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Teaching Agricultural Biotechnology with Animation to Enhance Students Visual Literacy and Food Security Understanding

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Abstract: Food security is a global strategic issue that requires science and technology-based innovations, one of which is plant tissue culture biotechnology. However, tissue culture is abstract and difficult for students to understand because it involves microscopic processes that cannot be directly observed. Therefore, instructional media that can visually illustrate these concepts are needed. This study aimed to develop an animated video on plant tissue culture, based on visual literacy principles and to evaluate its feasibility and effectiveness in biotechnology learning related to food security. This research employed a Research and Development (R&D) approach, using a modified 4D model through the development stage. The trial was conducted with 20 ninth-grade junior high school students who had not previously used animated video media in tissue culture learning and were willing to participate in the entire sequence of learning activities, using a one-group pretest-posttest design. Research instruments included expert validation sheets, student response questionnaires, and pretest and posttest assessments. Data were analyzed using descriptive and inferential statistics, including the Wilcoxon Signed Rank Test and N-gain analysis. The study results showed that the developed media was highly feasible, with an overall validation score of 98.89% from six validators, all of whom were media and material experts, who categorized it as "very feasible." Student responses were also very positive, with 81.2% in favor. Effectiveness analysis showed a significant improvement from pretest to posttest scores ($p < 0.001$), with an N-gain of 0.7722 (high category), indicating that the media effectively enhanced students' conceptual understanding of plant tissue culture. The novelty of this study lies in integrating visual literacy indicators and the food security context, and utilizing Artificial Intelligence technology to develop educational animation. These findings suggest that AI-based animated media can concretize complex biotechnology concepts and improve the quality of science learning.

Keywords: Biotechnology; Food Security; Plant Tissue Culture; Video Animation; Visual Literacy.

Introduction

Food security is a global strategic issue that constitutes a central focus of the Sustainable Development Goals (SDGs), particularly Goal 2: Zero Hunger. The SDGs aim to end hunger, achieve food security, and improve nutrition by promoting sustainable agriculture while enhancing the productivity and resilience of food systems against climate change and natural disasters [1]. In the national context, food security is even more complex, as it is closely related to population growth, land limitations, and socio-economic dynamics. Food security encompasses multiple dimensions, including food availability, price stability, distribution, and healthy consumption patterns [2]. Therefore, science education plays a strategic role in developing young people's literacy and confidence in sustainable agricultural innovations as a long-term solution to food security challenges. Agricultural biotechnology, in particular, plays an important role in fostering the understanding of food security, especially the plant tissue culture techniques. Plant tissue culture is a biotechnological method that enables rapid plant propagation with high-quality outcomes. This technique is based on the theory of cell totipotency, which states that every plant cell has the capacity to develop into a complete plant when placed in a supportive environment [3]. Tissue culture offers opportunities to produce superior plant varieties efficiently and supports the conservation of local plant genetic resources [4]. Research has shown that tissue culture can reduce dependence on original genetic resources, sustain agricultural production, and enhance food security across regions [5]. Other studies indicate that tissue-cultured seedlings exhibit greater resistance to diseases and improved yield quality, thereby contributing to long-term food stability [6]. Thus, tissue culture is not merely a biotechnology topic but also has strong contextual relevance to global and national food security issues that students need to understand, both conceptually and practically.

Despite its high scientific and contextual importance, junior high school students' understanding of plant tissue culture concepts remains relatively low. This topic is inherently abstract because it involves microscopic processes and laboratory procedures that cannot be directly observed in classroom settings. Many students struggle to understand tissue culture due to the predominantly theoretical instructional approach, limited opportunities for hands-on practice, and a lack of interactive visual media [7]. In addition, limited laboratory facilities in schools constitute a major constraint in enhancing students' understanding of tissue culture technology [8]. Biotechnology instruction at

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the junior high school level is still largely dominated by lecture-based methods and textbook use, providing students with insufficient opportunities to develop a deep and contextual understanding of the scientific processes involved [9]This condition indicates a mismatch between the material's abstract, complex nature and the instructional approaches employed. Therefore, innovative learning media are needed to concretize abstract concepts through systematic and meaningful visual representations.

Visual literacy represents a relevant approach to addressing this gap. It encompasses the ability to read, interpret, and create effective visual representations, as well as to understand how visual elements contribute to meaning [10]. Visual literacy not only supports content comprehension but also enhances students' critical and analytical thinking skills in evaluating and interpreting complex visual information [11]. Engagement with visual materials can stimulate deeper cognitive processes, thereby facilitating more effective learning [12]. In the context of tissue culture, visual literacy skills such as visual reasoning, critical viewing, visual association, and meaning construction are crucial for developing an understanding of sequential, systematic biological processes [13]. Accordingly, the development of instructional media explicitly aligned with visual literacy indicators has significant potential to improve the quality of biotechnology learning.

