Edubiotik : Jurnal Pendidikan, Biologi dan Terapan
ISSN 2528-679X (print), ISSN 2597-9833 (online)
Vol. 10, No. 01, May 2025, pp. 304 – 319

Available online at:
https://ejurnal.uibu.ac.id/index.php/edubiotik

Research Article

OPEN ACCESS

E-comic geneius: Contextual genetics learning media to enhance cognitive learning outcomes

Zahra Firdaus [1,a], Siti Zubaidah [1,b,*], M Iqbal Najib Fahmi [1,c], Deny Setiawan [1,d], Chun-Yen Chang [2,e]

[1] Biology Department, Universitas Negeri Malang, Malang, Indonesia
[2] Graduate Institute of Science Education, National Taiwan Normal University, Taipei, Taiwan
Email: firdausszahra@gmail.com [1,a], siti.zubaidah.fmipa@um.ac.id [1,b,*], muhammadiqbalnajibfahmi@gmail.com [1,c], setiawan.fmipa@um.ac.id [1,d], changcy@ntnu.edu.tw [2,e]
* Corresponding author

Article Information

Article History:
Submitted: 2025-02-21
Revision: 2025-06-25
Accepted: 2025-07-14
Published: 2025-07-22

Keywords:
E-comic;
genetic;
learning outcome

ABSTRACT

Understanding genetics remains a challenge for high school students due to the abstract nature of the content and its limited connection to everyday experiences. Traditional teaching methods often rely on memorization without promoting meaningful conceptual understanding. This study aims to develop contextual genetics learning media in the form of an electronic comic (e-comic) titled "Geneius", and to test its validity, practicality, and effectiveness in improving students' cognitive learning outcomes. The e-comic integrates fictional storylines with genetics concepts based on everyday situations to enhance conceptual understanding. This research employed the Lee and Owens multimedia-based instructional design model, consisting of analysis, design, development, implementation, and evaluation stages. The quasi-experimental design used was a pretest-posttest control group design involving 60 high school students. The effectiveness of the media was tested using 10 cognitive questions (6 HOTS and 4 LOTS), and data were analyzed with a One-way ANCOVA. The results showed that the material and media validation scores were 100% and 95% (very valid), respectively, and the practicality of the media was 92.5% (very practical). Although the ANCOVA significance value was 0.018, an increase was observed in students' HOTS performance. These findings indicate that the "Geneius" e-comic is a feasible and engaging alternative to support genetics learning and improve cognitive outcomes. The study recommends the implementation of interactive, contextual digital media in genetics education.

Publisher
Biology Education Department
Universitas Insan Budi Utomo,
Malang, Indonesia

How to Cite
Firdaus, Z., Zubaidah, S., Fahmi, M. I. N., Setiawan, D., & Chang, C.-Y. (2025). E-comic geneius: Contextual genetics learning media to enhance cognitive learning outcomes. *Edubiotik : Jurnal Pendidikan, Biologi Dan Terapan*, *10*(01), 304-319. https://doi.org/10.33503/ebio.v10i01.1251

INTRODUCTION

The increasing relevance of genetic science in everyday life makes genetic literacy an essential aspect for students to learn (Dorfman et al., 2019; Lindemann, 2022; Bouali et al., 2022). Over the past

few decades, research breakthroughs in genetics have influenced public policy, health, and public knowledge (Hadiprayitno et al., 2019). Understanding the structure of genetic material and genetic bioprocesses is necessary to achieve a thorough understanding for students (Furniss et al., 2021). A good understanding of genetics is essential for all students (Rissanen & Costello, 2023). However, it is still found that many students have difficulty in understanding genetics material, because the nature of the material is abstract, complex, and involves bioprocesses (White, 2016; Choden & Kijkuakul, 2022).

The difficulty of understanding genetic material results in many students needing a higher cognitive understanding (Revell, 2019). Students' low cognitive scores result from needing a more in-depth understanding of a topic. The concepts of genetic material structure, inheritance of traits, and gene expression that are often encountered in everyday life are still materials that are difficult for students to understand (Riyanto et al., 2020; Brasier et al., 2019). Even though genetic material is the basis of various concepts in biology, so difficulties in understanding this material can cause students to experience obstacles in learning other biological topics.

Studies show that the difficulties experienced by students are caused by the learning methods used, where most students tend to memorize genetics material without understanding the mechanism of action in the body and its impact. Learning in the modern era should lead to life-based learning to bring students closer to real-world problems. Life-based learning allows students to understand genetics concepts, making learning more accessible and more useful in students' daily lives. One example is genetic changes that can affect phenotypes in living things, disease risk, and body activity (Raspa et al., 2021). Therefore, learning media is needed that makes it easier for students to understand the concept of genetics in everyday life better.

The delivery of genetics concepts has a variety of ways, one of which is by using technology-based learning media (Lai and Chen, 2023). Many technologies have been developed to optimize learning in the classroom (Leonora et al., 2021; Susanto et al., 2022). Genetics learning can use technology-based learning media, such as virtual, video podcasts, and animations, to help students better understand genetics concepts (Najib et al., 2024; Rejeki et al., 2024). The selection of learning media must be tailored to the essence of the material so that students can understand genetics concepts more efficiently and more useful in everyday life (Ahn et al., 2021). The results of the needs analysis show that many high school students have difficulty in understanding genetics concepts due to their abstract, complex, and mechanistic nature. Observations at SMAN 2 Malang showed that genetics learning is still dominated by the use of textbooks, PowerPoint slides, and YouTube videos that lack integration of daily life phenomena and often lack interactive components. Students expressed difficulty in connecting genetic mechanisms with real-world examples, while teachers recognized the challenge of providing concrete illustrations of genetic bioprocesses. This indicates the need for an innovative learning medium that can bridge conceptual understanding with contextual experiences.

Electronic comic interactive media is one of the potential technologies to be applied in genetics learning, where it can combine visual storytelling and biological content. E-comics provide an engaging and narrative-based format, which is particularly suited to digital-native learners. Prior studies have shown that e-comics can enhance understanding in science learning (Taufiq et al., 2020). However, most of the existing works have not focused on developing contextual phenomena relevant to students' lives. The illustrations used tend to be conventional, with visual designs that are less attractive and limited to simple cartoon characters. In fact, modern comic illustrations have developed rapidly with a variety of visual styles, including anime and visual novel-style approaches that are more interactive and immersive. Based on the background described above, it is necessary to conduct research and development of interactive

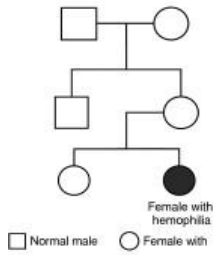
contextual digital comics with a modern style that embeds genetics concepts into everyday life narratives. This research specifically aims to produce e-comic learning media that is valid, practical, and effective in improving students' cognitive learning outcomes in genetics learning in high school.

