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Development of Cloning Biotechnology Learning Media Based on Virtual Laboratory to Enhance High School Students' Learning Motivation

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ABSTRACT

To evaluate the validity, practicality, and effectiveness of a cloning-based Virtual Laboratory in enhancing high school students' learning motivation. Specifically, this study addresses: (1) the objectives of the research; (2) how the study was conducted; (3) the results obtained; and (4) the novelty of the work. This research employed a Research and Development (R2D2) approach consisting of definition, design-development, and dissemination phases. Media validation involved subject matter experts, instructional design experts, media experts, and biology teachers. Effectiveness was measured using the ARCS questionnaire (Attention, Relevance, Confidence, Satisfaction) and analyzed with a Paired Sample t-test. The media demonstrated very good validity (84.72–97.29%), high readability and practicality (85.20% and 90.69%, respectively), and positive student responses (86.62%). Students' learning motivation increased significantly across all ARCS dimensions, with an average improvement of 0.77. This study addresses a gap in the application of Virtual Laboratories to the high school cloning topic—a complex and abstract area rarely implemented due to limited laboratory facilities. The novelty lies in the development and validation of a cloning-specific Virtual Laboratory combined with motivation measurement using the ARCS model, offering an adaptive and effective solution to bridge the gap between curriculum demands and schools' laboratory constraints.

INTRODUCTION

Biotechnology is a branch of applied biological science that integrates scientific principles to utilize organisms or their parts in producing beneficial products on an industrial scale (Dinata, 2011; Picataggio, 2009; Tang & Zhao, 2009). In its development, modern biotechnology not only includes conventional techniques, but also involves genetic engineering, tissue culture, and DNA-based technology that require the support of advanced infrastructure as well as trained human resources (Kumar et al., 2023; Zhang & Meng, 2024). The utilization of biotechnology demands mastery of theoretical concepts and adequate practical skills so that natural resources can be managed sustainably, and biological phenomena in the surrounding environment can be understood and applied in everyday life (Nursanti, 2016). In the context of formal education, biotechnology learning requires a contextual approach that links the material to real situations, supported by thorough planning, high-tech laboratory facilities, and significant operational costs (Sari et al., 2017). Limitations of resources in many secondary schools, particularly in developing countries, lead to a gap between curriculum demands and the capacity to conduct practicums (Rahman, 2022). Therefore, there is a critical need for innovative learning media that not only offers an alternative to traditional methods but also effectively bridges the gap between theoretical knowledge and practical application.

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This media must be efficient and adaptable to the rapid advancements in educational technology.

Efforts to leverage Information and Communication Technology (ICT) in biotechnology education have already shown promising results (Mercado, 2023). For instance, the use of interactive multimedia has been proven to significantly enhance students' understanding of modern biotechnology concepts, with average scores rising dramatically from 54.03 to 92.36 (Mercado, 2023). Furthermore, the development of instructional videos for courses like tissue culture has achieved high satisfaction levels across various trial groups, from individual students to small and large field trials (Batubara, 2023). These findings clearly affirm the potential of digital media to make abstract biotechnology concepts more concrete and accessible.

Nevertheless, field observations at SMAN 1 Banyuwangi revealed real problems in learning genetic engineering, particularly the cloning topic. Based on interviews, students' learning motivation was relatively low due to the abstract nature of the material and the absence of direct practice. The learning process was dominated by the lecture method with the aid of PowerPoint, while the use of interactive multimedia was minimal due to teachers' limited technological proficiency. In addition, practicums could not be conducted due to cost constraints, the need for modern equipment, and lengthy time requirements. These findings indicate a gap between curriculum demands, such as KD 3.10 on understanding principles of bioprocess-based biotechnology, and classroom learning realities.