Animated media is widely regarded as an effective form of visual representation for facilitating the learning of abstract concepts. Animation consists of a sequence of images arranged and displayed over time to create the illusion of motion [14]. It enables more vivid and engaging visualizations that can help students better understand complex concepts [15]. The development of animation-based learning media is grounded in the Cognitive Theory of Multimedia Learning proposed by Richard E. Mayer, which emphasizes the integration of words and images in the learning process [16]. Numerous studies have shown that animation can enhance students' motivation and learning outcomes [17]. However, these studies generally have not systematically integrated visual literacy indicators into media design, have not explicitly linked tissue culture content to the context of food security, and have not utilized Artificial Intelligence (AI) technology in the development process. This situation indicates a clear research gap in the conceptual integration of visual literacy, the food security context, and technological innovation in the development of biotechnology animation media.

Previous studies have consistently shown that animation-based and interactive digital media are effective in improving students' motivation, engagement, and learning outcomes in biotechnology learning because visual animations help students understand abstract concepts more clearly and systematically [18],[19],[20]. Several studies also emphasized the role of visual and audiovisual representations in helping students understand abstract concepts such as plant tissue culture because microscopic and procedural processes can be visualized in a more concrete and observable form [21],[22]. However, most previous studies primarily focused on media feasibility, practicality, and effectiveness, without systematically integrating visual literacy indicators into the instructional design process. In addition, the contextual relationship between biotechnology learning and food security issues has rarely been explicitly incorporated into educational media development. Although recent studies have increasingly utilized digital technology and animation in science education, these technologies can support learning by making instructional materials more interactive and easier for students to follow [23], [24]. The integration of Artificial Intelligence (AI) to support visual literacy-based biotechnology learning remains limited. Therefore, the present study contributes by integrating visual literacy principles, food security context, and AI-assisted animation development into a single biotechnology instructional media framework, thereby offering both pedagogical and technological innovation.

Along with the rapid advancement of digital technology in 21st-century education, Artificial Intelligence (AI) has begun to play a strategic role in improving learning management and educational media development. AI enables media production processes to become more efficient and adaptive while generating complex visual representations more systematically than conventional methods [25]. In science education, which often involves abstract and microscopic concepts such as biotechnology and AI, AI can visualize scientific phenomena more concretely, thereby facilitating students' comprehension [26]. In this study, the use of AI in developing animated videos on tissue culture functions not only as a technical tool but also as an innovative approach to producing sequential, dynamic, and easily understandable visualizations of tissue culture procedures. The AI-generated visuals are expected to support key visual literacy indicators, including the ability to interpret visual information critically, connect multiple visual representations, engage in visual reasoning, and construct meaning from scientific images or illustrations. In addition, AI helps maintain consistency in visual design and narrative structure, resulting in media with stronger pedagogical quality. Although the application of AI in education continues to expand, its integration into visual literacy-based biotechnology animation media for food security remains limited, underscoring the novelty and technological and pedagogical contributions of this study.

Based on the foregoing discussion, it can be asserted that no study has developed a comprehensive animated video on plant tissue culture that integrates visual literacy indicators, explicitly links the content to food security issues, and incorporates Artificial Intelligence (AI) into its development. This research gap highlights the need for innovative instructional media that are not only valid in content and design but also empirically effective at improving students' understanding and learning outcomes. Therefore, this study aims to develop an animated video on plant tissue culture to support students' visual literacy and understanding of food security, and to evaluate its feasibility and effectiveness through expert validation, student feedback, and analysis of learning outcomes.

Research Methods

Participants

The study was conducted at a public junior high school in Semarang, Indonesia, with ninth-grade students enrolled in a biotechnology science course. Participants were selected using purposive sampling based on the alignment between the instructional material being studied and the developed product, namely an animated video on plant tissue culture. The selection criteria included: (1) students had not previously received instruction on tissue culture using animated video media, and (2) students were willing to participate in the entire sequence of learning activities involved in the study. Students at this grade level were considered to possess sufficient foundational biological knowledge to engage with biotechnology concepts. The study was implemented through a limited trial involving 20 students. The developed media was designed to assist students in understanding biotechnology concepts, particularly plant tissue culture, which are abstract and difficult to observe directly. The use of animation was intended to facilitate a more engaging and comprehensible learning process.

