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Development of "Appera" Based on Arduino Uno for Grade XI MA Students on The Subtopic of The Human Circulatory System Process

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Abstract

The human circulatory system is one of the biology topics requiring educational teaching aids. Teaching aids serve as learning materials that help facilitate the understanding of concepts such as the circulatory system. Focusing on the human circulatory process subtopic for Grade XI high school students, this study aims to describe the feasibility and usefulness of a teaching aid based on the Arduino Uno microcontroller named "Appera." This research and development study employed the 4D model (Define, Design, Develop, Disseminate). The feasibility subjects included three content experts—two Biology Education lecturers from FKIP ULM, one MA Negeri 3 Banjarmasin partner teacher, and one media expert. Practicality testing involved twenty Grade XI science students from MA Negeri 3 Banjarmasin. The validation results showed that the "Appera" teaching aid received a conformity score of 113.56 ("very good" category), a feasibility score of 66.00 ("highly feasible"), and a practicality score of 87.07 from students ("very good" category). Based on these quantitative results, it can be concluded that "Appera" is a highly feasible and practical tool for teaching biology, especially the human circulatory system.

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INTRODUCTION

One of the key indicators of a country's development is the quality of its education. High-quality education leads to human resources capable of thriving in an increasingly advanced environment. Learning and education processes are closely connected. Teachers and educators implement teaching practices (Lekwa et al., 2019; Lestari & Nuryani, 2022; Maskur, 2017; Suprayogi et al., 2017). Furthermore, education contributes to behavioral and mental development—without it, people lack the knowledge to overcome life's challenges.

As education leaders, teachers must create supportive, dynamic, and innovative learning environments across all subject areas to enhance teaching quality. One effective teaching strategy is selecting appropriate educational media, which is critical to student success. Teachers must be able to select or even create relevant instructional materials (Mupa & Chinooneka, 2015; Salim et al., 2019; Yustina et al., 2020).

Biology studies life, including microorganisms, plants, animals, humans, and their interactions. It offers a variety of experiences to understand scientific concepts and methods. As a branch of natural science, biology develops through identifying and solving natural phenomena using analytical, inductive, and deductive reasoning skills (Firmansyah, 2009; Tereshchuk et al., 2023). Students should actively discover key ideas from the curriculum through experiments, observations, diagrams, and presentations (Agustina, 2016).

Learning media are tools that enhance teacher-student communication and streamline the teaching-learning process. Teachers can enrich lessons with educational media to support student comprehension. They must balance teaching methods with appropriate media. Hidayatullah (2017) states that learning media deliver messages and knowledge, whether purposefully created or adapted to help students grasp certain concepts. Tafonao (2018) adds that learning media engages students and makes learning more exciting and inspiring.

Although various instructional tools have been developed, microcontroller-based teaching aids like Arduino Uno are rarely used in teaching the human circulatory system. Most existing studies focus on visual aids like PowerPoint animations, comics, or anatomical torsos (Rosadi & Karimah, 2022; Yuliansah, 2018). However, these tools are typically passive and lack interactive, dynamic engagement. Microcontroller technology, like Arduino Uno, offers real-time simulations of blood circulation using visual indicators such as red and blue LEDs.

Microcontrollers can make the learning experience more interactive and contextual by simulating physiological processes like blood flow and heart function (Guntoro & Somantri, 2013; Husdi, 2018). This technological gap calls for innovative research that creates attractive, applicable learning media for classroom use. This study focuses on developing an " Appera " teaching aid based on Arduino Uno to dynamically and educationally visualize the human circulatory process.

According to Khusairi (2023), teaching aids make abstract concepts tangible and easier to understand. Their use improves student learning outcomes by offering concrete experiences. However, teaching aids have limitations: difficulty in large classrooms, the need for facilities, constraints on student autonomy, and varied memory retention (Atun & Latupeirisa, 2021; Alshatri et al., 2019; Rohani, 2006).

Suliani (2020) emphasized that teaching aids increase student engagement and enthusiasm. They encourage positive student attitudes, which lead to better learning outcomes—observable changes in knowledge, attitudes, and skills (Koroy et al., 2024). Learning outcomes are not limited to grades but include improvements in thinking, discipline, and other developmental aspects (Hamalik, 2014).

