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DEVELOPMENT OF A WEB EXTENDED REALITY (WEBXR) BASED SMART FARMING SIMULATION GAME FOR SOYBEAN CULTIVATION

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Abstract

Although digital simulation media in agriculture have received considerable scholarly attention, limited research has specifically examined the development of Web Extended Reality (WebXR)-based smart farming educational simulations to address the low regeneration of young farmers. This study aims to design and develop a WebXR-based smart farming simulation game for soybean cultivation as an interactive learning medium accessible through WebXR-enabled browsers and to evaluate its feasibility and user experience. This study employed a Research and Development (R&D) approach using the Multimedia Development Life Cycle (MDLC) model, consisting of concept, design, material collection, assembly, testing, and distribution stages. Data were collected through observation, interviews, and literature review, involving 50 student respondents from Universitas Pendidikan Ganesha through direct application testing. User experience data were obtained using the Game Experience Questionnaire (GEQ), covering In-Game and Post-Game modules. The findings show that all system functions operated properly based on black box testing, and the application was declared highly valid by content experts (1.00) and media experts (1.00). GEQ results for the In-Game components showed competence at 2.88 (high/good), sensory and imaginative immersion at 2.90 (high/good), flow at 2.37 (moderate/fair), challenge at 2.74 (high/good), tension/annoyance at 1.33 (low), positive affect at 3.21 (very high), and negative affect at 0.43 (very low). The Post-Game components showed positive experience at 3.07 (high/good), negative experience at 0.30 (very low), tiredness at 0.44 (very low), and returning to reality at 0.95 (low). The study concludes that the WebXR-based smart farming simulation game is feasible for broader implementation and effective in providing an immersive, enjoyable, and interactive learning experience for soybean cultivation. These findings contribute to agricultural education technology by demonstrating the potential of WebXR-based simulation games as modern digital learning media to support smart farming literacy and encourage youth engagement in agriculture.

Keywords: Agricultural Education Technology; Game Experience Questionnaire; Smart Farming Simulation; Soybean Cultivation; Web Extended Reality

INTRODUCTION

Agriculture is a strategic sector in the Indonesian economy, yet it still faces various challenges, particularly concerning soybean commodities. National soybean production has been unable to meet domestic demand, rendering Indonesia dependent on imports to fulfill market needs. Data shows that national soybean production in 2023 only reached approximately 953,571 tons, whereas national consumption demand was significantly higher, leaving imports as the primary solution for fulfilling soybean-based food needs (Puja Pratama Ridwan, 2023). On the other hand, the agricultural sector also faces the issue of a low regeneration rate among young farmers. Based on data from the Central Bureau of Statistics in 2023, only about 21.93% of farmers in Indonesia are within the 19–39 age range, indicating a low interest among the younger generation toward the modern agricultural sector (Umbara, 2025). This condition poses a serious threat to national food security if it is not counterbalanced by technological innovation and adaptive educational approaches geared toward the digital era.

One approach that has been increasingly implemented in the modern agricultural sector is smart farming. Smart farming is a technology-based agricultural system that utilizes automation to enhance work efficiency, productivity, and the effectiveness of agricultural land management (Bantaika et al., 2024). The implementation of smart farming can take the form of automated watering, automated fertilizing, and time-based automated pest spraying systems, which help farmers reduce manual workloads and improve the precision of crop maintenance. Nevertheless, the application of smart farming technology in Indonesia remains suboptimal, particularly among young farmers. Limited knowledge, access to training, and a lack of interactive educational media are factors hindering the widespread adoption of this technology (Rachmawati, 2021).

In the context of modern education, technology-based immersive learning media are being developed to improve the effectiveness of the learning process. Interactive learning media can provide a more engaging, realistic, and contextual learning experience compared to conventional methods (Saraswati et al., 2026). One rapidly developing technology is Virtual Reality (VR), a technology that allows users to experience a three-dimensional virtual environment in an immersive and interactive manner (Putu Sava Adikara Budi et al., 2025). VR technology has been widely utilized in education, simulation, healthcare, and industrial training because it can enhance user understanding through direct experience within a virtual environment.

The advancement of immersive technology has subsequently given rise to the concept of Web Extended Reality (WebXR), a web-based technology that enables VR and Augmented Reality (AR) experiences to be accessed directly through a browser without requiring the installation of specific applications (Matahari, 2022). WebXR offers ease of accessibility and application distribution as it can be executed via local networks or the internet using devices that support modern browsers. This technology is considered more flexible than conventional VR applications because it reduces dependency on standalone platform-based application distribution. Furthermore, WebXR enables the integration of an interactive virtual environment that is lightweight and easily accessible within digital learning processes.