Research Design

This study employed a Research and Development (R&D) approach, aiming to develop a specific educational product while simultaneously assessing its feasibility and effectiveness. In this study, the developed product was an educational animated video on plant tissue culture designed as a visual literacy-based instructional medium to support students' understanding of biotechnology and food security concepts. The development model adopted was the Four-D (4D) model proposed by Thiagarajan, Semmel, and Semmel (1974), which consists of four main stages: define, design, develop, and disseminate. However, the present study was modified to include only up to the development stage. This stage involved expert validation, product revision, and a limited trial to evaluate the feasibility and effectiveness of the developed media. Selecting this model enabled a systematic media development process, beginning with a needs analysis and culminating in a product suitable for classroom implementation. The detailed stages of the animated video development process are presented in Table 1, and the animation's content flow is shown in Table 2.

Table 1. Modified 4D Stage Process from Thiagarajan 1974 [27]

Stage	Step
Define	1. Analysis of biotechnology learning problems at the junior high school level, particularly students' low understanding of plant tissue culture concepts and visual literacy. 2. Literature review of journals, scholarly articles, and curriculum documents related to biotechnology instruction, animation media, and visual literacy. 3. The findings from this stage served as the basis for formulating a solution in the form of developing an animated video as a visual literacy-based instructional medium.
Design	1. Development of the video storyline and script based on the problem identification results from the Define stage. The narrative structure covered the opening, main content, and closing sections, including scientific content on tissue culture. 2. Creation of a storyboard to guide the visualization of the video content. The storyboard mapped the narration, illustrations, animations, and visual transitions. 3. Development of visual literacy indicators integrated into the media design. 4. Development of research instruments, including: a) Expert validation questionnaires to evaluate media and content quality. b) Student response questionnaires regarding the animated media. c) Written tests (pretest and posttest) to measure students' visual literacy and learning outcomes.
Develop	1. Expert validation conducted by two categories of experts: a) Subject-matter experts evaluated the accuracy of biotechnology content and its relevance to food security. b) Media experts evaluated visual quality, narration, and overall feasibility of the animated video. 2. Revision of the product based on expert feedback to refine both content and visual presentation. 3. Field testing involving junior high school students in a limited group trial.

Table 2. Animated Media Content Flow

Video Flow	Tissue Culture Content	Modified Visual Literacy Indicators from Avgerinou, 2009[13]
Opening	1. Presents the background of food security issues at both global and national levels. 2. Emphasizes the importance of collective awareness, particularly among younger generations, in maintaining food availability and sustainability. 3. Introduces modern biotechnology as a strategic solution, particularly plant tissue culture techniques. 4. Provides a brief overview of the definition and fundamental benefits of tissue culture. 5. Invites viewers to understand and take part in achieving food security.	1. Visual Reasoning: Presents logical images/animations comparing traditional and modern agricultural systems to support initial understanding. 2. Visual Association: Links visuals of healthy plants with the narrative of food security solutions through tissue culture.

Main Content	1. Systematically explains the stages of rice plant tissue culture, including explant selection, culture media preparation, callus formation, and plant regeneration. 2. Describes the advantages of tissue culture, such as rapid propagation, large-scale production, uniform superior quality consistent with parent traits, and resource efficiency. 3. Explains the role of tissue culture in supporting food security through increased productivity, disease resistance, and the provision of high-quality seedlings. 4. Provides concrete examples of farmers applying tissue culture technology in agricultural modernization. 5. Encourages younger generations to participate in agricultural transformation through innovation and technology.	1. Visual Reasoning: Displays a logical visual sequence of tissue culture stages for clarity. 2. Critical Viewing: Encourages viewers to critically reflect on the technology's impact and real-world relevance. 3. Visual Association: Integrates narrative explanations with illustrations to enhance meaning.
Closing	1. Summarizes the key points regarding the contribution of tissue culture as a biotechnological solution to achieving food security. 2. Delivers an inspirational message emphasizing individual potential and responsibility in safeguarding future food availability. 3. Invites viewers to reflect on their potential role in supporting national food security.	1. Constructing Meaning: Encourages viewers to synthesize visual and verbal messages presented throughout the video. 2. Visual Association: Reinforces key messages through recurring imagery and reflective prompts.

Experimental Design

The effectiveness of the developed media was examined using a quasi-experimental design with a one-group pretest–posttest format. In this design, a single group of students was administered a pretest to determine their initial level of understanding before the intervention. The students then received instruction using the animated video on plant tissue culture as the treatment, followed by a posttest. The differences between pretest and posttest scores were subsequently analyzed to determine the intervention's impact.