RESEARCH METHODS

This study uses a research and development (R&D) methodology with Lee and Owens' multimedia-based instructional design model, which consists of five stages: analysis, design, development, implementation, and evaluation (Lee & Owens, 2004). This model was chosen because it specializes in electronic media development and it's a comprehensive needs analysis. First, in the analysis stage, researchers conducted a needs analysis and front-end analysis to identify learning difficulties in genetics and the limitations of existing instructional media. Interviews were conducted with students, finding that the learning of genetics has been done so far using textbooks, and it is not easy to integrate the theory into the reading with everyday phenomena. Interviews with teachers showed that teachers needed help providing concrete examples of integrating genetic material into everyday life. Teachers can only give examples, but need help explaining the bioprocesses that occur. Second, the design stage involved creating storyboards, comic scripts, and visual interface plans that were aligned with the independent curriculum and adapted to the cognitive characteristics of senior high school students. Third, in the development stage, the comic was digitally illustrated using Adobe Illustrator, adopting an anime-style visual novel format with realistic backgrounds and manga-inspired characters. The finished comic image is uploaded to the webtoon page to facilitate use.

The implementation stage uses a quasi-experimental pretest-posttest control group design to determine the effectiveness of the learning media that has been developed in improving student understanding of genetic material. This study was conducted at SMAN 2 Malang, East Java, Indonesia, involving 60 students of class XII MIPA consisting of two classes, namely MIPA 3 (n=30) and MIPA 5 (n=30). The class used in the implementation stage was first tested for equality from the grade XI report card. The test results showed a significance value of 0.1. This value is greater than 0.05, indicating that there is no difference in the initial abilities of the two classes. Based on this, then random sampling was carried out by drawing lots. The results obtained in MIPA 3 class as an experimental class, namely in learning using E-comic biogenesis media, MIPA 5 class as a control class, namely in learning without using E-comic biogenesis media. To measure learning effectiveness, students completed a 10-item essay test covering genetics concepts, consisting of 6 HOTS questions (analyzing and evaluating) and 4 LOTS questions (remembering and understanding) (Table 1). The selection of only four cognitive levels (C1, C2, C4, and C5) in the preparation of the genetics essay test was based on the principles of measurement effectiveness, the suitability of the essay format to the depth of thinking, and the orientation of genetics learning based on critical reasoning and scientific ethics. Levels C3 and C6 were not used because they are more suitable for alternative assessment formats such as practicum, case study, or research-based project. The reliability of the instrument obtained was 0.64 which was classified as good, while the differentiating power value of 1.78 was in the acceptable category. Based on the results of the trial, the instrument proved to be valid and reliable in measuring students' understanding of genetic material. Cognitive pre-test and post-test learning outcomes values will first be tested for normality using the Kolmogorov-Smirnov test and homogeneity using the Levene test, then analyzed using analysis of covariance (one-way ANCOVA) at the 5% significance level.

Table 1. Genetics Essay Questions by Cognitive Level

Question Level	Questions
Lower Order Thinking Skills (C1)	Explain the definition of genes, alleles and chromosomes and give one example of each!
	Name and explain the three basic laws of trait inheritance proposed by Gregor Mendel!
Lower Order Thinking Skills (C2)	Describe the differences between DNA and RNA in terms of structure and biological function!
	Why do recessive traits not always show up in the phenotype of offspring? Explain with relevant examples!
Higher Order Thinking Skills (C4)	Take a look at the following picture!  Based on the picture, there is a family tree that shows a daughter with hemophilia, while both parents appear normal. Analyze the possible genetic inheritance patterns and explain the biological reasons!
Higher Order Thinking Skills (C4)	Compare the effects of genetic mutations in somatic cells and germ cells on individuals and their offspring. Include specific examples of each!
Higher Order Thinking Skills (C4)	A child has blood type AB, while his father has blood type A and his mother has blood type O. Analyze whether the possibility of his parents' genotypes supports this information. Explain with reasons!
Higher Order Thinking Skills (C5)	Evaluate the benefits and risks of using CRISPR-Cas9 technology in gene editing in human embryos from the perspective of genetics and bioethics!
Higher Order Thinking Skills (C5)	Do you think gene therapy is a long-term solution for genetic diseases such as sickle cell anemia? Give scientific arguments for and against!
Higher Order Thinking Skills (C5)	Two plant varieties were crossed: one red-flowered (RR) and one white-flowered (rr). When crossed, all F1s have pink flowers. Evaluate the type of inheritance of the trait and give a genetic interpretation!

In the fourth stage, namely multimedia evaluation, an assessment is carried out as the final part of the media development process. The purpose of this stage is to assess the quality of the product in the learning process, both before and after the media is implemented. The general procedures carried out include measuring user responses or reactions (reactions), assessing knowledge mastery (knowledge), and assessing media performance (performance). Response measurement includes a practicality test filled out by students after using the developed media. Assessment of knowledge mastery regarding the comparison of learning outcomes between control and experimental classes. The results were tested using the one-way ANCOVA test. Meanwhile, media performance assessment includes validation of materials, media experts, and practitioners. Validation and practitioner measurements use formula (1). The validation and practitioner measurement values are then compared with the criteria developed by Aka et al. (2018), as presented in Table 2. The data obtained in this study are both quantitative and qualitative data. ANCOVA data, practicality test, and validation are quantitative data, while qualitative data comes from suggestions and comments.

$$\text{Validity/Practicality\%} = \frac{Total\ Score}{Maximum\ Score} \text{ x } 100\ \% \quad (1)$$

Table 2. Validity and Practicality Criteria of the Product

Validity Criteria	Validity Level
X = 100	Highly valid or practical and can be used without revision
80 ≥ X < 100	Valid or practical and can be used after minor revision
60 ≥ X < 80	Less valid or practical, and cannot be recommended for future usage with moderate revision
40 ≥ X < 60	Non-valid or non-practical, required great revision great, and cannot be used 20 ≥ X < 40
	Highly non-valid or non-practical, should not be used and requires total revision

Source: Aka et al., (2018)

FINDING AND DISCUSSION

The results of the initial analysis stage in this study were obtained through interviews and a needs questionnaire. The students' needs analysis revealed that the difficulty in learning genetics is primarily due to the lack of integration between learning materials and real-life phenomena. The interview with the teacher indicated challenges in explaining the genetic processes in a way that connects to everyday life as students find it difficult to visualize how these processes occur within the body. Furthermore, student interviews showed that textbook readings were perceived as unengaging, overly text-heavy, and difficult to relate to real-life situations. The questionnaire results indicated that 92% of respondents found genetics to be a difficult topic in Grade 12, 87% reported difficulty in understanding the bioprocesses involved in genetics, and 95% stated that they did not understand how to integrate genetic concepts into daily life events. Although animated videos on YouTube were considered the most helpful in explaining genetic bioprocesses, they still lacked the ability to effectively connect these processes to real-world phenomena. The outcome of the design stage was a material draft that serves as the foundation for the storyline in the genetics e-comic.