Globally, the Virtual Laboratory is developing as an innovative solution to overcome these constraints. A virtual laboratory is a computer-based simulation environment that enables students to conduct practicums interactively without being limited by space and time (Helenti et al., 2014). This advantage makes the Virtual Laboratory relevant for schools with limited facilities. The implementation of the Virtual Laboratory can increase motivation and learning outcomes in other biology topics such as the excretory system and eubacteria (Dewi & Prasetiyo, 2023).

However, despite promising global results in using ICT for biotechnology education, a significant research gap remains: the implementation of a virtual laboratory for cloning at the high school level is still rarely found in existing literature. This is particularly problematic in a local context where schools face challenges providing conventional laboratory practicums for complex, abstract topics like cloning. While previous studies show that instructional videos and interactive multimedia can improve understanding (Mercado, 2023; Batubara, 2023), they often fall short of providing a true, hands-on simulated experience. Therefore, this study's novelty lies in its specific focus on developing and validating a virtual laboratory designed to bridge this gap, allowing students to engage with cloning concepts in a practical, accessible way. The research further distinguishes itself by not only creating the tool but also rigorously measuring its impact on student motivation using the ARCS model (Attention, Relevance, Confidence, Satisfaction), thereby offering a comprehensive evaluation of its effectiveness.

The urgency of this research is reinforced by the need for technology-based science learning that can foster active engagement, higher-order thinking skills, and motivation. Theoretically, this study is grounded in the ARCS instructional motivation design model (Hamoraon, 2010), which posits that a well-designed learning tool can capture students' attention, connect the material to their lives, build their confidence, and ultimately provide a sense of satisfaction in their learning journey.

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Based on the above description, this study aims to: (1) test the validity of the cloning-based Virtual Laboratory media developed through assessments by experts and practitioners; and (2) test its effectiveness in increasing high school students' learning motivation. The research questions posed are:

1. To what extent is the validity of the cloning topic Virtual Laboratory for use in high school biology learning?
2. Does the use of the Virtual Laboratory significantly increase students' learning motivation based on the ARCS model?

RESEARCH METHOD

The research method contains the type This study uses R2D2 (Reflective, Recursive, Design and Development) which has been modified by the researchers (Mubayrik & Al-Mutairi, 2022). This study employs the Reflective, Recursive, Design and Development (R2D2) model, which has been adapted to create and validate a virtual laboratory for high school cloning education. The process began with the Definition stage, where a collaborative team of experts was assembled and a thorough needs analysis was conducted to identify the core problem: the difficulty of teaching abstract cloning concepts without a practical, hands-on environment. Next, the Planning and Development stage was initiated. This involved strategically choosing a 3D simulation format to visualize complex biological processes, meticulously outlining the curriculum content, and iteratively designing and developing the virtual laboratory. This recursive approach allowed for continuous testing and refinement to ensure the user interface was intuitive and the scientific content was accurate. The final prototype was then subjected to rigorous expert validation by a panel of a biologist, an educational technology specialist, and a high school teacher. Finally, in the Dissemination stage, the validated virtual lab was implemented in a high school setting. The dissemination stage involved the implementation of the validated virtual laboratory in a controlled research setting.

Participant and Research Instruments

The study was conducted at a public high school, utilizing a single eleventh-grade biology class as the study population. The participants comprised 35 students who were engaged in the standard high school curriculum covering advanced life sciences topics. This specific setting was chosen because the eleventh-grade biology curriculum includes the complex topics that the Virtual Laboratory is designed to address. To measure the impact of the developed product on learning motivation, a pre-test and post-test design was utilized. An ARCS instructional motivation questionnaire was administered to measure students' motivation levels before and after engaging with the virtual laboratory. The data collected from these questionnaires was then statistically analyzed using a Paired Sample t-Test to determine if there was a significant increase in students' learning motivation. This study used several data collection techniques, namely:

a. Validation Sheet The validation sheet was given to validation experts to measure the validity of the developed learning media.
b. Readability and Practicality Instruments of the Media The readability and practicality instruments of the media were administered to determine the quality of the virtual laboratory developed in this study.
c. Learning Motivation Questionnaire (ARCS) The ARCS questionnaire was given to students in one class before and after participating in the learning activities (Mei, 2025).