O1	X	O2

Figure 1. One–group pretest-posttest design

In this study, the independent variable was the use of the animated video on plant tissue culture as a visual literacy-based instructional medium. The dependent variable was students' learning outcomes in biotechnology, particularly tissue culture concepts, as measured by pretest and posttest scores. The differences between pre- and post-intervention scores were used to assess learning improvement and the effectiveness of the developed media.

Instruments and Validation

Three types of instruments were used in this study: expert validation questionnaires, student response questionnaires, and written tests administered as pretest and posttest assessments. The expert validation questionnaires were employed to evaluate the feasibility of both the media design and the instructional content of the developed animated video on plant tissue culture. Validation was conducted by media and subject matter experts using a rating scale to assess aspects such as visual presentation, design quality, content accuracy, language clarity, and instructional usefulness. The instruments were validated by media and subject-matter experts to ensure content appropriateness and instructional feasibility. In addition, permission was obtained from the participating school, and students participated voluntarily in all learning and assessment activities conducted during the study. A detailed description of the research instruments is presented in Table 3.

Table 3. Research Instruments

Data Types	Method of Collecting Data	Instrument
Feasibility of the animated video on plant tissue culture	Questionnaire	An expert validation questionnaire to evaluate media design and instructional content
Effectiveness of the animated video on students' visual literacy and learning outcomes	Written test (pretest and posttest)	Multiple-choice written test
students' visual literacy and learning outcomes	Questionnaire	Student response questionnaire

Data Analysis

Data analysis was conducted on expert validation results, students' responses, and students' learning outcomes. Data obtained from media and subject-matter expert validations were analyzed using descriptive quantitative methods, with mean scores calculated to determine the feasibility level of the developed instructional media. Similarly, data from the student response questionnaires were analyzed descriptively to identify the levels of attractiveness, ease of use, and perceived usefulness of the animated media in learning. Students' learning outcome data were derived from pretest and posttest scores and analyzed to determine improvements in visual literacy and understanding of plant tissue culture concepts. Before conducting the difference test, the data were examined for normality using the Shapiro-Wilk test. The Shapiro-Wilk test was selected due to the relatively small sample size. All statistical analyses were performed using SPSS version 27. The normality test results indicated that the data were not normally distributed; therefore, further analysis was conducted using the nonparametric Wilcoxon Signed Rank Test to determine whether there was a significant difference between pretest and posttest scores. In addition, improvements in students' learning outcomes were analyzed using the normalized gain (N-gain) calculation to determine the effectiveness of the developed animated media.

Results and Discussion

The instructional media developed in this study consisted of an animated video on plant tissue culture designed to visualize processes that are abstract, complex, and not directly observable by students. Tissue culture material involves microscopic stages, including explant sterilization, inoculation, callus formation, and plantlet regeneration, which are difficult to comprehend when delivered solely through lectures or textual explanations. Therefore, dynamic visualization through animation was considered essential to help students understand the sequence of processes and the systematic relationships between stages. The media were designed to integrate a visual literacy approach, defined as the ability to interpret, connect with, and construct meaning from visual information. The visual literacy indicators used in this study included visual reasoning, critical viewing, visual association, and meaning construction [13]. Through visual reasoning, students were guided to understand the logical sequence of tissue culture stages. Critical viewing encouraged them to evaluate the relevance and implications of biotechnology applications in real-life contexts. Visual association facilitated connections between scientific explanations and visual representations, while constructing meaning enabled students to synthesize visual and verbal information into coherent conceptual understanding. The integration of these aspects positioned the animated media not merely as an illustrative tool but as a cognitive instrument that supported the construction of conceptual knowledge. By transforming abstract biological processes into structured visual narratives, the developed product demonstrated pedagogical value in facilitating more meaningful and organized biotechnology learning at the junior secondary school level.

Table 4. Modified Visual Literacy Indicators from Avgerinou 2009 [13]

Visual Literacy Indicators	Description
Visual Reasoning	Students' ability to use visual representations logically to understand procedural structures and cause-and-effect relationships in the tissue culture process. This indicator was operationalized by students' ability to systematically identify the sequential stages and explain the interrelationships between them based on the presented animation.
Critical Viewing	Students' ability to analyze and evaluate visual information critically and reflectively. This aspect was measured through the accuracy of interpreting the meaning of images or animations, distinguishing relevant from irrelevant information, and providing scientific arguments regarding the presented visualizations.
Visual Association	Students' ability to connect various visual representations with previously learned biotechnology concepts. This indicator was reflected in their ability to relate each stage of tissue culture to its scientific function and purpose, as well as to understand the interconnections among processes holistically.
Constructing Meaning	Students' ability to construct new conceptual understanding through the integration of visual information with prior knowledge. Measurement was conducted by assessing their ability to draw comprehensive conclusions about tissue culture concepts and to explain their relevance to food security, based on the animated visualizations.