The utilization of immersive technologies such as VR, AR, and XR in agriculture has garnered attention in several previous studies. Research conducted by Arif Prastiyanto demonstrates that VR technology can serve as an innovative agricultural counseling medium for millennial farmers, as it can increase interest and understanding of modern agricultural technology (Prastiyanto, 2021). Another study by Agtecher also explains that immersive technologies like VR, AR, and XR can be utilized as simulation media for agricultural training to understand crop cultivation processes virtually and realistically (Agtecher.com, 2023). Additionally, research conducted by Novia Yunanda and Muhammad Furqan proves that the use of VR and AR media can significantly increase the motivation and learning outcomes of agricultural students (Yunanda & Furqan, 2024).

The development of immersive technology in the field of smart farming has also been carried out through the integration of mixed reality and the Internet of Things (IoT). Research by Youssef Alj developed a mixed reality application based on smart agriculture capable of displaying real-time agricultural data through immersive headset devices as a simulation and training medium for modern agriculture (Alj et al., 2022). However, most previous studies have still focused on the implementation of VR or mixed reality based on standalone devices and have not widely developed smart farming educational simulations based on WebXR that can be accessed more flexibly via local browsers.

In addition to technological aspects, the use of games as educational media is also considered capable of increasing user engagement and motivation in the learning process. Games are a form of interactive simulation that combines rules, challenges, goals, and user experiences within a virtual environment to create a more engaging learning process (Dewi et al., 2026). In the context of modern agriculture, a gamification approach can help users understand the crop cultivation process step-by-step through simulations that resemble real conditions in the field.

The commodity utilized in this study is Edamame soybean (*Glycine max L.*), which is a soybean variety that possesses high economic value and continuously increasing export demand. Edamame requires a fairly complex cultivation process, ranging from land preparation, planting, watering, fertilizing, pest control, to harvesting with precise timing to maintain the quality of the yield (Lismayanti et al., 2024). Therefore, Edamame cultivation is highly relevant to be used as a simulation scenario in implementing the concept of immersive technology-based smart farming.

Application development in this research was carried out using several supporting software applications, such as Unity as the main game engine for building the interactive simulation environment (Permadi et al., 2022), Blender for the process of creating and processing three-dimensional assets (Darma Widnyana et al., 2025), and Visual Studio Code as the code editor in developing the WebXR-based application. Application testing also utilized immersive devices such as the Meta Quest 2 to ensure the user experience runs optimally within the interactive virtual environment (Dilananda et al., 2025).

Based on the aforementioned description, this study aims to develop a Web Extended Reality (WebXR)-based smart farming simulation game for soybean cultivation as an interactive learning medium capable of providing an immersive and easily accessible learning experience through a local browser. This research also focuses on the implementation of smart farming features, including automated watering, automated fertilizing, and automated pest spraying within a virtual simulation environment. The novelty of this research lies in the development of a WebXR-based smart farming simulation using an interactive gamification approach that can be accessed via localhost, thereby providing flexibility in application distribution while expanding the utilization of immersive technology in modern agricultural education.

METHODS

This study utilizes a Research and Development (R&D) approach, which aims to design and develop a Web Extended Reality (WebXR)-based smart farming simulation game for soybean cultivation as an interactive learning medium based on immersive technology. The R&D approach was selected because the research does not only focus on theory testing, but also aims to produce an interactive multimedia product that can be directly utilized in modern agricultural education processes (I Dewa Made Ditha Utama P et al., 2024). The study was conducted at Universitas Pendidikan Ganesha, involving 50 students as respondents for user testing.

The development model employed is the Multimedia Development Life Cycle (MDLC) proposed by Sutopo, as it offers systematic multimedia development stages that are suitable for developing WebXR-based interactive simulation applications. The MDLC stages consist of concept, design, obtaining content material, assembly, testing, and distribution, as illustrated in Figure 1.

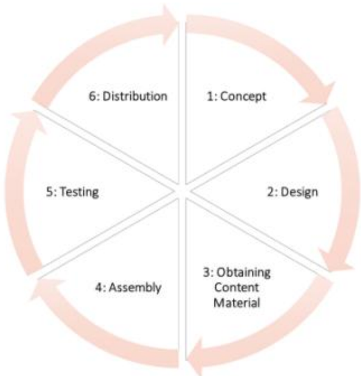


Figure 1 Multimedia Development Life Cycle (MDLC)
(Source: (Sutopo, 2003))

Based on Figure 1, the following is an explanation of each development stage carried out in this study.

