectiveness of these products. in this study, the steps to develop learning designs and produce products are determined using the Lee & Owens research procedure. In this case, the development of geolocated games AAR learning media on the role of bacteria is good for grade X high school students. As for the selection of Lee & Owens research procedures on the grounds that this procedure has a systematic and structured framework, especially when used to develop effective and relevant learning media. In addition to having easy and structured development steps, this procedure also provides an opportunity to make revisions and evaluations repeatedly at each stage passed in order to produce valid and effective learning media products.

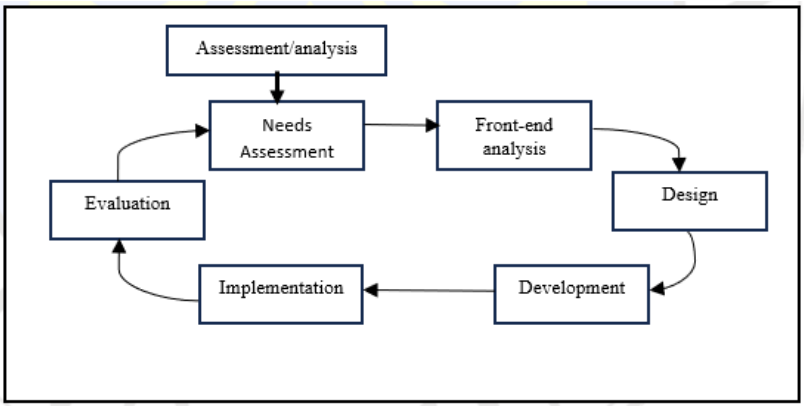


**Figure 1. Development Model Lee & Owens**

### 2.1 Analysis

The Analysis stage in the Lee & Owens model is the first step that will determine the product in the research and development process. At this stage, the main focus is to identify the need assessment and front-end analysis.

2.1.1 Need Assessment

Need assessment or needs analysis is done by observing learning activities in the classroom. Observation activities were carried out at SMA Nasional Malang when classroom learning took place. This analysis aims to identify the needs between the actual conditions and the desired conditions.

Based on the results of observations conducted at SMA Nasional Malang, several interesting things were found. One of them is that during learning, the teacher seems to only deliver material in one direction without involving students in discussions or more dynamic learning activities. As a result, the classroom atmosphere became passive, and only a handful of students really focused on paying attention to the teacher's explanation. Another finding that reinforces the assumption that the use of media and learning methods that are not varied can reduce the effectiveness of the teaching and learning process. From some of these problems, it can be concluded that media is needed that can improve students' understanding of the material presented, and can meet the needs of students' diverse learning modalities including visual, auditory, and kinesthetic.

2.1.2 Front-End Analysis

Front-end analysis is a stage that aims to determine and identify development needs in science subjects in class X SMA Nasional Malang, there are several aspects that need to be known. Further explanation is as follows.

2.1.2.1 Audience Analysis

This stage of participant and user analysis is needed to determine the target population. target characteristics that will be targeted in the development of learning media based on AAR geolocated games. This user will later respond to the development of media is SMA Nasional Malang class X semester 2 students in science subjects. The characteristics of these students in the formal operational stage are in the age range of 12 years to adulthood which at this stage, they will develop the ability to think abstractly, use logic to solve problems, and learn to plan things.

2.1.2.2 Technology Analysis

This stage is carried out to determine the type of technology that will be used in the development process. For the use of AAR geolocated games media, it can be accessed using a smartphone, laptop or computer with the gadget connected to the internet network. The presence of a laptop or computer in a classroom learning situation is optional.

2.1.2.3 Situation Analysis

The situation analysis aims to identify the condition of the learning environment as a consideration in developing learning media based on AAR geolocated games. SMA Nasional Malang has a large enough school environment as a place to play or learning will take place. The environment already includes strategic places that are used to deliver material in the form of AAR PoIs.

2.1.2.4 Task Analysis

This stage is carried out with the aim of describing how students carry out the tasks contained in the learning media based on AAR geolocated games. Students will explore the school environment to find scattered AAR PoIs. Then, students working together in teams will complete the quizzes that have been provided to complete the learning.

2.1.2.5 Critical Analysis

This analysis aims to determine the important information that must be taught and identify what does not need to be taught. Analyzing the subject objectives that will be selected as learning materials in the media to be developed, in this metaverse-based learning media the material to be used is the role of good bacteria.

2.1.2.6 Objective Analysis

At this stage, it is carried out to analyze the learning objectives to be achieved in the development of learning media based on AAR geolocated games. The objectives to be achieved,

namely based on the learning design that has been prepared, are that students can explain the role of beneficial bacteria in everyday life through literature study and discussion correctly.