In addition to being grounded in a visual literacy framework, the developed media also incorporated Artificial Intelligence (AI) technology in its production process to generate accurate, consistent, and efficient visualizations. Specifically, the animation was developed using Pippit AI, an AI platform that supports the automated, structured creation of animated and educational videos. The use of this platform facilitated the creation of representative biological illustrations and animations that depict the complex stages of plant tissue culture. The integration of AI technology into instructional media development aligns with the broader transformation of education in the digital era, which increasingly demands technology-driven innovation to enhance learning quality [25]. AI-based tools enable educators to create engaging learning resources without advanced technical design skills, thereby enabling more efficient, adaptive instructional management.

Furthermore, AI-assisted visualization enables richer forms of representation, transforming abstract biological processes into more concrete and comprehensible visual experiences [26]. These advantages indicate that the developed media did not merely utilize technology as a technical aid but positioned AI as a pedagogical instrument that enhances content presentation and strengthens students' learning experiences. By improving visual clarity and structural coherence, AI-supported animation facilitated conceptual understanding in biotechnology learning.

The animated video product on plant tissue culture was developed through a systematic process using a modified 4D model, progressing through the development stage. During the define stage, a needs analysis revealed that tissue culture is one of the most challenging biotechnology topics for junior secondary students due to its abstract nature and the invisibility of its microscopic processes. The analysis also considered the characteristics of junior secondary learners, who generally require concrete and visual representations to grasp complex scientific concepts. The findings from the define stage served as the foundation for determining the media specifications, aligned with instructional objectives and expected competency outcomes. Thus, the developed product was not solely oriented toward technological innovation, but toward addressing authentic classroom learning needs. This needs-based approach ensured strong pedagogical relevance and prevented the development process from becoming speculative. Consequently, the define stage served as a conceptual foundation, anchoring the media development process in real instructional challenges.

During the design stage, the media was systematically planned, including developing the content flow, creating storyboards, visualizing tissue culture stages, and integrating visual literacy indicators into each animation segment. The design aimed to ensure that the information was not only visually engaging but also logically structured and comprehensible for students. The incorporation of Artificial Intelligence (AI) at this stage facilitated the production of consistent, scientifically representative visual elements depicting complex biological objects. The use of Pippit AI enabled the rapid generation of visual assets compared to manual design methods, thereby accelerating the development process without compromising visual quality. AI-assisted production also ensured stylistic consistency and improved the scientific accuracy of representations, both of which are essential elements in science education. Beyond technical efficiency, the integration of AI during the design phase reflected an adaptive approach to contemporary developments in educational technology [25]. Thus, the design stage did not merely produce a technical blueprint; it also ensured that the media met both visual and pedagogical quality standards.

The development stage focused on product refinement through expert validation and revision based on evaluative feedback. This process ensured that the instructional media met feasibility standards for both content accuracy and media quality before field implementation. Revisions included improvements in visual clarity, alignment of content with curriculum objectives, and language refinement to enhance comprehensibility. The use of AI at this stage further enabled efficient visual adjustments, such as modifying illustrations and animations in line with validators' recommendations. The results of the development stage indicated that the final product was not only visually appealing but also academically valid and suitable for classroom implementation. This systematic development process aligns with the principles of the 4D model proposed by Sivasailam Thiagarajan 1974, which emphasizes structured stages of analysis, design, and development to produce high-quality educational products. Consequently, the developed animated media can be regarded as the outcome of a scientific and reflective process rather than merely a technological creation.

The feasibility of the developed animated video media was evaluated through an integrated validation process involving six validators: three material experts and three media experts. Validation by the material experts focused on graphic aspects, effectiveness, and quality, each of which obtained a percentage of 100%, thus falling into the "very feasible" category, indicating that the visual appearance, animation, and quality of the media presentation had met the standards as an effective and engaging learning medium. Meanwhile, validation by media experts assessed content and language feasibility, yielding 94.45% for content and 100% for language, both in the "very feasible" category. A high score on the content aspect indicates that the material presented aligns with the concept of biotechnology and is systematically arranged to support student understanding. In contrast, perfect language feasibility means using communicative language that aligns with the characteristics of junior high school students. The integration of visual quality, language clarity, and material accuracy is an important factor in increasing the effectiveness of visual literacy-based learning, especially in presenting complex concepts such as plant tissue culture. Overall, the average score for media and material validation was 98.89%, which falls within the "very feasible" category, indicating that the developed animated video media is not only visually attractive but also academically valid and ready for implementation in science learning. The detailed results of the media and material validation are presented in Figure 2.