The next stage is the design phase, which is divided into material design and media design. The material design is aligned with genetics content based on the independent curriculum and adapted to the cognitive characteristics of high school students. Meanwhile, the media design includes the development of a storyboard, comic script, and a visual interface plan. The storyline is structured to support scientific accuracy while maintaining student engagement through relatable characters and dialogues. Visual elements are planned with attention to clarity, color contrast, and illustration style to enhance conceptual understanding and visual appeal.

The result of the development stage is an electronic comic titled "Geneius". In the development stage, the media was created using the Procreate application, resulting in four chapters of the comic. "Geneius" e-comic is divided into four chapters, each of which explores everyday phenomena related to genetics. There are three main characters, namely Liza, Fairuz, and Alex. Chapter 1 tells the story of Alex, a student with curly hair, even though both of his parents have straight hair. This chapter introduces the definition of genes, gene structure, and genes that influence hair phenotype. It also explains how genetic processes determine hair type, providing students with a relatable example of genetic inheritance. Several excerpts from the e-comic are presented in Figure 1. Chapter 2 follows Liza, who participates in a school-organized blood test. Surprisingly, it is revealed that Liza has blood type O, while her mother has type A and her father has type B. This raises the question of whether it is possible for parents with

blood types A and B to have a child with type O. This chapter explores the inheritance patterns of blood types. Several excerpts from the e-comic are presented in Figure 2.