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In filling out this questionnaire sheet, it was adjusted to the opinions of each student by placing a checklist (✓) in the column provided.

d. Student Response Questionnaire The student response questionnaire was used to obtain students' feedback after the learning activities regarding the developed learning media.

The data analysis used in this study is as follows:

Analysis of Validation Results Data

The analysis of validation results data was carried out to determine the level of validity of the Virtual Laboratory media. Validity was determined by the mean score given by validators for each aspect. The data obtained were in the form of qualitative data derived from validators' suggestions and comments, and quantitative data derived from assessment aspects using a checklist (✓) in accordance with the assessment criteria (Akbar, 2013). To determine the validation of the developed instruments, validation was conducted by experts by calculating the scores obtained using the formula:

$$P = n/N \times 100\%$$

Explanation:
P = percentage of assessment (%)
n = total score obtained
N = maximum total score

The analysis of the Virtual Laboratory media assessment can be seen in Table 1.

Table 1. Evaluation Criteria for Virtual Laboratory Media on the Cloning Topic.

Percentage	Description	Follow-Up Action
81.25–100%	Very Good (VG)	The new product is ready to be implemented in real learning activities.
62.5–81.25%	Good (G)	The product can be continued by adding what is lacking, making certain considerations; the additions are not major or fundamental.
43.75–62.5%	Fair (F)	Revise by carefully re-examining and identifying weaknesses of the product for improvement.
25–43.75%	Poor (P)	Conduct major and fundamental revisions of the product.

Readability and Practicality Test Analysis of the Media

The readability questionnaire was used to determine how easily students understand the content of the media. The practicality questionnaire was used to determine how practical the media is to use. The results of the readability test were analyzed descriptively by examining the readability outcomes of the learning media. Readability and practicality scores were obtained using the formula:

$$P = A/B \times 100\%$$

Explanation:
P = Assessment percentage
A = Number of students who chose
B = Total number of students (Trianto, 2010).

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The percentage assessment data obtained were then converted into descriptive quantitative data as shown in Table 2 below:

Table 2. Readability and Practicality Assessment Criteria according to Akbar (2013)

Validity Level (%)	Media Qualification
81.25 ≤ SP ≤ 100	Very Good
62.5 ≤ P < 81.25	Good
43.75 ≤ CP < 62.5	Fair
25 ≤ KP < 43.75	Poor

Student Learning Motivation

Students' learning motivation was measured using the ARCS questionnaire by comparing before and after learning using the Virtual Laboratory media, followed by analysis using the Paired Sample t-Test.

Student Response Analysis

The analysis data were obtained from students' responses on the questionnaire used to measure the practicality of the cloning virtual laboratory.The formula used is:

$$\text{Student response percentage } (\%) = SM/TS \times 100\%$$

Explanation:
SM = Number of students who chose
TS = Total number of students

Subsequently, these data were converted into descriptive quantitative data using the following assessment criteria:

Table 3. Criteria for Student Response Results.

Percentage	Criteria	Decision
81.25 ≤ SP ≤ 100	Very Good	The learning media is highly practical, requires no revision, and is ready to use.
62.5 ≤ P < 81.25	Good	The learning media is practical, requiring only minor revisions.
43.75 ≤ CP < 62.5	Fair	The learning media is moderately practical, requiring medium-scale revisions.
25 ≤ KP < 43.75	Poor	The learning media is less practical, requiring major revisions.

RESULTS

Validity of Virtual Laboratory Media

The Virtual Laboratory learning media on the cloning topic developed was validated by four parties: material experts, teaching material development experts, media experts, and biology teachers as users. The quantitative assessment results showed that all aspects obtained the Very Good category (Table 4).