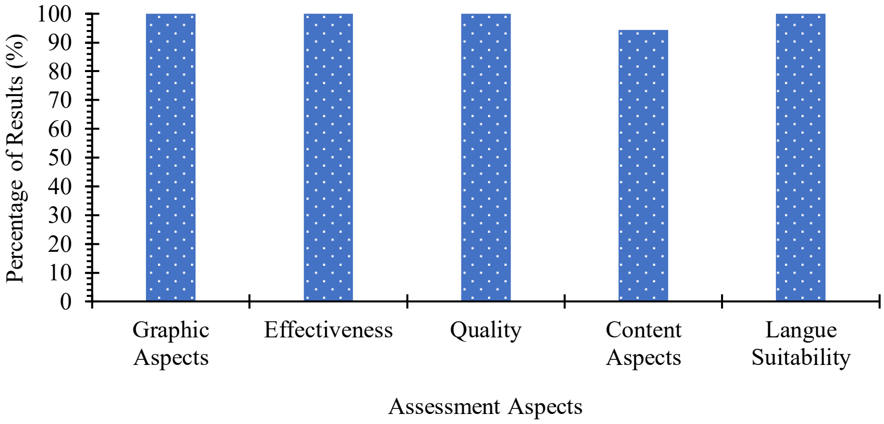

Figure 2. Results of Validation by Material Experts

Overall, the validation results indicate that the developed animated media met the feasibility criteria for both visual design and content substance. The alignment between visual quality and content accuracy demonstrates that the media is not only aesthetically engaging but also academically valid. This balance is essential, as effective instructional media must present scientifically accurate information while remaining accessible and comprehensible to students. The high feasibility ratings from both media and subject-matter experts suggest that the systematic development process based on the 4D model successfully produced a product ready for classroom implementation. The integration of visual literacy principles and Artificial Intelligence (AI) further enhanced the representational quality of the media, particularly in visualizing complex biological processes that are otherwise difficult to observe directly. Consequently, the developed animated video on plant tissue culture is suitable for implementation in junior secondary science learning.

Feedback from the validators served as the basis for product revisions. The revisions included adjustments to background elements deemed less appropriate, as well as corrections to minor textual inaccuracies to improve clarity and precision. These refinements ensured that both visual and linguistic components met instructional standards. A detailed summary of the revisions made in response to expert suggestions is presented in Figures 3 and 4.

(a) (b)

Figure 3. (a) Before validation was carried out, the background was not suitable for the "wow, it turns out the explanation has to" section, which looked plain. (b) After validation, the background is adjusted to avoid being plain and to match the sentence.

(a) (b)

Figure 4. (a) Before validation was carried out, the Latin name for rice was still incorrect. (b) After validation, the Latin name for rice is now correct, namely "Oryza sativa".

The effectiveness of the developed animated video on plant tissue culture was analyzed by comparing pretest and posttest scores to measure improvements in students' learning outcomes and visual literacy. The results indicated an increase in scores following the implementation of the animated media in classroom instruction. This improvement suggests that students experienced enhanced conceptual understanding of biotechnology, particularly in tissue culture, which had previously been identified as challenging due to its abstract nature. To assess data distribution, a normality test was conducted using the Shapiro–Wilk test in SPSS version 27. The results revealed that the pretest data had a significance value of 0.132 (> 0.05), indicating a normal distribution. In contrast, the posttest data showed a significance value of 0.023 (< 0.05), suggesting that the data were not normally distributed. Because one dataset did not meet the normality assumption, further analysis was conducted using the nonparametric Wilcoxon Signed-Rank Test to determine whether there was a significant difference between pretest and posttest scores. The Wilcoxon test results showed an Asymp. Sig. (2-tailed) value of < 0.001, indicating a statistically significant difference between students' scores before and after the use of the animated media. This finding confirms that implementing the developed instructional media had a significant positive effect on students' learning outcomes and on the development of visual literacy. The detailed results of the normality test are presented in Table 5, while the results of the Wilcoxon Signed Rank Test are provided in Table 6.

Table 5. Normality Test Results using Shapiro–Wilk

Results	Statistics	df	Sig.
Pretest	0.926	20	0.132
Posttest	0.886	20	0.023

Table 6. Results of the Nonparametric Wilcoxon Signed Rank Test

Z	-3.931
Asymp. Sig. (2-tailed)	< 0.001

In addition to statistical significance testing, the effectiveness of the developed media was further examined using the normalized gain (N-gain) metric to quantify learning improvement. The results indicated an N-gain of 0.7722, corresponding to 77.2%, which falls within the 'great improvement' category [28][28]. This finding demonstrates that the developed animated media were highly effective in enhancing students' understanding of the subject matter. A detailed summary of the N-gain calculation results is presented in Figure 5.