2.1.2.7 Issue Analysis

During the observation conducted in February, several issues were found. One of them was that the teacher seemed to only deliver material in one direction without involving students in discussions or more dynamic learning activities. As a result, the classroom atmosphere became passive, and only a handful of students really focused on paying attention to the teacher's explanation. Another finding that reinforces the assumption that the use of media and learning methods that are not varied can reduce the effectiveness of the teaching and learning process. From some of these problems, it can be concluded that media is needed that can improve students' understanding of the material presented, and can meet the needs of students' diverse learning modalities including visual, auditory, and kinesthetic.

2.1.2.8 Media Analysis

Media analysis aims to determine the type of media developed. Geolocated AAR is an innovative solution to improve students' understanding of the role of good bacteria by utilizing real locations in the school environment. For example, when students approach the school cafeteria, they can hear an audio narration explaining about the food produced using the role of bacteria along with examples of food types.

2.1.2.9 Extand-Data Analysis

At this stage, analyzing existing data such as analyzing teaching modules from schools to determine the material that will be used as content in this geolocated AAR-based learning media. This learning media is tailored to the needs and learning objectives at school.

2.1.2.10 Cost Analysis

This stage analyzes the cost of procurement in the development. This learning media development uses elements that are freely available or free of additional costs in accessing the main features provided.

**2.2 Design**

Design is the product or media planning stage. Lee & Owens (2004) explain several important steps that must be taken, including the preparation of a schedule, project team, media specification, lesson structure, and configuration control.

2.2.1 Schedule

The development of AAR geo-located games-based learning media began in February after making observations. The media will then be validated by material experts and media experts, which will then be tested on class X students of SMA Nasional Malang.

2.2.2 Project team

The development of learning media based on geo-located games AAR, all responsibilities and project tasks were carried out by researchers, who then conducted validation testing on media experts on educational technology lecturers and material experts on biology education lecturers.

2.2.3 Media Specification

For the development of learning media based on geolocated games AAR, devices with adequate specifications are needed so that the program can run perfectly. On the smartphone side, the recommended device should use Android operating system with at least 4GB RAM, but ideally 6GB or more for smoother performance. In addition, a minimum of 32GB of internal storage space is required to store apps and game data, as well as the availability of a stable network connection. Meanwhile, for the computer or laptop hardware used in the development process, recommended specifications include the use of a Core i3-equivalent processor or higher

and supported by an Intel HD3000-equivalent graphics processing unit (GPU) or comparable. The computer or laptop device must also be running on Windows 10 or later operating system.

2.2.4 Lesson Structure

The following is the lesson structure or content contained in the geolocated AAR-based learning media.


**Figure 2. Lesson Structure**

2.2.5 Configuration Control

In this Configuration Control section of the AAR geo-located learning media development, it is important to ensure all learning elements remain consistent and well coordinated throughout the project lifecycle. This includes documenting changes, monitoring content revisions, approving adjustments before they are implemented. With effective configuration control, the development of this media can run more smoothly and avoid conflicts or inconsistencies that can disrupt the learning process.

## 2.3 Development

The development stage is the implementation of the design that has been made at the design stage. Some complete stages in the media development process are as follows.

**Table 1** Production Stages of Development

| Tahapan | Media |
|---|---|
| **Pre-Production** | At this stage planning the material used in the development of learning media based on geolocated games AAR. The selection of materials selected is in accordance with the needs analysis that has been done. After making the material then validate the material expert. |
| **Production** | At this stage, media development begins with creating a website that is used as the main hub, along with a supporting environment so that it runs effectively on smartphones (Android) or computer devices. After that, the preparation of scripts for AR audio recordings began and continued with the stages of recording narration, editing audio, and uploading it into the geolocated AAR software. Then create a quiz that becomes an element in geolocated games AAR. After all the previous elements are in the finished production status, all these elements will be prepared in the main hub that was previously prepared. |
| **Post-Production** | At this stage after the media production is completed, the researcher reviews the media that has been made by conducting experiments to ensure that there are no obstacles in the implementation process. Before proceeding to the implementation stage, the developer validates the media to media experts. |

## 2.4 Implementation

Content accuracy and media feasibility testing were carried out by involving material experts and media experts. Trials were conducted so that the product was declared feasible as augmented reality learning media which included several aspects, namely content suitability,

material accuracy, material recency, motivation, convenience, attractiveness and quality aspects in learning. This product will be tested to obtain data. Questionnaires or questionnaires are used as research instruments to collect data for evaluating and testing the learning media developed. The questionnaires made will be used to assess the quality of the media obtained from material experts and media experts.