1. Concept

The concept stage was conducted to determine the application development objectives, user requirements, and the scope of the smart farming simulation to be built. At this stage, observations, interviews, and literature reviews were carried out regarding the low regeneration rate of young farmers, the implementation of smart farming, and the utilization of immersive technology in agricultural learning media. Additionally, the core features of the application—including automated watering, automated fertilizing, and time-based automated pest spraying for Edamame soybean cultivation—were identified.

2. Design

The design stage was performed to design the application structure, gameplay mechanics, user interface, interaction flow, and the WebXR-based virtual environment to be developed. The design was aimed at ensuring the application is capable of providing an interactive, immersive, and easily accessible learning experience through browsers that support WebXR technology.

3. Obtaining Content Material

The obtaining content material stage was carried out by gathering all the materials and assets required for the application development. The collected materials included information on Edamame soybean cultivation, smart farming systems, agricultural environment references, supporting audio, and three-dimensional visual assets. The process of creating and processing 3D assets was conducted using Blender, while the implementation of the virtual environment and application interactions was developed using Unity and Visual Studio Code.

4. Assembly

The assembly stage is the process of implementing the entire application design into the WebXR system. This stage involved integrating 3D assets, the user interface, gameplay mechanics, user interaction systems, and smart farming features into the interactive virtual environment. Furthermore, browser-based application access was implemented so that the application could be executed via localhost as well as browsers supporting WebXR technology.

5. Testing

The testing stage was conducted to ensure that all application functions operate according to the design and are capable of providing a good user experience. The evaluation included black box testing, content expert validity testing, media expert validity testing, and user experience testing using the Game Experience Questionnaire (GEQ).

a. Black Box Testing

Black box testing was performed to test all system functions based on usage scenarios without examining the source code structure. Testing was conducted on navigation features, object interactions, gameplay mechanics, and the implementation of smart farming features within the WebXR application.

b. Content and Media Expert Validity Testing

Validity testing was conducted by two content experts and two media experts to assess the suitability of the material, visual appearance, interactivity, and the feasibility of the application as a learning medium. The assessment utilized questionnaire instruments, which were subsequently analyzed using the Gregory formula. The expert assessment tabulation is shown in Table 1.

Table 1. Expert Assessment Tabulation
(Source: (Gregory, 2014))

		Expert 1	
		Less Relevant	Highly Relevant
Expert 2	Less Relevant	(A)	(B)
	Highly Relevant	(C)	(D)

The validity score was calculated using the Gregory formula as follows.

$$\text{Validity} = \frac{D}{A+B+C+D} \qquad (1)$$

(Source: (Gregory, 2014))

Description:

A = Both experts state less relevant

B = Expert 1 states relevant and Expert 2 states less relevant

C = Expert 1 states less relevant and Expert 2 states relevant

D = Both experts state relevant

The validation level criteria for the expert testing are shown in Table 2.

Table 2. Validation Level Criteria for Expert Testing
(Source: (Candiasa, 2010))

Validity Coefficient	Qualification	Criteria
0,91 – 1,00	Very High	Very Valid
0,71 – 0,90	High	Valid
0,41 – 0,70	Moderate	Moderately Valid
0,21 – 0,40	Low	Less Valid
0,00 – 0,20	Very Low	Very Less Valid

c. User Experience Testing Using GEQ

User experience testing was conducted using the Game Experience Questionnaire (GEQ) developed by (Wijnand et al., 2013). The GEQ instrument was selected because it is specifically designed to evaluate the psychological experiences of users within game applications and interactive virtual environments based on immersive technology.

In this study, two GEQ modules were utilized: the In-Game Module and the Post-Game Module. The In-Game Module was used to measure the user experience while interacting with the application, whereas the Post-Game Module was used to measure the psychological state of the users after completing the simulation. The utilization of these two modules was chosen because it aligns with the characteristics of the WebXR application, which emphasizes immersive experiences and user engagement during the simulation process. The Social Presence Module was not utilized because the application was developed in single-player mode without multiplayer interactions or non-player characters (NPCs).