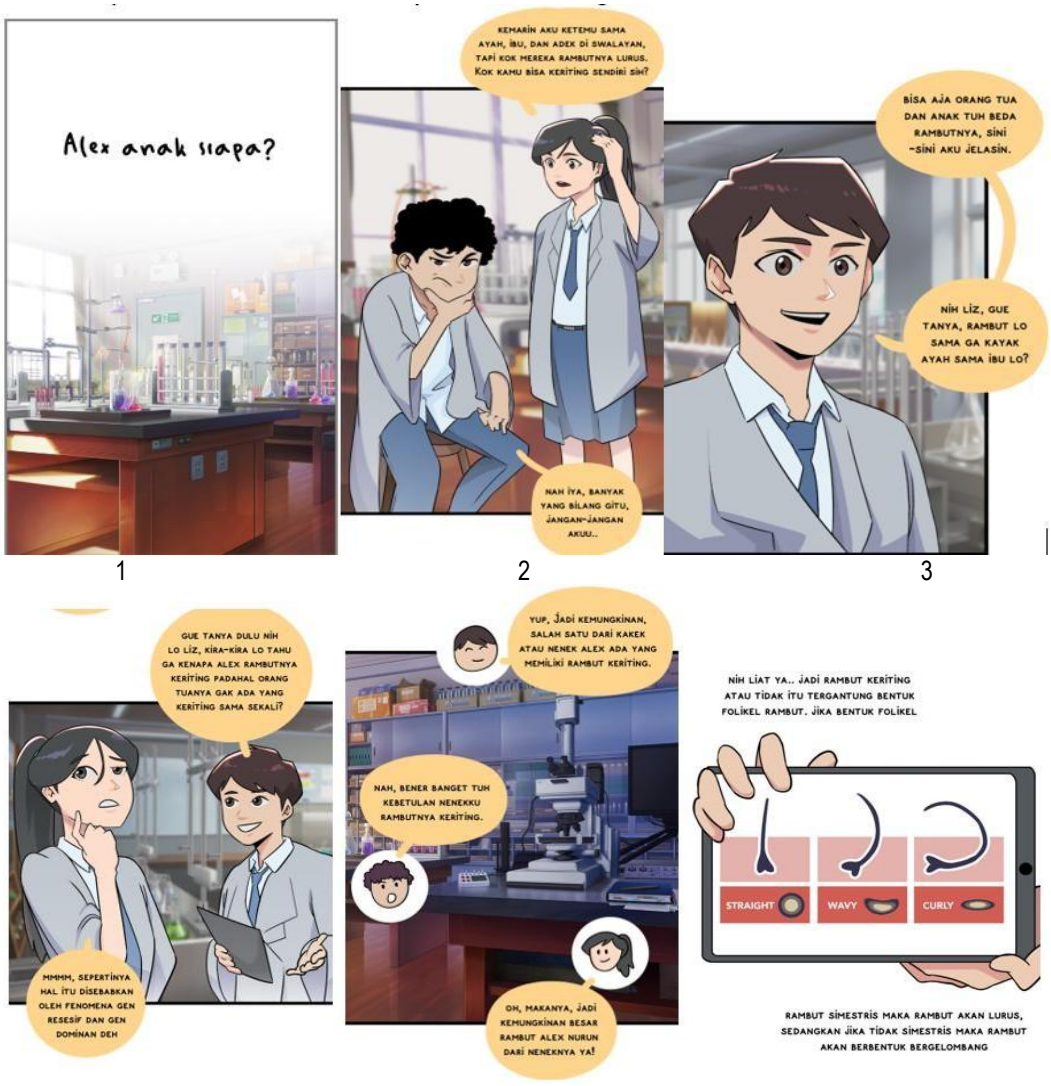


Figure 1. Part of Chapter 1

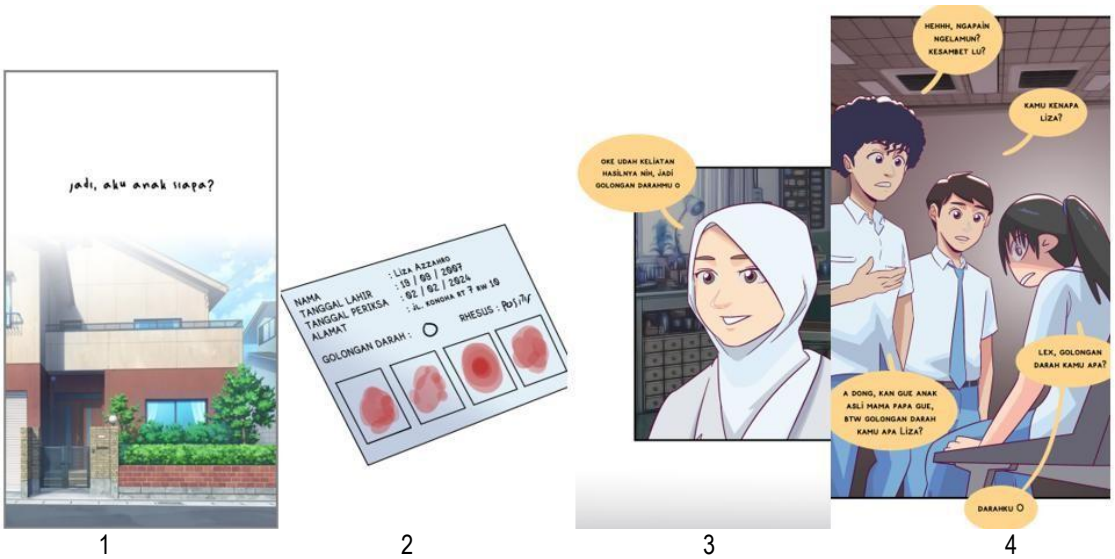


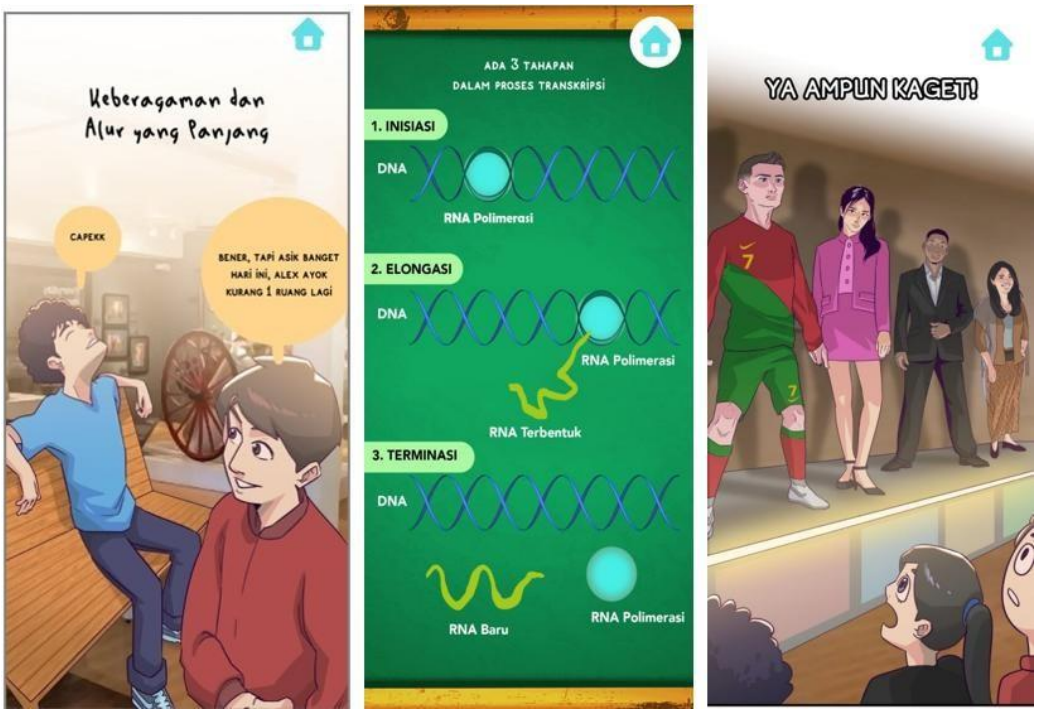
Figure 2. Part of Chapter 2

Chapter 3 features an adventure involving Liza, Alex, and their friend Fairuz as they explore a futuristic genetics museum to uncover the reasons behind blood type inheritance. During their visit, they meet an AI robot that explains complex topics such as the Rhesus factor, blood type inheritance mechanisms, and how seemingly unlikely blood types can be passed on from parents to children. These explanations help resolve Liza's initial confusion. Several excerpts from the e-comic are presented in Figure 3.

Figure 3. Part of Chapter 3

Chapter 4 continues their exploration of the museum. The storyline introduces the concept of human diversity based on gene expression. The AI robot further explains how genetic variations occur due to changes in genetic material. It walks the students through the location and function of genetic material—from the cell nucleus to genes—while also discussing how genetic material is inherited. The chapter details key biological processes such as DNA replication, transcription, and translation in protein synthesis. These complex processes are visualized clearly in Figure 4. Through these four chapters, students are guided to understand genetic concepts by connecting them to familiar real-life contexts. The comic is published on the Webtoon platform, providing easy and wide accessibility for users across different locations.

Expert validation was also conducted at this stage. According to experts, the indicators of a product's validity consist of content or material components, such as the alignment of the material with the core or basic competencies of the curriculum, accuracy, relevance, conceptual correctness, and the appropriateness of the difficulty level with students' cognitive development. Other indicators include media presentation, quality, visual appearance, and effectiveness. The validation process was carried out through face validity by media experts and content validity by subject matter experts (Bouali et al., 2022). The validation results are presented in Table 3.



1 2 3

Figure 4. Part of Chapter 4

Table 3. Validation by Media Experts and Material Experts

Experts	Validation Average (%)	Category
Visual Appearance	100	Very valid
Format Appropriateness	100	Very valid
Navigation and Interactivity	100	Very valid
Technical Functionality	100	Very valid
Platform Compatible	100	Very valid
Effectiveness of Subject Delivery	100	Very valid
Curriculum Alignment	100	Very valid
Conceptual Accuracy	100	Very valid
Content Completeness	93	Very valid
Appropriateness of Difficulty Level	92	Very valid
Real-Life Relevance	93	Very valid
Content Organization and Coherence	92	Very valid
Total Average	97.5	Very valid

The average of the two experts is 97.5%, which can be categorized as valid, with some revisions according to the validation expert's suggestions. It was then tested on five teachers and 30 students. The average results of teacher and student responses to the genetics e-comic can be seen in Table 4.

Table 4. Teacher and Student Responses

Participants	Validation Average (%)	Category
Teacher	90	Valid
Student	95	Very valid
Total Average	92.5	Very valid

The validation value range of 81%-100% can be categorized as valid (Wiratna, 2015) so from the values obtained, it can be concluded that the genetics e-comic received a good response from teachers and students. This good student response shows students are happy when learning using mobile learning media. Learning using technology can make students happy because of its attractive design display

(Susanto, et al., 2022). Suggestions obtained from teachers are to provide learning objectives and indicators of achievement by the independent curriculum, while the suggestions obtained from students are to improve the image resolution, which still needs to be HD. Based on suggestions from teachers and students, improvements were made to using more precise resolutions.