The validity instrument for the development of geolocated AAR learning media uses a rating scale with 4 scales, without using a doubtful/neutral scale. With reference to (5) strongly agree, (4) agree, (3) doubt, (2) disagree, and (1) strongly disagree. As for knowing learning outcomes, this study used a test instrument in the form of a cognitive test with a type of multiple choice questions of 10 items. This test aims to determine whether the learning outcomes of students have increased or not after using the media. The questions given to the research subjects were in the form of pretests and posttests.

### 2.5 Evaluation

The evaluation stage in this research procedure is an important step to ensure that the learning media developed is effective and meets the learning objectives that have been set. In the evaluation stage, developers collect data and feedback from students and educators to assess the quality and effectiveness of the learning media, as well as the increase in learning motivation and the completeness of student learning outcomes.

## Results and Discussion

### 3.1 Result

The result of product development in this study is a learning multimedia prototype that has applied the product framework designed at the design stage and has gone through the validation stage by experts. In the early stages, product development includes collecting information on the technologies that will be used in product development, determining the content to be presented, as well as the facilities and infrastructure used both to develop products and to use product prototypes at the trial stage later. In the next step, the development continues until it produces a learning multimedia product prototype that is in accordance with the initial product design. After the prototype can be operated without problems, product validation is carried out by media experts to find out and assess that the learning media for geolocated games based on Audio Augmented Reality is valid for use in the field. Also, the product will go through a content validation stage which aims to ensure that the content used is in accordance with relevant learning resources.

Design validation is a process to assess whether a new product design will be rationally more effective than the previous product (Sugiyono, 2013). The criteria for experts who will become media validators is a lecturer in the Department of Educational Technology with a master's degree and has expertise in the field of learning media. Then for the material expert is a lecturer in the Department of Biology Education with a master's degree in biological education expertise. Data on the validity of media and content is obtained from a questionnaire given to experts. After that, the product will go through an initial revision stage to adjust to the input from the experts.

Geolocated games learning media based on Audio Augmented Reality is one of the AR concepts that is suitable for use in subjects that involve direct student interaction with nature, one of which is biology. In biology, especially the material on the role of good bacteria, students have difficulty understanding the material if they only read or listen to explanations from teachers that take place only in the classroom. Students find it difficult to understand the context in which the location of the studied bacteria plays a role in nature. The existence of this geolocated AAR technology, students can be helped in understanding the material because

students will be directly outside the room to learn the material, especially in the school environment where bacteria play a role in everyday life. In the world of education, AAR technology has been used on a small scale for several sciences. Likewise with geolocated AR which is one of the concepts in location based AR, where in one of the previous studies it was explained that location based AR is easy to use, satisfying, and educationally useful if developed by emphasizing the importance of gamification and storytelling in increasing learning engagement and motivation (Kleftodimos et al., 2023).

The prototype of the product produced in this research is in the form of geolocated games based on geolocated AAR on Echoes for class X biology subject at National High School Malang. There are several platforms used to create this geolocated games AAR, including Odoo website which is used to develop a website-based main hub where the initial learning process will take place, Echoes which is used as a geolocated AAR platform, and Google Form which is used to create a quiz which is one of the gameplay elements of this AAR-based geolocated games.