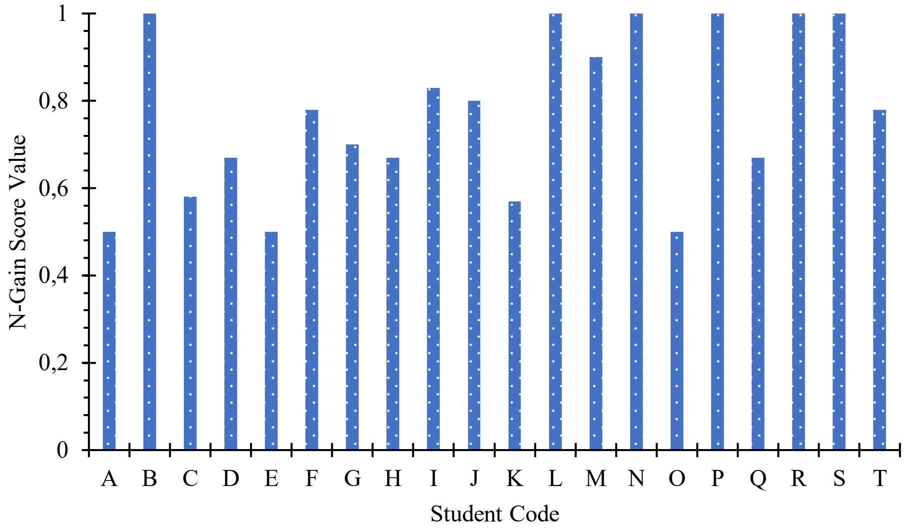

Figure 5. Student N-Gain Score Results

Students' responses to the animated video on plant tissue culture were analyzed to determine the level of acceptance and perceived usefulness of the media for learning. Evaluation was conducted through a questionnaire covering three main aspects: media appearance, language clarity, and conceptual understanding. The media appearance aspect assessed visual attractiveness, animation clarity, and comfort in following the instructional flow. The language aspect evaluated the clarity of narration, the communicative use of scientific terminology, and its appropriateness for junior secondary school students. Meanwhile, the conceptual understanding aspect measured the extent to which the media facilitated comprehension of abstract tissue culture concepts. The analysis yielded a total score of 893 out of a maximum of 1100 (81.2%), placing it within the "very feasible" category [29]. This percentage indicates that students responded positively to the use of animated media in the learning process. A positive student reception is an important indicator of instructional feasibility, as engagement and perceived clarity are closely related to meaningful learning experiences.

The improvement in students' understanding of tissue culture material was not solely influenced by the use of animation as a technological medium. Still, it was fundamentally driven by the integration of a visual literacy approach into media design. Visual literacy enables students to systematically interpret, analyze, and construct meaning from visual representations, thereby supporting comprehension of abstract and hierarchical scientific concepts. In this study, the visual literacy indicators included visual reasoning, critical viewing, visual association, and constructing meaning, as adapted from Maria Avgerinou 2009 [13]. Collectively, these indicators supported the development of conceptual understanding in biotechnology learning. Visual reasoning helped students logically follow the sequential procedures of tissue culture. Critical viewing encouraged reflective evaluation of visual information rather than passive acceptance. Visual association enabled students to connect individual stages into an integrated conceptual framework, while constructing meaning supported the formation of new understanding by integrating visual representations with prior knowledge. Visual literacy is the ability to understand and effectively use visual information in learning contexts [11]. Therefore, animated media designed based on visual literacy principles facilitated comprehension of biological processes that cannot be directly observed. By structuring visual information systematically and in context, the media served as a cognitive scaffold, strengthening students' conceptual construction.

Tissue culture material represents a biotechnology concept that is microscopic, procedural, and inherently complex, making it difficult to comprehend through verbal explanation or static text alone. The systematic integration of visual elements in animated media helped reduce abstraction by presenting concrete representations of processes that typically occur in laboratory settings. Through animation, transitions between stages such as sterilization, inoculation, callus formation, and plantlet regeneration were dynamically visualized, enabling students to understand the causal relationships among procedural steps. This finding aligns with the Cognitive Theory of Multimedia Learning proposed by Richard E. Mayer 2009, which posits that the combination of verbal and visual information enhances comprehension by engaging dual cognitive channels simultaneously. The use of color-coding, symbols, and motion in the animation further emphasized essential elements of the process, thereby guiding students' attention to critical information. Sequential visualization supported the development of structured knowledge schemas, which are more effective for conceptual understanding than static textual presentation. Therefore, the effectiveness of the developed media cannot be separated from its pedagogically grounded visual design. The animation was not created merely for aesthetic enhancement but was intentionally structured to facilitate cognitive processing and conceptual integration.