The findings from the implementation stage, conducted using a quasi-experimental pretest-posttest control group design, were used to assess the effectiveness of the media. Teacher preparation was carried out through a briefing session using the media, while student preparation involved providing instructions on how to use the media before the learning session. The tools/media used were smartphones or laptops to access the learning media. The effectiveness of using e-comic genetics on cognitive learning outcomes is seen from the results of e-comic implementation using a quasi-experimental design. The cognitive learning outcomes of students in the control and experimental class show a significant difference in mean scores. The control class's mean pretest and posttest scores were 66.47 and 74.93, respectively, with a difference of 8.46. The mean values of the pretest and posttest of the experimental class were 65 and 80, respectively, with a difference of 15. A homogeneity test was carried out before conducting a single ANCOVA test.

The homogeneity test results get a sig value. 0.339 > 0.05, so it can be concluded that the data is homogeneous. The effect of learning media on improving cognitive learning outcomes was tested using One-way ANCOVA. The One-way ANCOVA test results get a sig value. 0.018 < 0.05, so using e-comic affects learning outcomes. The results of the one-way ANCOVA test are presented in Table 5. Students' cognitive learning outcomes can be categorized into LOTS (Lower Order Thinking Skills) and HOTS (Higher Order Thinking Skills). A mapping of student responses based on LOTS (Lower Order Thinking Skills) and HOTS (Higher Order Thinking Skills) was also conducted to indicate the students' level of understanding, as shown in Figure 5.

Table 5. One-way ANCOVA Test Result

Souce	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	613.214[a]	2	306.607	4.282	0.019	0.131
Intercept	6827.971	1	6827.971	95.351	0.000	0.626
Pretest	228.147	1	228.147	3.186	0.080	0.053
Class	424.312	1	424.312	5.925	0.018	0.094
Error	4081.720	57	71.609			
Total	364760.000	60	306.607			
Corrected Total	4694.933	59	6827.971			

To evaluate the effectiveness of the learning intervention, students were given a 10-item essay test covering genetics concepts. The test consisted of 6 questions designed to assess higher-order thinking skills (HOTS: analyzing and evaluating) and 4 questions targeting lower-order thinking skills (LOTS: remembering and understanding), based on cognitive levels C1, C2, C4, and C5 (Table 1). The pretest and posttest results were analyzed to determine the development of students' cognitive abilities in both the control and experimental groups. The accompanying diagram illustrates the average accuracy levels of students in answering HOTS and LOTS questions before and after the intervention. During the pretest, the average accuracy for HOTS questions was only 16.78%, while for LOTS questions it was 21.86%. After the intervention, there was a significant increase, with the average accuracy rising to 45.59% for HOTS questions and 37.63% for LOTS questions.

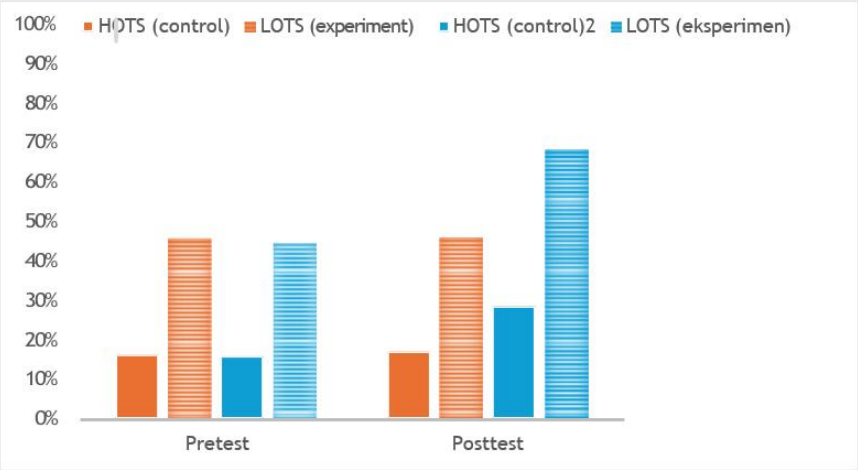


Figure 5. Comparison Diagram of HOTS and LOTS

These results indicate that the intervention had a positive impact on improving students' thinking abilities, particularly in higher-order thinking. The sharp increase from 16.78% to 45.59% in HOTS performance reflects the effectiveness of the learning media in stimulating critical and analytical thinking skills. Although the improvement in LOTS performance—from 21.86% to 37.63%—was not as substantial, it still demonstrates a meaningful enhancement in students' foundational understanding of genetics concepts. The conclusion that can be drawn from this data is that the intervention was more effective in improving higher-order thinking skills (HOTS) compared to lower-order thinking skills (LOTS). This is evident from the more significant increase in the posttest results for HOTS compared to LOTS. However, the improvement in LOTS performance also suggests that the intervention did not solely focus on enhancing higher-order thinking but also positively impacted students' basic thinking skills.

The use of a genetics e-comic proved to be more effective in boosting higher-order thinking skills (HOTS) compared to lower-order thinking skills (LOTS). This is reflected in the more substantial improvement in HOTS posttest results compared to LOTS. Nonetheless, the improvement in LOTS performance also indicates that the intervention was not solely focused on enhancing higher-order thinking but also had a positive impact on students' basic thinking skills (Qasrawi & Abdelrahman, 2020). The significant increase in HOTS can be attributed to the use of digital comic media on genetics, which presented various genetic phenomena. This innovative educational media likely played a crucial role in engaging students and enhancing their understanding of complex genetic concepts, thereby improving their higher-order thinking skills. The visual and narrative elements of the digital comic may have facilitated deeper cognitive processing and retention of genetic information, ultimately contributing to the observed improvement in HOTS performance.

Thus, this approach not only supports the development of critical thinking and problem-solving skills but also provides a more interactive and engaging learning experience for students (Zubaidah et al., 2019; Zubaidah, 2018). The use of digital comics on genetics reflects the integration of technology into the learning process, which can have a positive impact on student learning outcomes. This media effectively presents complex information in a more understandable and engaging manner, thereby increasing students' motivation to learn (Hariri et al., 2021). By leveraging compelling stories and visuals, digital comics can help students build better connections with the learning material, which in turn can enhance their understanding of the concepts being taught.

Digital comic media also supports differentiated learning, where students with varying levels of ability can learn at their own pace and in their preferred learning style. Students who may struggle to

understand genetic concepts through conventional teaching methods might benefit more from the visual and narrative approach (Weng, et al., 2020). Digital comics not only enrich the learning experience but also help create a more inclusive learning environment. However, even though the improvement in HOTS is more significant, it should not be overlooked that LOTS performance also saw a meaningful increase (Roemintoyo & Budiarto, 2023). This demonstrates that digital comic media is not only effective in teaching more complex concepts but also capable of reinforcing students' foundational understanding (Susanto, et al., 2024). The importance of basic thinking skills is a necessary foundation for developing higher-order thinking skills. Therefore, this approach offers dual benefits by enhancing both aspects of students' thinking skills.