The assessment components of the In-Game Module consist of competence, sensory and imaginative immersion, flow, challenge, tension/annoyance, positive affect, and negative affect. Meanwhile, the components of the Post-Game Module consist of positive experience, negative experience, tiredness, and returning to reality. Each statement item in the GEQ utilizes a 5-point Likert scale with a score range of 0–4, namely not at all (0), slightly (1), moderately (2), fairly (3), and extremely (4). The score interpretation guidelines for the GEQ are shown in Table 3 and Table 4.

Table 3. In-Game GEQ Score Guidelines
(Source: (Wijnand et al., 2013))

Component	Composing Items
Competence	2, 9
Sensory and Imaginative Immersion	1, 4
Flow	5, 10
Challenge	12, 13
Tension/Annoyance	6, 8
Positive Affect	11, 14
Negative Affect	3, 7

Table 4. Post-Game GEQ Score Guidelines
(Source: (Wijnand et al., 2013))

Component	Composing Items
Positive Experience	1, 5, 7, 8, 12, 16
Negative Experience	2, 4, 6, 11, 14, 15
Tiredness	10, 13
Returning to Reality	3, 9, 17

The final score for each GEQ component was obtained by calculating the average score of all statement items within each respective component using the following formula.

$$\bar{x} = \frac{\sum x}{n} \qquad (2)$$

(Source: (Wijnand et al., 2013))

Description:

$\bar{x}$= average score of the GEQ component

$\sum x$= total sum of scores

n= number of questionnaire items

User testing was conducted on 50 students of Universitas Pendidikan Ganesha through direct testing techniques after utilizing the WebXR application (Ijsselsteijn et al., 2013).

6. Distribution

The distribution phase was conducted by deploying the WebXR application via localhost and browsers that support WebXR technology. This phase aimed to ensure that the application can be accessed flexibly without requiring additional application installations on the users' devices.

RESULTS

1. Results of the Conceptualization Phase (Concept)

The WebXR-based smart farming simulation game was developed as an interactive learning medium to introduce the Edamame soybean cultivation process based on modern agricultural technology. The application was designed to be accessible via browsers supporting WebXR technology, enabling users to run the simulation without requiring additional application installations. The core concept of the application emphasizes an immersive learning experience through virtual interactions within a digital farming environment.

The developed simulation encompasses several soybean cultivation activities, such as automated watering, automated fertilizing, automated pest spraying, and the harvesting process within a three-dimensional virtual environment. Additionally, the application provides user orientation and training features to assist in understanding the system's operational mechanisms before entering the main practical laboratory phase.

2. Results of the Design Phase (Design)

The design phase was conducted by constructing storyboards, a system mind map, user interface designs, and the application's navigation structure as the baseline for implementing the WebXR-based smart farming simulation game. The design was aimed at ensuring that users can easily and interactively comprehend the application's operational flow.

A mind map was utilized to map the relationships between features, virtual environments, simulation mechanisms, and user activities within the WebXR application. Designing the mind map assisted the system development process by ensuring that each developed feature was interconnected in accordance with the predetermined gameplay flow and learning objectives. The system mind map results are shown in Figure 2.