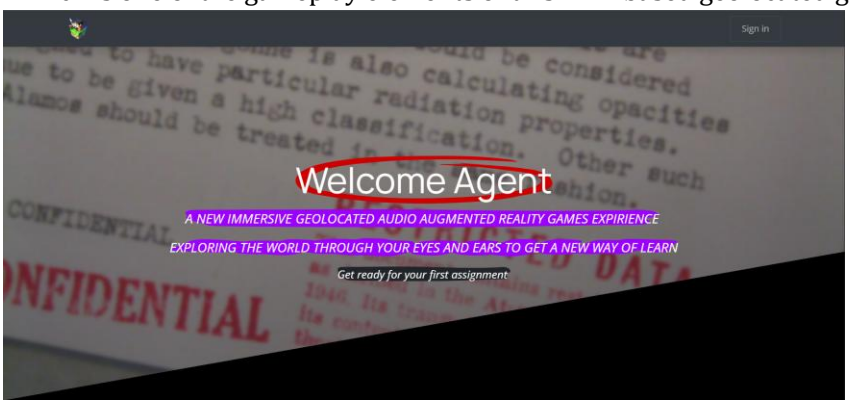


**Figure 3 Main Hub Display**

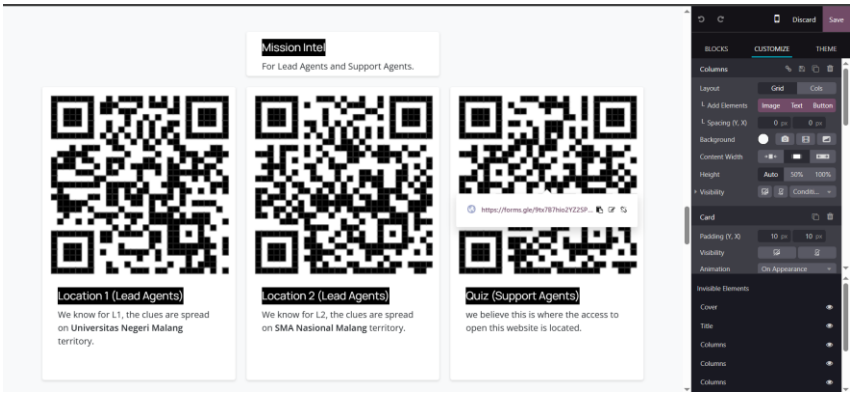


**Figure 4 Main Hub Development Process**

The main hub in the form of a website is a place where students (players) make initial preparations before playing games which will mainly use Echoes for geolocated AAR and Google Form for quizzes. In the main hub, there are contents including a guide book as a playing guide, a link to download the Echoes application, a link to access the location in the Echoes application, and a link to access the quiz in the form of a Google Form. Location and quiz links use the QR code concept that players can scan or click directly. The design of the main hub web is based on the principles of learning media including the layout of writing elements, images, and color composition that does not interfere with the course of learning.

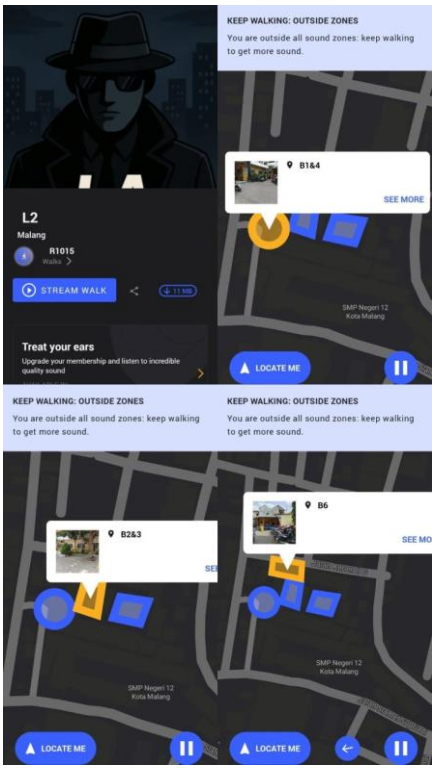


**Figure 5 Echoes Android App**

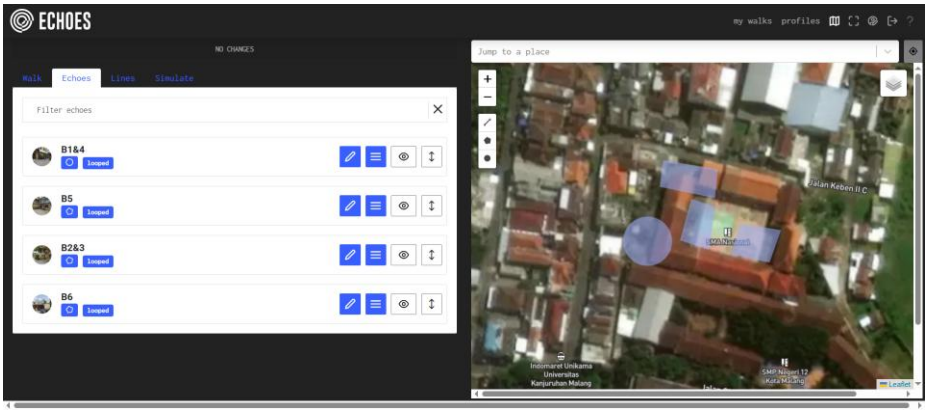


**Figure 6 PoI Determination Process**

The Echoes application is used to access geolocated AR containing audio narration recordings which contain explanations related to bacteria used to answer quizzes later. The narrative recording will be played automatically if the player is within the range of the Point of Interest which can be in the form of a circle or other PoI shape. The way this application works is that after the player starts streaming, the player will be faced with a virtual map display containing several PoIs that must be visited. Furthermore, the player must be within range of the PoI location to trigger the narration recording to start automatically. Clue PoI players can find out if they click on one of the PoIs where there will be a photo where the PoI location is located and can find the exact location by following the round arrow icon which is a representation of the player's original location based on the Global Positioning System in realtime.