Qualitative inputs included improvements in the depth of material, adjustment of menu terminology, arrangement of background sound, and addition of supporting images. Revisions were carried out before the media was used at the implementation stage.

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Table 4. Validator Assessment Results on Virtual Laboratory Media

Validator	Aspect	Average Assessment Result (%)	Category
Material Expert	a. material coverage b. material accuracy c. presentation components	84.72	Very Good (VG)
Teaching Material Development Expert	a. presentation technique b. material presentation support c. learning presentation d. presentation components	88.54	Very Good (VG)
Media Expert	a. artistic and aesthetic b. ease of navigation c. language d. overall function	96.66	Very Good (VG)
User (Teacher)	a. content/material b. presentation c. overall function of the Virtual Laboratory media	97.29	Very Good (VG)

Figure 1. Quiz Menu Display

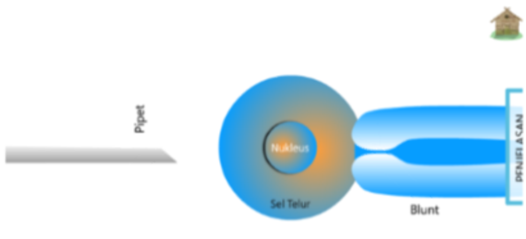

Figure 2. Reference List Menu Display

Readability and Practicality of Media

The readability test by students showed an average score of 85.20% (Very Good category), with the highest aspect on Clarity of Presentation (87.15%). The practicality test obtained Very Good category, with the highest score on Media Usefulness (95.55%) (Table 5 and Table 6).

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Table 5. Readability Test

Validator	Aspect	Average Assessment Result (%)	Category
Material Expert	a. material coverage b. material accuracy c. presentation components	84.72	Very Good (VG)
Teaching Material Development Expert	a. presentation technique b. material presentation support c. learning presentation d. presentation components	88.54	Very Good (VG)
Media Expert	a. artistic and aesthetic b. ease of navigation c. language d. overall function	96.66	Very Good (VG)
User (Teacher)	a. content/material b. presentation c. overall function of Virtual Laboratory media	97.29	Very Good (VG)

These results indicate that the media is easy to understand, attractive, and can be used effectively in learning.

Table 6. Readability Test Results of Virtual Laboratory Media

Validator	Aspect	Average Assessment Result (%)	Category
Material Expert	a. material coverage b. material accuracy c. presentation components	84.72	Very Good (VG)
Teaching Material Development Expert	a. presentation technique b. material presentation support c. learning presentation d. presentation components	88.54	Very Good (VG)
Media Expert	a. artistic and aesthetic b. case of navigation c. language d. overall function	96.66	Very Good (VG)
User (Teacher)	a. content/material b. presentation c. overall function of VirtualLaboratory media	97.29	Very Good (VG)

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Table 7. Practicality Test Results of Virtual Laboratory Media

Validator	Suggestions and Comments	Note
Material Expert	1) Improvements in depth and clarity of material are needed	The product is ready to be used in learning activities.
Teaching Material Development Expert	1) The menu section terminology is less appropriate. 2) When the video material about the nuclear transfer process is played, the voice should not compete with the background sound. 3) The list of materials should be clarified if the concept uses a book. 4) For the history section material, it is better to add pictures and not let the text fill the screen too much.	The product is ready to be used in learning activities but needs improvement in the initial menu, background sound, and addition of images in the Virtual Laboratory media.
Media Expert	1) Improvements according to the suggestions given.	The product is ready to be used in learning activities.
User (Teacher)	1) Based on the above assessment, this application can be used with revisions.	The product is ready to be used in learning activities with revisions in the background of practicum activities.

Student Responses to Media

The student response questionnaire after learning showed Very Good category. Students assessed that this media is practical, interesting, and relevant to their learning needs. These results are consistent with previous research findings which stated that the Virtual Laboratory can overcome the limitations of laboratory facilities.