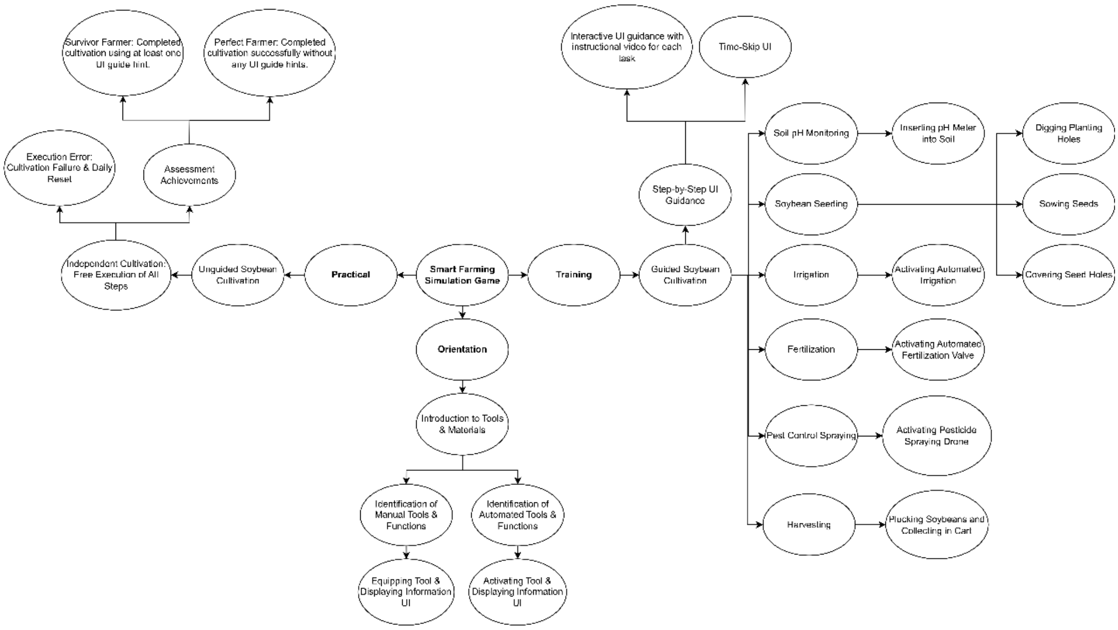


Figure 2. Mind Map of the WebXR Smart Farming System

Based on Figure 2, the application consists of several main virtual environments, namely the main menu, orientation, training, and practical laboratory. Additionally, the system integrates smart farming features, such as automated watering, automated fertilizing, automated pest spraying, and virtual harvesting processes within the simulation environment.

Furthermore, a storyboard was utilized to illustrate the visual flow and user interactions across each application scene, ranging from the main menu interface to the smart farming practical laboratory phase. The storyboard assisted in visualizing the application design prior to the implementation phase. The storyboard results are shown in Table 5.

Table 5. Storyboard of the Smart Farming Simulation Game

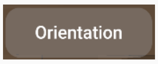
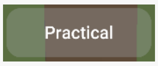
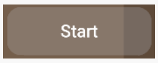
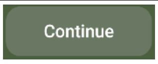
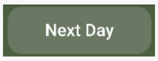
Main Menu		
Scene	Illustration / Visual	Description
1		The accompanying illustration represents the storyboard layout showing a user wearing a VR headset and positioned within the main menu environment, where they can select the training, orientation, or practical laboratory menus.
Orientation Menu		
Scene	Illustration / Visual	Description
1		The accompanying illustration represents the storyboard layout showing the user entering the orientation menu. This menu features an introduction to the tools and materials utilized in smart farming for soybean cultivation. Users can pick up objects or activate the available smart farming method buttons to display a UI containing the name and function of each tool.

Training Menu		
Scene	Illustration / Visual	Description
1		The accompanying illustration represents the storyboard layout showing the user entering the training menu. Within this scene, the user is guided through the soybean cultivation process, starting from land preparation, soil pH verification, seed planting, to watering. This training process is equipped with audio narration, UI displays, and explanatory videos on each UI. Once all stages are completed, a UI prompt will appear to perform a time-skip to the next few days to monitor plant growth.
2		The accompanying illustration represents the storyboard layout showing the user positioned several days after the soybean planting stage, where the soybean plants have begun to sprout. At this stage, a UI prompt appears providing instructions to perform a time-skip to the following day.
3		The accompanying illustration represents the storyboard layout showing the user positioned several days after the soybean plants have sprouted and grown larger. At this stage, the user is required to activate the automated pest sprayer. Subsequently, as in the previous stage, the user is directed to execute a time-skip to the next few days to check the development of the soybean plants.
4		The accompanying illustration represents the storyboard layout showing the user positioned several days after conducting plant maintenance, where the soybean plants have entered the flowering stage. At this stage, a UI prompt appears containing instructions to execute a time-skip to the following day.
5		The accompanying illustration represents the storyboard layout showing the user positioned several days after the flowering stage, where the soybeans have produced pods and are ready for harvest. At this stage, the user is instructed to harvest the soybeans by picking them and placing them into the harvesting basket. Upon completion of the harvesting process, a UI prompt will appear instructing the user to return to the main menu.

Practical Menu		
Scene	Illustration / Visual	Description
1		The accompanying illustration represents the storyboard layout showing the user entering the practical laboratory menu. This menu is structurally similar to the training menu; however, it differs in the absence of instructional UI guidance. Additionally, the time-skip UI is persistently visible, unlike in the training menu where it only appears after the user completes the designated steps. In this practical menu, users are required to conduct the soybean cultivation process independently from start to finish, following the correct procedures. If the user commits a step error or fails to follow the specified protocol, a failure UI display will appear.