**Figure 7 Field Testing**

The gameplay element is the task of the lead agents. In the game, lead agents are tasked to find where the PoI locations are and listen to the recorded narration. The next task is that the lead agents will explain the clues of the material they get to their friends in the group (support agents) to complete the quiz prepared in the google form. The narration recording process begins with the preparation of scripts in accordance with the content to be presented. This is followed by recording and editing, which is done entirely in Audacity. These processes have paid attention to aspects of audio composition and gameplay time that will be played. Furthermore, the audio results from Audacity will be uploaded to the Echoes.xyz website while determining the PoI according to the location of the game environment that adjusts the context of the content presente

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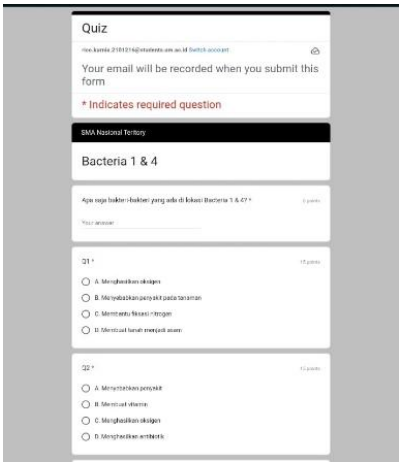


**Figure 8 Quiz on Google Form**

Quiz is one part of the gameplay of geolocated games AAR which is made in the form of short answer and multiple choice quizzes on google form totaling 12 questions. The level of difficulty and number of questions have been adjusted to the duration of the gameplay to be played, and have also been adjusted to the content in the geolocated AAR. In the gameplay, completing the quiz is the task of the support agents in the group that has been formed. Cooperation between group members is an important element in the game session so that it can be completed as quickly as possible with the highest score.

Before field testing, the product validation stage is first carried out by two validators to determine the validity of the media so that it is valid to be tested in the field. The validity instrument for the development of geolocated games AAR learning media uses a 5-scale rating

scale, with reference to (5) strongly agree, (4) agree, (3) doubt, (2) disagree, and (1) strongly disagree. The media validation process was carried out by a lecturer at the Department of Educational Technology, State University of Malang with a master's degree and expertise in the field of learning media. Meanwhile, the content validation process was carried out by a lecturer at the Department of Biology Education, State University of Malang with a master's degree in biological education expertise. The validation results for both media and content are shown in the following graph.