In general, the subjects supported and gave an excellent response to the e-comic media. Students feel happy if the teacher uses multimedia-based interactive games as learning media. The findings support the results of research proving that the integration and application of computer games into the classroom can help students learn more fun and effectively (Leksono et al., 2021). Students enjoy learning using technology because they see technology as something exciting and entertaining (Suryapranata et al., 2023). This follows the results of research stating that game design can attract student interest and be an effective learning media (Agos, 2013). Interest in learning media can be seen from the enthusiasm of students in listening to material in the form of text, images, and videos. The use of learning media also affects the increase in student motivation in learning (Mar'atussolichah et al., 2024). This is in accordance with the results of research showing that smartphone-assisted games as learning media can increase student motivation (Geng, et al., 2019). The learning process that integrates interactive multimedia also increases students' interest and enthusiasm in learning (Safitri & Hartati, 2016). This is in accordance with the results of research showing that multimedia can motivate students with student-centred learning. The results of technology-based media development research prove that computer-based educational games can make students happy, so the student are more motivated and enthusiastic about continuing learning (Jabali, et al., 2020).

Students like the appearance of the material contained in the e-comic interactive multimedia because it not only contains text but also images, audio, video, and animation (Safitri et al., 2021). The game media display is more interesting than the usual learning using textual books. Students also find it easier to understand the material because the material is concretized with images and videos in e-comic media (Taufiq, et al., 2020). The study results show that students prefer picture stories to get new information and memorize, making it easier for them to understand the material. The theory is also supported by the results of research proving that the ore varied the learning media used, the more information received and can improve learning outcomes (Valverde-Berrocoso et al., 2020). Images have more value and can explain complex concepts that can facilitate students learning (White, 2016). Elementary school students are also interested in the presentation of material using animation. The use of visuals in comics has a positive influence on increasing student learning goals (Rosba et al., 2021). Learning objectives that are well achieved will increase student learning outcomes (Mahanal et al., 2019). Complex material such as genetics is easily understood using e-comic because it is displayed concretely. The findings follow the research results that linking learning with everyday phenomena can improve cognitive abilities such as remembering in memory. Students have a visualization of bioprocesses in the body, making understanding easier (Muhamedyev et al., 2014). Content in technology-based media helps pleasure students and is an effective learning media used in learning. E-comics are not only made for entertainment but can potentially increase learning success (Görgen et al., 2020).

Students learn enthusiastically because e-comic media stimulates students to be actively involved in learning. Based on observation, students enjoy learning and follow the game flow seriously. Research results state that interactive systems facilitate deep learning by actively involving students (Valverde-Berrocoso, et al., 2020). Games in interactive multimedia also make students active in thinking. Students are interested and want to continue reading until the last chapter. The e- comic makes students excited about learning and not quickly bored.

Interactive multimedia integrated with learning can assist teachers in achieving learning objectives. The achievement of learning objectives due to multimedia has proven effective in education, so teachers need to develop multimedia for learning media (Gobert, 2022). Integrating technology in the classroom is also helpful in preparing students for the future. Based on the research results, teachers, school managers and education stakeholders are advised to integrate technology into the learning process. Based on the findings, teachers need to use game media to improve the quality of learning. Game media makes student learning more exciting and fun (Lumbantoruan & Ditasona, 2024; Lai & Chen, 2023). The interactive multimedia display, which consists of text and images, also helps students understand the material better (Yadav & Chakraborty, 2023). The presence of comics integrated with biological material makes students active in learning the material. Teachers are advised to use multimedia to improve student responses and achieve learning objectives optimally.

An optimal learning process can improve students' understanding of the material (Saputro, et., 2016). The increase in student understanding is directly proportional to the increase in students' cognitive learning outcomes (Yadav & Chakraborty, 2023; Saputri & Corebima, 2020). The significance of the increase in cognitive learning outcomes in this study can be seen in the mean value of the control class pretest and posttest, respectively, 66.47 and 74.93, with a difference of 8.46. Based on the results of one-way ANCOVA, e-comic has a significant effect on cognitive learning outcomes. E-comic media can improve cognitive learning outcomes.

The process of using e-comic in teaching genetics resulted in a significant improvement in learning outcomes, as students who used this media showed superior learning outcomes. However, in collecting research data, researchers experienced obstacles; some students needed to be more interested in the genre raised in the e-comic in this first series. Therefore, it is hoped that there are stories with other genres that can be an option for students. In addition, the material presented is limited to basic genetics concepts so it would be better if there is development on different topics.

The evaluation stage process was carried out at each stage of development: analysis, design, development, and implementation. During the analysis stage, it is recommended that evaluation be conducted offline to obtain more accurate and reliable data. In the design stage, evaluation is best conducted through a focus group discussion with media experts to minimize revisions during the validation process. The development stage involved formative evaluation conducted by experts. Media experts suggested that the media dimensions be optimized for accessibility on both smartphones and laptops. Meanwhile, subject matter experts recommended expanding the comic format to cover additional topics in the curriculum. For the implementation stage, summative evaluation was conducted with students. Some of the student feedback is presented in Table 6.

Based on the results of the interviews, most students stated that they were happy and supported using e-comic media as learning media. Based on observations of using e-comic media, students listened to the material seriously. Students pay attention to the material and focus on their respective smartphones. Students learn independently without asking for help from friends, but some students sometimes ask for

teacher guidance. Students are enthusiastic about reading the material presented through interactive e-comics.

Table 6. Students' Feedback and Reflections

Participants	Feedback
Student 1	"I like using e-comic-based learning media because it provides interesting visuals".
Student 2	"I become interested in reading the material presented using e- comic-based learning media".
Student 3	"I want to learn more often using e-comic-based learning media because there are interesting pictures so that learning becomes easier".
Student 4	"I prefer to learn using interactive learning media because it makes the material not boring".
Student 5	"I am more interested in learning using a smartphone than a textbook just because I do not get bored quickly".
Student 6	"I am very excited to learn because thematic learning is done using a smartphone".

Based on students' opinions, the display of e-comic media motivates them to learn. Students are encouraged to learn because the material displayed is interesting. However, there are student comments regarding the text on the e-comic media, namely that the font is too small, so it needs to be corrected. The technical aspect consists of ease of media operation and navigation (Taufiq et al., 2020). Based on the questionnaire results from the technical aspect, it shows that e-comic media is easy to use and the navigation is easy to understand. Students are accustomed to using applications on cell phones, so they have no difficulty using interactive multimedia. Based on student information, the buttons on this e-comic media are simple and have been accompanied by clear instructions, so students are evident in using interactive multimedia. In addition, interactivity makes students excited about learning because of the feedback from multimedia-based interactive e-comics.