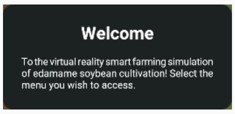
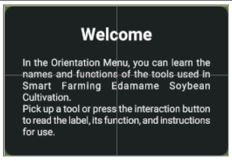
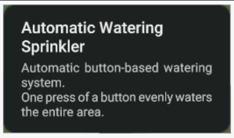
Additionally, the application's navigation structure was designed to be simple, ensuring that users can easily understand the system's operational mechanisms. The application's navigation button design results are shown in Table 6.

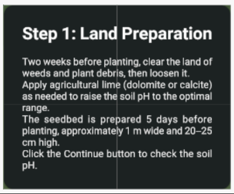
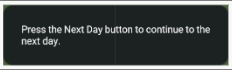
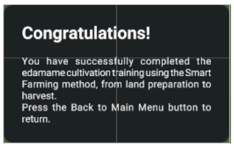
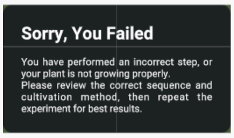
Table 6. Navigation Button Design Results

No	Button Design / Aset	Description
1		Button to enter the orientation menu for agricultural tools and materials introduction
2		Button to enter the training menu with step-by-step instructions
3		Button to enter the independent practical laboratory menu without guidance
4		Button to toggle/change the language settings
5		Button to start the simulation and practical laboratory, located within the training and practical laboratory menus
6		Step navigation button in the training menu to proceed to the next stage
7		Button to advance to the next day, located within the training and practical laboratory menus
8		Button to return to the main menu after completing the simulation, located within the training and practical laboratory menus
9		Button to retry an incorrect or failed step

Additionally, the user interface design was conducted to ensure that the application is easy to use and capable of providing an engaging visual experience. The user interface design results are shown in Table 7.

Table 7. User Interface Design Results

No	UI Layout / Visual	Description
1		Welcome UI display on the main menu
2		Welcome UI display when entering the orientation, training, and practical laboratory menus (identical layout with different description texts)
3		UI label display on agricultural equipment
4		UI display for tool names and their functions, appearing when agricultural equipment is picked up or activated

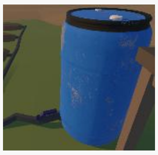
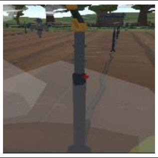
5		Text-based guide UI (without video) in the training menu
6		Video-assisted guide UI in the training menu
7		UI prompt/guide to proceed to the next day
8		Congratulatory UI display upon completing simulations in the training and practical laboratory menus
9		Failure/Game Over UI display when incorrect steps are taken in the practical laboratory menu
10		Achievement UI display for "Perfect Farmer" and "Survivor Farmer"

3. Results of the Obtaining Content Material Phase

The obtaining content material phase was conducted by gathering Edamame soybean cultivation materials, smart farming system references, supporting audio, and three-dimensional visual assets used within the virtual environment. The 3D assets were acquired from several asset repositories, with some being modified using Blender to align with the specific requirements of the WebXR simulation. The visual materials and three-dimensional objects used are shown in Table 8.

Table 8. Visual Materials and 3D Assets

No	Model / Visual Asset	Description
1		3D model of a pH meter tool
2		3D model of a seed planter tool (tugal)
3		3D model of edamame soybean seeds
4		3D model of a pest spraying drone and drone controller

No	Model / Visual Asset	Description
1		3D model of a pH meter tool
5		3D model of a drum and valve for automated or drip fertilization
6		3D model of an automated watering system or sprinkler
7		3D model of a harvesting basket
8		3D model of a farming land or soil bed (bedengan)
9		3D models of plant status icons and warning icons
10		3D models of harvest-ready soybean pods and soybean flowers
11		3D models of the soybean plant lifecycle (sprout, mature, flowering, and harvest stages)
12		3D models of achievement trophies for "Survivor Farmer" and "Perfect Farmer"
13		3D models of guide arrows and helpers for the training menu

4. Results of the Assembly Phase

The assembly phase was conducted by integrating all assets, interfaces, interaction systems, and smart farming features into the WebXR platform using Unity. The implementation was carried out progressively, starting from building the virtual environment, user control systems, and gameplay mechanisms, to optimizing browser-based access. The main menu environment of the application is shown in Figure 3.

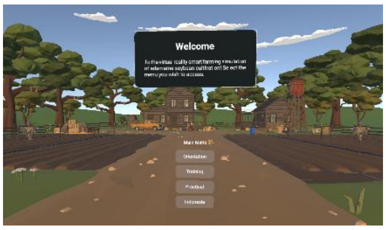


Figure 3. Main Menu Environment

Figure 3 shows the initial interface of the application, which contains the primary navigation buttons leading to the orientation, training, and practical laboratory features. The orientation environment is shown in Figure 4.