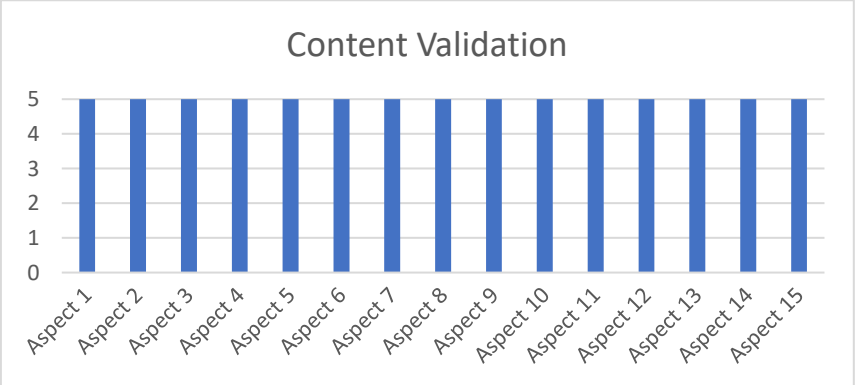


**Figure 9 Content Validation Results**

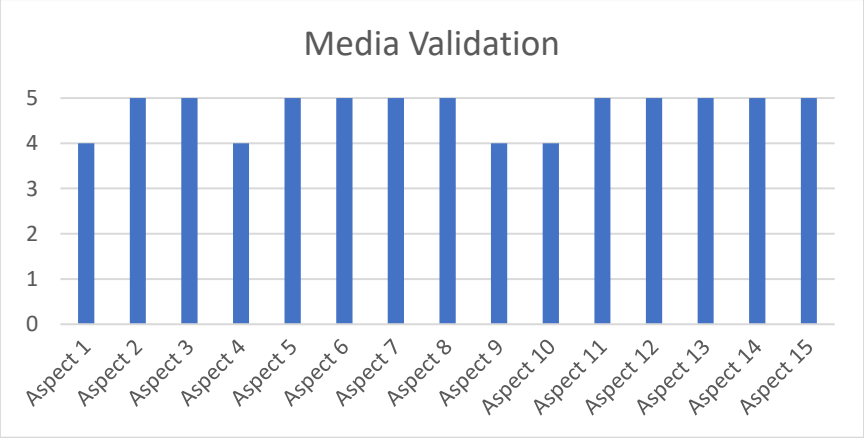


**Figure 10 Media Validation Results**

The results of the content validation questionnaire assessment given by the content validator obtained 75 points from a total of 75 maximum points that can be obtained or 100% with the conclusion that the AAR-based geolocated games learning media for class X SMA biology subjects are very valid for field testing with minor revisions. These points are obtained from 15 aspects that are assessed to get a maximum score of 5 (Strongly Agree) as shown in the diagram above. As for the results of the media validation questionnaire assessment, the media validator gave a score with a total of 71 points out of 75 maximum points that can be obtained or in a percentage of 94.67% with the conclusion that the AAR-based geolocated games learning media for class X SMA biology subjects are very valid for field testing without revision. These points are obtained from 15 aspects assessed as many as 11 aspects get a maximum score of 5 (Strongly Agree) and 4 aspects get a score of 4 (Agree) as shown in the diagram above.

**Table 2 N-Gain Score Acquisition Table**

| No. | N-Gain Score (%) |
|---|---|
| 1. | 86 |
| 2. | 71 |
| 3. | 57 |
| 4. | 100 |
| 5. | 75 |
| 6. | 83 |
| 7. | 40 |
| 8. | 29 |
| 9. | 100 |
| 10. | 100 |
| 11. | 75 |
| 12. | 75 |
| 13. | 100 |
| 14. | 100 |
| 15. | 100 |
| 16. | 100 |
| 17. | 100 |
| 18. | 80 |
| 19. | 67 |
| 20. | 100 |
| 21. | 100 |
| 22. | 100 |
| 23. | 100 |
| 24. | 78 |
| **Average** | 83,98 |
| **Minimum Score** | 29 |
| **Maximum Score** | 100 |

The results of field testing were also obtained through pre-test and post-test results to determine the increase in learning outcomes before and after the use of AAR-based geolocated games learning media. The test was attended by 24 students of class X-A SMA Nasional Malang with the general result that all students experienced an increase in scores on the post test or after using the tested product. To find out more, the N-Gain test was conducted from the pre-test and post-test scores, the results of which can be seen in the table above. Based on these results, it is known that the average N-Gain score is 83.98% or included in the effective category. The minimum N-Gain score is at 29% and 100% at the maximum value. The conclusion from the N-Gain score test is that the use of AAR-based geolocated games learning media effectively improves student learning outcomes in biology subjects on the role of good bacteria.

To ensure the test results, researchers also took the time to ask students' opinions after using the geolocated games AAR product. The questions included general impressions after using, attractiveness, and suggestions for product development. In general, students gave a positive impression of the media on the grounds that it was the first time they were presented with the concept of geolocated AAR and helped students to understand the material on the role of bacteria well. Then, for the suggestions submitted in the form of suggestions related to technical matters and the content of the content which hopefully can be clarified for future product development.

### 3.2 Discussion

The product development of geolocated games Audio Augmented Reality (AAR) follows the basic design principles of geolocated games AAR which presents a holistic way of learning by integrating three main pathways through vision (through maps and images), hearing (as the core of material and instructions), and physical movement (by encouraging students to explore locations). While the audio aspect is the main focus, AAR's geolocated games are reinforced by visual elements and the need for students to be active, creating an immersive, multi-sensory learning environment. By making students the main actors in the learning process, AAR geolocated games not only deepen the understanding of concepts through various sensory channels, but also build strong emotional and physical connections.

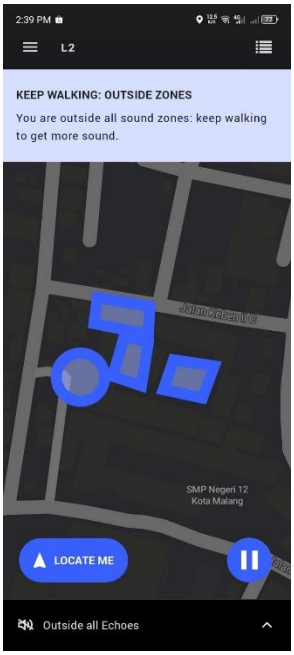


**Figure 11 Echoes Display**

So that learning feels more alive, memorable, and effective thanks to the combination of technological innovation with educational principles. The basis of the development, then gave birth to a prototype product resulting from the development of AAR-based geolocated games learning media which received positive results with some development notes. These results can be seen from the validator's assessment questionnaire for media and content validation, pre and post test results in the field test, and student responses after using the tested product.

The results obtained from the content validation questionnaire were very positive. The total points obtained were 75 out of a total of 75 maximum points that could be obtained or if in a percentage of 100%. The positive value includes 15 aspects assessed by validators who get the highest points. From this assessment, it was concluded that the learning media tested was declared very valid for field testing with some notes and suggestions given by the content validator to the developer to make minor revisions to the content in the tested media. The notes and suggestions include improving the writing of the name of the bacteria and the learning objectives set.