Effectiveness of Media in Increasing Learning Motivation

Learning motivation was measured using the ARCS questionnaire before and after using the media. The results showed an increase in all aspects: Attention increased by 0.87; Relevance increased by 0.65; Confidence increased by 0.79; Satisfaction increased by 0.70. The average increase in motivation was 0.77 (Table 8).

The Shapiro-Wilk normality test showed that the data were normally distributed. The Paired Sample t-Test resulted in $p = 0.000$ ($p < 0.05$), indicating that the media had a significant effect on learning motivation.

Table 8. ARCS Scores Before and After Using Virtual Laboratory Media

Aspect	Percentage (%)	Category
Readability of Media	84.57%	Very Good
Clarity of Presentation	87.15%	Very Good
Media Attractiveness	83.88%	Very Good
Overall Average	85.20%	Very Good

Synthesis of Results

The Virtual Laboratory media on the cloning topic was proven to have high validity, very good readability and practicality, and was effective in increasing students' learning motivation in all ARCS aspects. The main advantage lies in its ability to visualize practicum activities that are difficult to conduct in real laboratories, while at the same time providing an interactive learning experience that encourages student engagement.

DISCUSSION

The results of this study indicate that the development of the Virtual Laboratory learning media on the topic of cloning possesses high validity, excellent readability and practicality, and is effective in increasing the learning motivation of high school students. The analysis, executed through the ARCS instructional motivation model (Attention, Relevance, Confidence, Satisfaction), consistently demonstrates that the Virtual Laboratory significantly enhanced student learning motivation. The highest gain was recorded in the Attention component, primarily attributed to the interactive visual displays and realistic practicum simulations which successfully captured student interest, affirming the media's effectiveness in tackling abstract concepts. Furthermore, Confidence saw a substantial increase, driven by the self-evaluation quiz feature that allowed students to immediately test and reinforce their understanding. Satisfaction also showed a strong gain, resulting from the students' sense of achievement upon successfully completing the virtual practicum independently. The Relevance component increased by a moderate but meaningful, due to the material being effectively aligned with the curriculum and clearly linked to real-world biotechnology phenomena.

The increase in learning motivation was significant in all ARCS aspects, namely Attention, Relevance, Confidence, and Satisfaction. These findings are consistent with the ARCS theory put forward by Nurul et al., which states that learning media designed to be engaging, relevant, confidence-building, and satisfying will enhance students' learning motivation (Lail et al., 2022). The increase in the Attention aspect, for example, can be explained by the presence of interactive visualizations and practicum simulations that stimulate students' curiosity, in line with the findings of Riani and Triyanti, who stated that interactive multimedia can concretize abstract biotechnology concepts (Riani et al., 2015; Triyanti, 2022). The Relevance aspect also increased because this media connects cloning material with students' real-life experiences, supporting the findings of Afifah and Farida that meaningful learning is achieved when students see the connection between the material and everyday life (Afifah et al., 2025; Farida, 2016). Likewise, the increase in Confidence and Satisfaction aligns with the research of Abuzar et al. and Ratna et al., who emphasized the importance of self-confidence in supporting academic achievement and learning satisfaction (Abuzar & Purwandari, 2024; Ratna Sari & Suryanawa, 2022). Thus, the use of the Virtual Laboratory not only facilitates access to practicums that are difficult to conduct in real laboratories but also strengthens students' motivational aspects in biotechnology learning.