CONCLUSION

Research and development of genetics e-comic titled "Geneius" has successfully developed a valid, practical, and effective research product. The results showed that the material and media validation scores were 100% and 95% (very valid), respectively, and the practicality of the media was 92.5% (very practical). This media has been tested to be practical and effective in improving students' cognitive learning outcomes through various advantages of genetics e-comic (sig. < 0.05). Recommendations for further research are to make a follow-up series with different materials, implementation at higher education levels, and more varied comic genres.

ACKNOWLEDGMENT

The author would like to thank all related parties, supervisors, and the Universitas Negeri Malang. This research is funded by the Internal PNBP project of Universitas Negeri Malang based on the chancellor's decree number 5.4.1/UN32/KP/2023

REFERENCES

Agos, C. T., et al. (2013). Game development of ibong adarna visual novel. *Fatima University Research Journal, 5*(1), 1-1. https://www.ijstr.org/final-print/sep2013/Game-Development-Of-Ibong-Adarna-Visual-Novel.pdf

Ahn, I., Chiu, M. M., & Patrick, H. (2021). Connecting teacher and student motivation: Student-perceived teacher need-supportive practices and student need satisfaction. *Contemporary Educational Psychology*, 64, Article 101950. https://doi.org/10.1016/j.cedpsych.2021.101950

Aka, K. A., Akbar, S. D., & Sahertian, J. (2018). Development of validation instrument for interactive multimedia learning implementation plan. In Prosiding 1st International Conference on Early Childhood and Primary Education, 244, 118-123. Atlantis Press. https://doi.org/10.2991/ecpe-18.2018.25

Bouali, R., Zaki, M., Agorram, B., Benjelloun, N., Anouar, A., & Lhoussaine, M. (2022). Effectiveness of animation-based instruction on university students' achievement in cell biology. *World Journal of Educational Technology, 14*(5), 1422-1433. https://doi.org/10.18844/wjet.v14i5.7213

Brasier, D. J., Melville, M., Hershock, C., & Rule, G. (2019). Pairing practice and feedback with animations optimizes student learning in online module. *Journal of Computer Assisted Learning, 35*(6), 782-793. https://doi.org/10.1111/jcal.12388

Choden, T., & Kijkuakul, S. (2020). Blending problem based learning with scientific argumentation to enhance students' understanding of basic genetics. *International Journal of Instruction, 13*(1), 445-462. https://doi.org/10.29333/iji.2020.13129a

Dorfman, B. S., Terrill, B., Patterson, K., Yarden, A., & Blonder, R. (2019). Teachers personalize videos and animations of biochemical processes: Results from a professional development workshop. *Chemistry Education Research and Practice, 20*(4), 772- 786. https://doi.org/10.1039/C9RP00057G

Furniss, C. S., et al. (2021). Novel models of genetic education and testing for pancreatic cancer interception: Preliminary results from the GENERATE study. *Cancer Prevention Research, 14*(11), 1021-1032. https://doi.org/10.1158/1940-6207.CAPR-20-0642

Geng, S., Law, K. M. Y., & Niu, B. (2019). Investigating self-directed learning and technology readiness in blending learning environment. *International Journal of Educational Technology in Higher Education, 16*(1), 1-22. https://doi.org/10.1186/s41239-019-0147-0

Gobert, G. N. (2022). Electronic teaching resources for university cell biology supports improved student learning outcomes. *Biochemistry and Molecular Biology Education, 50*(1), 91-98. https://doi.org/10.1002/bmb.21595

Görgen, R., Huemer, S., Schulte-Körne, G., & Moll, K. (2020). Evaluation of a digital game-based reading training for German children with reading disorder. Computers & Education. https://doi.org/10.1016/j.compedu.2020.103834

Hadiprayitno, G., Muhlis, & Kusmiyati. (2019). Problems in learning biology for senior high schools in Lombok Island. *Journal of Physics: Conference Series, 1241*(1), 1-8. https://doi.org/10.1088/1742-6596/1241/1/012054

Hariri, H., Karwan, D. H., Haenilah, E. Y., Rini, R., & Suparman, U. (2021). Motivation and learning strategies: Student motivation affects student learning strategies. *European Journal of Educational Research, 10*(1), 39-49. https://doi.org/10.12973/eu-jer.10.1.39

Mar'atussolichah, Ibda, H., Al Hakim, M. F., Faizah, F., Aniqoh, A., & Mahsun, M. (2024). Benkangen game: Digital media in elementary school Indonesian language. Journal of Education and Learning, 18(2), 480-488. https://doi.org/10.11591/edulearn.v18i2.21091

Jabali, S. G., Supriyono, S., & Nugraheni, P. (2020). Pengembangan media game visual novel berbasis etnomatematika untuk meningkatkan pemahaman konsep pada materi aljabar. *Alifmatika: Jurnal Pendidikan dan Pembelajaran Matematika, 2*(2), 185-198. https://doi.org/10.35316/alifmatika.2020.v2i2.185-198

Lai, K. W. K., & Chen, H. J. H. (2023). A comparative study on the effects of a VR and PC visual novel game on vocabulary learning. *Computer Assisted Language Learning, 36*(3), 312-345. https://doi.org/10.1080/09588221.2021.1928226

Lee, W. W., & Owens, D. L. (2004). Multimedia-based instructional design: computer-based training, web-based training, distance broadcast training, performance-based solutions. John Wiley & Sons.

Leksono, S. M., Marianingsih, P., Ilman, E. N., & Maryani, N. (2021). Online learning media on biology conservation: Rawa danau nature reserve website. *International Journal of Interactive Mobile Technologies, 15*(8), 87-100. https://online-journals.org/index.php/i-jim/article/view/21567/9089

Leonora, J. I., Ratnapuri, A., & Adinugraha, F. (2021). E-module characteristics of the sensory system and students' perception of e-modules in grade xi SMA Trisakti Medan. *Indonesian Journal of Biological Education, 4*(2), 19-24. https://jurnal.untidar.ac.id/index.php/ijobe/article/view/5293

Lindemann, A. (2022). The Colony: An evo devo art performance on social life. Leonardo, 55(4), 338-344. https://doi.org/10.1162/leon_a_02222

Lumbantoruan, J. H., & Ditasona, C. (2024). Development of a mathematics module on circle material based on the small group discussion model. *Journal of Education and Learning, 18*(1), 18-25. https://doi.org/10.11591/edulearn.v18i1.20920

Mahanal, S., Zubaidah, S., Sumiati, I. D., Sari, T. M., & Ismirawati, N. (2019). RICOSRE: A learning model to develop critical thinking skills for students with different academic abilities. *International Journal of Instruction, 12*(2), 417-434. https://doi.org/10.29333/iji.2019.12227a

Muhamedyev, R. I., Mansharipova, A. T., & Muhamedyeva, E. L. (2014). Visualization of biological processes described by models of apoptosis. *Life Sciences Journal, 11*(10), 320-327. https://www.researchgate.net/publication/285952142