The results of the media validation questionnaire were also positive. The total points obtained are 71 out of a total of 75 maximum points that can be obtained or 94.67% if expressed in percentage form. Of the 15 aspects assessed, 11 aspects get 5 statement points, including clear instructions for operating the media, geolocated games based on audio augmented reality can

be accessed flexibly, geolocated games based on audio augmented reality can help users understand the application of beneficial bacteria in everyday life, geolocated games based on audio augmented reality can help users understand about the types of beneficial bacteria, geolocated games based on audio augmented reality can make it easier for users to understand where good bacteria are applied, quizzes in geolocated games based on audio augmented reality are in accordance with the material presented and do not interfere with user understanding, narration and sound effects support understanding of the material, the audio composition used is interesting and does not disturb the user, the challenges in each location are interesting and educational, location-based interactions increase learning engagement, and media design attracts user attention.

Then, as many as 4 aspects get statement points 4 including Geolocated Games Based on Audio Augmented Reality can be operated by users easily, Geolocated Games Based on Audio Augmented Reality effectively explains the concept of the role of beneficial bacteria, Geolocated Games Based on AAR has fulfilled learning modalities including visual, auditory, and kinesthetic, and AR audio experience design is interesting. From the results of the assessment, it was concluded that the learning media tested were very valid for field testing without revision with comments stating that the AAR-based geolocated games learning media were good and innovative.

**Figure 12** Situation students in game

The results of the pre-test and post-test, which were attended by 24 students of class X-A SMA Nasional Malang, obtained the general result that all students experienced an increase in scores on the post-test or after using the tested product. To deepen the results, N-Gain testing was conducted to determine whether the use of media was effective in improving student learning outcomes. The result of N-Gain score testing is an average value of 83.98% or included in the effective category with a minimum score of N-Gain score at 29% and 100% at the maximum score.

From these tests, it can be concluded that the use of AAR-based geolocated games learning media can improve student learning outcomes in biology subjects on the role of good bacteria. These results are in line with previous research which states that AR learning media developed are effective, practical, and able to improve students' cognitive understanding (Nahri et al., 2024). This was also found in research conducted by Lampropoulos et al. (2022) which states that the integration of AR and gamification can increase student engagement, motivation, active participation, and learning outcomes. AR media has a positive impact on students involved including positive behavioral and psychological changes, as well as improvements in knowledge acquisition and academic performance.

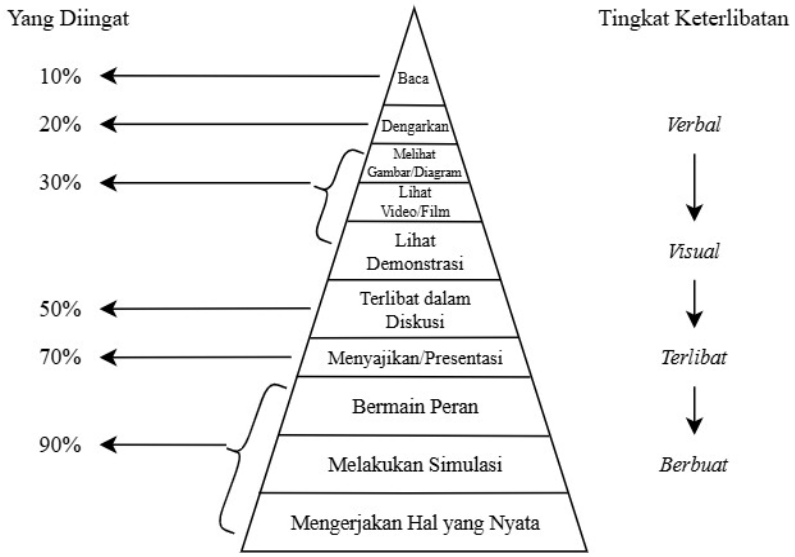


**Figure 13 Edgar Dale's Cone of Experience**

The N-gain score test results from the pre test and post test which are effective are obtained because the AAR-based geolocated games learning media tested bring learning experiences that make students do something in the course of learning activities. According to Edgar Dale, the learning process and results are influenced by the way of learning (Ambarwati, 2023). Based on Edgar Dale's cone of experience theory as shown in the figure above, the experience provided by AAR-based geolocated games is role playing or the level of students' ability to remember the material presented reaches 90%.