Visual literacy also contributed to students' ability to transfer knowledge to broader contexts, particularly regarding the relevance of biotechnology to food security issues. By visualizing tissue culture as a technique for producing superior plant varieties, students recognized the practical applications of biotechnology in real-world agricultural development. This demonstrates that visual representations function not only as instructional aids but also as tools for constructing contextual scientific understanding. Visual literacy involves the ability to interpret, evaluate, and construct meaning from visual information, competencies closely associated with higher-order thinking skills [12]. In this study, the integration of visual literacy principles served as a key factor in bridging the complexity of biotechnology material with the cognitive characteristics of junior secondary students. These findings reinforce the notion that science instructional media development should not focus solely on technological innovation, but also on the quality and pedagogical alignment of visual representations. Accordingly, visual literacy constitutes a fundamental pedagogical foundation in the development of animation-based learning media. By integrating structured visualization with scientific accuracy, instructional media can more effectively support conceptual understanding and meaningful learning experiences.

The findings of this study have important implications for science learning at the junior secondary school level, particularly for teaching abstract, non-observable biotechnology topics. The animated video, grounded in visual literacy, was shown not only to improve learning outcomes but also to facilitate more structured and meaningful conceptual understanding because the information was presented sequentially through visual and verbal explanations [30]. Similar findings have also been reported in previous studies, showing that interactive and animation-based learning media can improve student engagement and learning outcomes in science education by making students more focused and actively involved during the learning process [31], [32]. Furthermore, the integration of Artificial Intelligence (AI) in the media development process demonstrates that AI can serve as an effective supporting tool for producing engaging, efficient, and pedagogically aligned instructional resources. The use of AI-assisted design reflects the demands of 21st-century education, which emphasize technological literacy, innovation, and the development of critical thinking skills. When integrated thoughtfully, digital technologies can enhance both the quality of representation and the efficiency of instructional media production [23]. The effectiveness of the developed media is also consistent with the Cognitive Theory of Multimedia Learning, which is optimized when verbal and visual information are combined in accordance with cognitive processing principles [16]. The structured integration of animation, narration, color coding, and sequential visualization in this study illustrates the practical application of multimedia learning principles in science education [19]. The primary contribution of this research lies in integrating visual literacy principles, animated instructional media, and AI technology into plant tissue culture materials closely related to food security. This integrated approach positions visual literacy as an important pedagogical foundation in science learning media.

This study not only produced a feasible and effective instructional product but also offers an innovative, context-based development model for science education media. The proposed approach may serve as a reference for educators and researchers seeking to design technology-enhanced learning environments that meaningfully address complex scientific concepts in secondary education. Despite the positive findings, this study has several limitations that should be considered. The implementation involved a relatively small sample size and was conducted within a limited school context, which may restrict the broader generalizability of the findings. In addition, the study employed a one-group pretest–posttest design without a control group, making it difficult to fully attribute the observed improvements solely to the developed media intervention. Therefore, future studies are recommended to involve larger, more diverse participant groups, employ experimental designs with control groups, and examine the long-term effects of animation-based biotechnology learning through longitudinal research. Broader implementation across different educational settings is also necessary to strengthen the applicability and scalability of visual literacy-based instructional media integrated with Artificial Intelligence (AI).

Conclusion

This study successfully developed a visual literacy-based animated video on plant tissue culture to support students' understanding of biotechnology concepts and their relevance to food security. The feasibility and effectiveness of the developed media were empirically examined through expert validation, student responses, and statistical analysis of learning outcomes. The validation results showed that the media was highly feasible for classroom implementation, with an overall feasibility score of 98.89%, while students' responses indicated a very positive reception (81.2%). In terms of effectiveness, a statistically significant improvement was observed between pretest and posttest scores (Asymp. Sig. (2-tailed) < 0.001), with an N-gain value of 0.7722 categorized as high. These findings confirm that the developed animated media effectively enhanced students' visual literacy and conceptual understanding of plant tissue culture. The integration of visual literacy indicators and Artificial Intelligence (AI) technology also strengthened the quality of visual representation in biotechnology learning. Future researchers and educators can apply and adapt this animated media to other science topics and wider educational settings. However, this study was conducted with a limited number of students and in a single school context, so further studies involving larger samples and broader implementation are still needed.

Author's Contribution

T.N. Fadliya: Data curation, media design, writing, original draft. F. Fibriana: Funding acquisition, software license, writing and editing, review, and supervision.

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