Najib Fahmi, M. I., Zubaidah, S., Mahanal, S., & Setiawan, D. (2024). Virtual reality laboratory laws of inheritance enhancing students' technological literacy. International Journal of Interactive Mobile Technologies, 18(6), 159–172. https://doi.org/10.3991/ijim.v18i06.47945

Qasrawi, R., & Beni Abdelrahman, A. (2020). The higher and lower-order thinking skills (HOTS and LOTS) in unlock english textbooks (1st and 2nd editions) based on bloom's taxonomy: An analysis study. *International Online Journal of Education and Teaching, 7*(3), 744-758. https://iojet.org/index.php/IOJET/article/view/866

Raspa, M., Moultrie, R., Toth, D., & Haque, S. N. (2021). Barriers and facilitators to genetic service delivery models: Scoping review. *Interactive Journal of Medical Research, 10*(1), Article e23523. https://doi.org/10.2196/23523

Rejeki, N. I. T., Jamilah, J., Arif, W. P., Syamsul, S., Maulana, A., & Maulidya, F. (2024). Learning media: Video podcast for biodiversity exploration. *Edubiotik: Jurnal Pendidikan, Biologi dan Terapan, 9*(01), 19-31. https://ejurnal.uibu.ac.id/index.php/edubiotik/article/view/229

Revell, L. J. (2019). learnPopGen: An R package for population genetic simulation and numerical analysis. *Ecology and Evolution, 9*(14), 7896-7902. https://doi.org/10.1002/ece3.5412

Rissanen, A., & Costello, J. M. (2023). The effectiveness of interactive online tutorials in first-year large biology course. *Journal of Applied Research in Higher Education, 15*(3), 632-649. https://doi.org/10.1108/JARHE-09-2020-0312

Riyanto, R., Amin, M., Suwono, H., & Lestari, U. (2022). The new face of digital books in genetic learning: A preliminary development study for students' critical thinking. *International Journal of Emerging Technologies in Learning, 15*(10), 480-488. https://doi.org/10.3991/ijet.v15i10.14321

Roemintoyo, R., & Budiarto, M. K. (2023). Flipbook as innovation of digital learning media: Preparing education for facing and facilitating 21st Century learning. *Journal of Educational Technology, 5*(1), 8–13. https://ejournal.undiksha.ac.id/index.php/JET/article/view/32362

Rosba, E., Zubaidah, S., Mahanal, S., & Sulisetijono, S. (2021). Digital mind map assisted group investigation learning for college students' creativity. International Journal of Interactive Mobile Technologies, 15(5), 4-23. https://doi.org/10.3991/ijim.v15i05.18703

Safitri, D., Ika, L., Arifin, M., & Nurzengky, I. (2021). Web-based animation video for student environmental education at elementary schools. *International Journal of Interactive Mobile Technologies, 15*(11), 66-80. https://doi.org/10.3991/ijim.v15i11.22023

Safitri, D., & Hartati, T. A. W. (2016). Kelayakan aspek media dan bahasa dalam pengembangan buku ajar dan multimedia interaktif biologi sel. *Florea, 3*(2), 9-14. https://doi.org/10.25273/florea.v3i2.794

Saputri, W., & Corebima, A. D. (2020). The correlation between metacognitive skills and cognitive learning results of biology pre-service teachers on different learnings. *Journal of Turkish Science Education, 17*(4), 487-503. https://doi.org/10.25273/florea.v3i2.794

Saputro, E. B., Sopyan, A., & Subali, B. (2016). Kontribusi media pembelajaran interaktif untuk membantu meningkatkan pemahaman konsep pembiasan cahaya pada siswa kelas x SMA. *Phenomenon: Jurnal Pendidikan MIPA, 3*(2), 103-110. https://doi.org/10.21580/phen.2013.3.2.140

Suryapranata, L. K. P., Bahagia, F. I., & Lazarusli, I. A. (2023). Gamification using visual novel to improve chemistry learning motivation. *Journal of Games, Game Art, Gamification, 8*(1), 13-17. https://doi.org/10.21512/jggag.v8i1.9411

Susanto, H., Setiawan, D., Mahanal, S., Firdaus, Z., & Kusmayadi, C. T. (2024). Development and evaluation of e-comic nervous system app to enhance self-directed student learning. *JPBI (Jurnal Pendidikan Biologi Indonesia), 10*(1), 143-153. http://dx.doi.org/10.22219/jpbi.v10i1.31451

Susanto, L. H., Rostikawati, R. T., Novira, R., Sa'diyah, R., Istikomah, I., & Ichsan, I. Z. (2022). Development of biology learning media based on android to improve students understanding. *Jurnal Penelitian Pendidikan IPA, 8*(2), 541-547. https://jppipa.unram.ac.id/index.php/jppipa/article/view/1334

Taufiq, M., Wijayanti, A., & Fajriah, E. (2020). The implementation of e-comic earth layer to enhance students' self-directed learning. *Journal of Physics: Conference Series, 1567*(2). https://doi.org/10.1088/1742-6596/1567/2/022070

Valverde-Berrocoso, J., Garrido-Arroyo, M. del C., Burgos-Videla, C., & Morales-Cevallos, M. B. (2020). Trends in educational research about e-learning: A systematic literature review (2009–2018). *Sustainability, 12*(12), Article 5153. https://doi.org/10.3390/su12125153

Weng, C., Otanga, S., Christianto, S. M., & Chu, R. J. C. (2020). Enhancing students' biology learning by using augmented reality as a learning supplement. *Journal of Educational Computing Research, 58*(4), 747-770. https://doi.org/10.1177/0735633119884213

White, P. J. T. (2016). Molecular sculpting: Active learning of subcellular systems & processes. *The American Biology Teacher, 78*(6), 482-491. https://doi.org/10.1525/abt.2016.78.6.482

Wiratna, S. V. (2015). SPSS Untuk Penelitian Yogyakarta. Pustaka Baru Press.

Yadav, S., & Chakraborty, P. (2023). Reinforcing biology education in schools using smartphones: A post-COVID pandemic study. Education and Information Technologies. https://doi.org/10.1007/s10639-023-11987-z

Zubaidah, S. (2018). Mengenal 4C: Learning and innovation skills untuk menghadapi era revolusi industri 4.0. In *2nd Science Education National Conference*, 1-18. https://www.researchgate.net/publication/332469989

Zubaidah, S., Mahanal, S., Sumiati, I. D., Sari, T. M., & Ismirawati, N. (2019). RICOSRE: A learning model to develop critical thinking skills for students with different academic abilities. *International Journal of Instruction, 12*(2), 417-434. https://doi.org/10.29333/iji.2019.12227a