In this game learning concept, students are asked to answer quizzes whose answers are in the narrative of AAR material scattered in the school environment. In the game there are two roles that can be chosen by students with a group voting system that is done before the game starts. The two roles include Lead Agents whose job is to find where the PoI locations are located and listen to the recorded narration in it and explain the material clues they get to their friends in the group (support agents) to complete the quiz prepared in the google form. Then, the role of Support Agents is tasked with listening to the explanation of the Lead Agents and ensuring that they answer the quiz correctly based on the clues obtained and explained by the Lead Agents from the audio augmented reality (AAR). Game design that involves this kind of role division has been proven to increase student engagement and motivation (Herlansyah & Retnawati, 2024).

Students play the game in groups, where Lead Agents focus on finding AAR points and listening to the audio. The other members are responsible for paying attention to the Lead Agents' explanations and answering the quiz. In order for the quiz to be answered correctly, cooperation is needed between members from both the group leader and other members, because collaborative learning in a game environment can encourage active knowledge construction (Zheng et al., 2023). If each member performs their duties well, then the game will feel easier to complete.

After media testing, interviews were also conducted with students to find out their responses to the AAR-based geolocated games media. Most of the students gave positive responses to the tested media. The students of class X-A SMA Nasional Malang who were involved in the media testing stated that the media was fun and interesting. The outdoor learning experience was the main advantage, as it made the learning process more fun and

dynamic. It was also a new experience for the students, as they had never used similar learning media before.

Despite this, some shortcomings and obstacles were encountered during use. The main problem encountered was related to the unstable internet network, causing lag and confusion when accessing the media. In addition, the accuracy of the map was also an issue, where the location displayed on the media did not always match the actual physical location, such as an example of a location that should be in the field but was displayed in front of another class. The use of inaccurate GPS technology can be replaced with bluetooth beacons which are very accurate but have weaknesses in efficiency where the cost of using the technology is too expensive (Kounavis et al., 2018).

In terms of content and evaluation, students had difficulty in the quiz, especially in the part of writing the names of bacteria that were only delivered orally (audio). This suggests a challenge in converting auditory information into correct written form. The material that was considered the most difficult to understand was the biological terms contained therein. The auditory delivery of content makes it difficult for students to distinguish similar terms and requires repetition for deep understanding (Moreno et al., 2002).

Suggestions for improvement given by students emphasized the importance of improving map accuracy and network stability. Despite the shortcomings, students agreed that this media can help in learning the role of bacteria material well and provide a satisfying learning experience. The student responses given in this study are in line with several previous studies. Usfinit et al. (2024) said that the AR media they developed received a positive response from students and was effective in improving student understanding and could be used as an interesting and interactive learning tool. Lampropoulos et al. (2022) argue that the integration of AR and gamification can increase student engagement, motivation, active participation, and learning outcomes. gamification elements such as virtual rewards play an important role in increasing learning motivation.

Research conducted by Kleftodimos et al. (2023), argues that location-based AR experiences for education can emphasize gamification and storytelling to increase learning engagement and motivation. The use of gamification with AR can improve learners' critical skills, creativity, and teamwork ability (Petrovych et al., 2023). Criollo-C et al. (2024), in their research argue that AR can create an interactive and fun learning experience, which is very important for students at the early education level. Thus, the integration of AR in the education curriculum can be a strategic step to support more effective and sustainable learning, and meet the needs of today's digital generation.

## Conclusion

This research successfully developed learning media in the form of geolocated games based on Audio Augmented Reality (AAR) for the material of the role of good bacteria, which is intended for class X students of SMA Nasional Malang. The developed product integrates Odoo website as the main hub, Echoes as the geolocated AAR platform, and Google Form for quizzes. The learning media developed was declared very valid and worthy of testing based on the validation results. The material expert gave 100% assessment, while the media expert gave 94.67% assessment. This shows that both the content and design of the media have met the eligibility standards, although there are some minor revision suggestions from the material experts. The implementation of AAR-based geolocated games learning media proved effective in improving student learning outcomes. This is based on the acquisition of an average N-Gain score of 83.98% of 24 students who participated in the trial. Outdoor learning and the interactive nature of the media are considered as the main advantages that help understanding

the material and increase engagement. However, there were some technical issues such as network problems and map accuracy, as well as difficulties in writing bacterial names from the audio.

As for the suggestions that researchers can provide based on the results of this study for future concept development. Improvements need to be made to the technical aspects, especially in overcoming network instability and map inaccuracies. The use of alternative technologies such as bluetooth beacons can be explored for higher location accuracy, although cost considerations are needed. Considering offline features could also be a solution to network issues. To overcome students' difficulty in understanding and writing biological terms only from audio, it is recommended to add visual elements or supporting text at the Point of Interest (PoI) or inside the main hub. This geolocated games AAR model has the potential to be applied to other subjects or different levels of education, especially those that require contextual learning in the real environment.

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