Compared to previous studies, the results of this research show a different and more specific contribution. The application of the Virtual Laboratory has been effective in topics such as the excretory system and eubacteria (Adi et al., 2022), while Marlinda and Maulana reported its effectiveness in chemistry learning (Marlinda & Maulana, 2016). However, this study focuses on the topic of cloning, which has rarely been used as a subject for Virtual Laboratory trials due to its complex and abstract nature. Thus, the

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novelty of this research lies in the development and validation of Virtual Laboratory media specifically for the cloning topic, which has not been widely studied before, while also integrating the measurement of students' learning motivation through the ARCS model. This strengthens the research gap identified in the introduction, that the topic of cloning requires innovative media to bridge theory and practice. In addition, this research provides practical contributions to the field of education, especially in secondary schools that often experience limitations in laboratory facilities and biotechnology practicum costs. Therefore, this study not only confirms the effectiveness of the Virtual Laboratory as reported in previous studies but also expands its application to more complex areas of biotechnology.

The implications of these findings are quite broad for science learning practices in secondary schools. First, the Virtual Laboratory can serve as an alternative solution to overcome the limitations of biology laboratory facilities in schools, in line with the view of Wahyudi et al. (2023) that virtual laboratories enable students to conduct practicums without being limited by space and time. Second, the use of this media can encourage active student engagement, improve higher-order thinking skills, and facilitate independent learning. Third, the success of this media in increasing learning motivation also supports the development of information and communication technology (ICT)-based curricula, which is currently a global demand (Muhaimin et al., 2025; Zen et al., 2022). Thus, this study shows that Virtual Laboratory-based learning media are not merely technological innovations, but also pedagogical tools that can strengthen students' motivation, engagement, and learning outcomes. However, this study has limitations, namely that it was conducted in only one school with a limited sample size, so the generalization of the results should be made with caution. Therefore, further research is recommended to test the effectiveness of this media on a larger scale and to integrate cognitive aspects as well as practical skills, in order to obtain a more comprehensive picture of its impact on biotechnology learning in high schools.

CONCLUSION

This study concludes that the development of cloning-based Virtual Laboratory learning media has proven to have high validity, excellent readability and practicality, and significant effectiveness in increasing the learning motivation of high school students. Validation by experts showed a "very good" category in all aspects (84.72–97.29%), supported by readability and practicality results that also received a "very good" category. Student responses confirmed that this media is practical, engaging, and relevant to learning needs. ARCS analysis showed a significant increase in motivation in the aspects of Attention, Relevance, Confidence, and Satisfaction, with an average increase of 0.77. Thus, the cloning-based Virtual Laboratory not only bridges the gap between theory and practice in biotechnology but also strengthens student engagement and learning motivation. These findings provide practical implications for secondary schools with limited laboratory facilities, while also offering theoretical contributions to the development of innovative learning media in the field of biology. The results imply that virtual laboratory media can serve as an effective alternative to conventional laboratories, particularly in schools with limited infrastructure and resources. It provides an innovative instructional tool that enhances motivation, supports active learning, and fosters deeper understanding of biotechnology concepts. Teachers can adapt this model for other complex topics in science education, making learning more accessible and equitable.

This study was narrowly limited in scope to cloning-based biotechnology content only; while this allowed for a deep analysis of the virtual laboratory's effectiveness for this topic, the findings may not be broadly generalizable to other complex scientific disciplines. Second, the sample size was specific and limited, involving a single class of 35 eleventh-grade students from one public high school. This non-random selection and limited setting mean the results are heavily context-dependent, restricting the generalizability to diverse school environments or the wider student population. Finally, the research primarily examined motivation using the ARCS model and did not comprehensively assess broader, critical learning outcomes. Although motivation is vital, the study did not measure key academic metrics such as long-term knowledge retention, the development of critical thinking skills, or the mastery of practical laboratory skills, leaving a gap in the understanding of the virtual laboratory's full pedagogical impact.

Future studies should expand the scope of virtual laboratory development to cover other biotechnology topics and interdisciplinary STEM areas. Comparative studies between virtual labs and real laboratory practices could provide insights into effectiveness across different learning outcomes. Moreover, research should investigate scalability, integration with digital curricula, and the use of emerging technologies such as artificial intelligence, virtual reality, and gamification to further enhance engagement and motivation in STEM education.

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