Figure 4. Orientation Environment

Figure 4 shows the system introduction area used to assist users in understanding the basic controls and interaction mechanisms within the WebXR environment. The training environment is shown in Figure 5.

Figure 5. Training Environment

Figure 5 shows the user interaction training simulation prior to entering the main practical laboratory phase. In this phase, users learn the utilization of tools and smart farming mechanisms. The practical laboratory environment is shown in Figure 6.

Figure 6. Practical Environment

Figure 6 shows the main environment of the smart farming-based soybean cultivation simulation, which includes automated watering, automated fertilizing, pest spraying, and virtual harvesting processes.

5. Results of the Testing Phase

Testing was conducted through black-box testing, content expert validity testing, media expert validity testing, and user experience testing using the Game Experience Questionnaire (GEQ).

a. Content Expert Validation

Content expert validation was conducted by two experts to evaluate the alignment of the smart farming and soybean cultivation material with the learning objectives. Based on the testing results, the validity score was obtained as follows.

$$\text{Validity} = \frac{D}{A+B+C+D} = \frac{6}{0+0+0+6} = \frac{6}{6} = 1.00 \quad (3)$$

Based on the calculation results, a validity score of 1.00 was obtained, which falls into the very high category. This result indicates that the material presented in the application aligns with smart farming concepts and the expected learning objectives.

b. Media Expert Validation

Media expert validation was conducted by two experts to evaluate the aspects of visual presentation, navigation, interactivity, and the viability of the WebXR application as an immersive learning medium. Based on the testing results, the validity score was obtained as follows.

$$\text{Validity} = \frac{D}{A+B+C+D} = \frac{15}{0+0+0+15} = \frac{15}{15} = 1.00 \quad (4)$$

Based on the calculation results, a validity score of 1.00 was obtained, which falls into the very high category. This result indicates that the application possesses excellent visual presentation, navigation, and interactivity quality, and is highly viable for use as a WebXR-based learning medium.

c. User Experience Testing Using GEQ

User experience testing was conducted with 50 students from Universitas Pendidikan Ganesha using the Game Experience Questionnaire (GEQ) instrument. The testing was carried out to determine the users' experiences during and after using the WebXR simulation application. The final scores for the GEQ components are shown in Table 9.

Table 9. Final Scores of GEQ Components

Module	Component	Final Score	Category
In-Game	Competence	2.88	High / Good
	Sensory and Imaginative Immersion	2.90	High / Good
	Flow	2.37	Moderate
	Challenge	2.74	High / Good

Module	Component	Final Score	Category
Post-Game	Tension/Annoyance	1.33	Low
	Positive Affect	3.21	Very High
	Negative Affect	0.43	Very Low
	Positive Experience	3.07	High / Good
	Negative Experience	0.30	Very Low
	Tiredness	0.44	Very Low
	Returning to Reality	0.95	Low

Based on the results in Table 8, the positive affect component achieved the highest score of 3.21, indicating that users experienced a highly positive gameplay experience while using the application. Furthermore, the sensory and imaginative immersion score of 2.90 demonstrates that the application was capable of providing a good immersive experience within the WebXR virtual environment.

Meanwhile, the negative affect score of 0.43 and the negative experience score of 0.30 indicate that the application did not cause any significant negative experiences during the simulation process. These results demonstrate that the WebXR-based smart farming simulation game is capable of delivering an interactive, engaging, and comfortable learning experience for users.

6. Results of the Distribution Phase

The distribution phase was conducted by deploying the WebXR application via localhost and browsers that support WebXR technology. The testing results indicated that the application could be executed properly on modern browsers and devices that support the WebXR immersive environment. Additionally, browser-based distribution provides higher access flexibility compared to standalone applications, as users do not need to perform additional application installations on their devices.

DISCUSSION

The development of the WebXR-based Edamame soybean smart farming simulation game in this study successfully produced an interactive learning medium capable of providing an immersive learning experience through a browser-based virtual environment. The application development was conducted using the Multimedia Development Life Cycle (MDLC) model, which comprises the conceptualization, design, obtaining content material, assembly, testing, and distribution phases. The implementation of the MDLC model is assessed to be capable of supporting a structured multimedia application development process, spanning from the initial design phase to the distribution of the WebXR-based application.

Based on the black-box testing results, all system functionalities within the application operated properly without any significant functional errors being detected. All core features, including interface navigation, user interactions, cultivation phase systems, virtual agricultural equipment utilization, and smart farming features namely automated watering, automated fertilizing, and automated pest spraying were successfully executed in accordance with the test scenarios. These results indicate that the WebXR implementation is capable of supporting the development of an interactive, browser-based simulation environment with a high level of functionality.

The validity testing results from both the content expert and media expert achieved a score of 1.00, placing them in the very high category. These findings demonstrate that the soybean cultivation material, the smart farming concept implementation, the visual interface, navigation, and application interactivity are deemed highly feasible for use as a WebXR based learning medium. The high validation outcomes indicate that the application not only fulfills technical aspects but also aligns with the demands of modern agricultural learning that is both interactive and contextual.

In addition to the functionality and media feasibility aspects, the evaluation results using the Game Experience Questionnaire (GEQ) indicated that the application is capable of delivering a positive user experience. A competence score of 2.88 demonstrates that users felt capable of understanding the controls and successfully completing the simulation stages. A sensory and imaginative immersion score of 2.90 indicates that the WebXR based virtual environment successfully provided a sufficiently strong immersive experience for the users. Meanwhile, a positive affect score of 3.21 and a positive experience score of 3.07 show that users felt pleased, comfortable, and satisfied while utilizing the application. Conversely, a negative affect score of 0.43, a negative experience score of 0.30, and a tiredness score of 0.44 indicate that the application did not induce significant negative experiences or fatigue during the usage process.

The results of this study are aligned with the research conducted by Arif Prastiyanto, which states that immersive technology is capable of enhancing user interest and understanding of modern agricultural learning through interactive virtual simulations

(Prastiyanto, 2021). This study also supports the research by Novia Yunanda and Muhammad Furqan, which demonstrates that the utilization of VR and AR technologies can enhance user motivation and engagement within the learning process (Yunanda & Furqan, 2024). Furthermore, the findings of this study resonate with the research by Youssef Alj, which explains that immersive technology can be utilized as a smart agriculture simulation medium to improve the effectiveness of modern agricultural training (Alj et al., 2022).

Nevertheless, this study possesses several distinctions compared to prior research. The majority of previous studies predominantly focused on the implementation of Virtual Reality applications based on standalone devices, whereas this study developed a WebXR-based simulation accessible via web browsers without requiring specific application installations. This approach provides better application distribution flexibility and eases user access to a web-based immersive simulation environment. Additionally, this study integrates gamification concepts through achievement systems, such as "Perfect Farmer" and "Survivor Farmer," to boost user motivation during the simulative learning process.

The implications of this study indicate that WebXR technology holds significant potential for further development as a modern agricultural educational medium. The deployment of a browser-based immersive simulation enables the learning process to be conducted in a more flexible, interactive, and engaging manner compared to conventional learning methods (Saraswati et al., 2026). This application also has the potential to be utilized as an alternative training medium for students, undergraduates, and the general public who lack direct access to hands-on agricultural cultivation practices in the field. Moreover, the WebXR implementation in this study can serve as a reference for developing learning media based on immersive technology in other educational fields.

This study, however, still has several limitations. First, the application testing was conducted on a limited scale involving 50 student respondents, meaning the results do not yet fully represent all potential user demographics. Second, some interactions within the simulation could not be made entirely realistic due to technical constraints in animation and the hardware capabilities of the devices used. Third, the WebXR implementation in this study was still run on a local browser environment, meaning online distribution testing across a wider internet network has not been performed. Additionally, the visual quality and details of the agricultural environment still utilize a simplified scale to maintain stable application performance when executed on a browser-based WebXR platform.

CONCLUSION

This study successfully developed a WebXR-based smart farming simulation game for soybean cultivation as a browser-based interactive learning medium using the Multimedia Development Life Cycle (MDLC) model. The testing results indicated that the application operated smoothly and achieved content and media expert validity scores of 1.00, placing it in the very high category. Furthermore, the Game Experience Questionnaire (GEQ) results demonstrated that the application was capable of providing a positive and immersive learning experience for users.

This research contributes to the development of modern agricultural educational media based on immersive technology through a more flexible WebXR implementation that is easily accessible via browsers. Future research could focus on developing more complex simulation features, integrating real-time smart farming data, and conducting evaluations across a broader scope of users.

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