Cognitive learning objectives involve mental processes that evolve from basic to complex levels. Bloom's taxonomy categorizes this domain into six levels, ranging from knowledge and comprehension to application, analysis, synthesis, and evaluation (Mariati, 2018). Cognition involves intellectual or reasoning activities associated with the brain.

Observations at MAN 3 Banjarmasin show that biology teachers lack effective tools like heart torsos and circulatory system models. Existing aids are limited to static anatomical torsos. This indicates a strong need for functional teaching aids in biology education. According to Khasanah et al. (2008), teaching aids are essential to the overall instructional process. The available teaching aids are only torsos of human body organs, with the frequency of use adjusted to the material being taught (Putra et al., 2023).

A needs assessment among Grade XI science students at MAN 3 Banjarmasin showed that over 60% were interested in using teaching aids, especially in biology. Students also

utilized textbooks, worksheets, and YouTube videos. More than 50% strongly supported developing the "Appera" aid for the circulatory system. Compared to students who did not use teaching aids, research shows that their use significantly improves learning outcomes (Aisyah, 2018).

Given these findings, the study aims to develop and evaluate the feasibility and practicality of a microcontroller-based teaching aid called "Appera" as a biology learning tool for understanding the human circulatory system among Grade XI students.

"Appera" is used in biology lessons, especially on blood circulation. It allows students to experience the learning process directly, enhancing their understanding of abstract concepts. It features a model of the human body using red and blue LEDs to represent blood vessels and areas like the atrium and ventricle. The Arduino Uno controls the LEDs, which use the ATMega328P microcontroller. This setup includes a 16 MHz crystal oscillator, power connectors, USB ports, a reset button, ICSP headers, PWM outputs, analog inputs, and digital I/O pins. Power is supplied via a battery or AC-DC adapter (Bur et al., 2019).

Given this context, "Appera" is a novel innovation that provides real-time, interactive visualization of physiological processes. Students observe a simulation of blood flow in a model human body, enhancing engagement and conceptual understanding of the circulatory system, outperforming traditional static media. This study aims to describe the feasibility and usefulness of a teaching aid based on the Arduino Uno microcontroller named "Appera."

METHODS

The 4D Development Model by Thiagarajan et al. (1974) was employed in this study alongside the Research and Development (R&D) approach. This project aimed to develop a teaching aid called "Appera", which utilizes Arduino Uno to help Grade XI students understand the human circulatory system. The research was conducted from January to July 2023 at MAN 3 Banjarmasin, with participants including twenty Grade XI science students, one media expert, one biology teacher, and two biology education lecturers from FKIP ULM.

The research followed the 4-D model, which consists of four main stages: Define, Design, Develop, and Disseminate (Fitra & Haksum, 2021; Maskur et al., 2017). Implementing this model in the study involved defining the stage of analyzing the needs of teachers and students. The design stage involves designing the teaching aid and the evaluation instruments. The develop stage involves expert validation and practicality testing. The disseminate stage is carried out on a limited basis within the school setting.

The instrument used in this study was a questionnaire based on a 5-point Likert scale, where participants rated each item from 1 (strongly disagree) to 5 (strongly agree). This scale assessed three main aspects of the "Appera" teaching aid: suitability, feasibility, and practicality.

Before data collection, the questionnaire underwent validity and reliability testing: Content validity was assessed by three content experts and one media expert using an instrument validation sheet. A questionnaire item was considered valid if it was rated as "relevant" or "very relevant" by the experts. Reliability was measured using Cronbach's Alpha. A coefficient value above 0.70 indicates that the instrument is reliable (Azwar, 2014). The results showed high reliability, making the instrument suitable for this study.

The raw scores were converted into qualitative (interval) data using the Likert scale to evaluate the practicality of the Arduino Uno-based circulatory system teaching aid. Each

item on the scale had a maximum score of 5 and a minimum of 1. The average feasibility scores were compared to the standard criteria shown in Table 1.

Table 1 Suitability criteria for teaching aid

Category	Mean Score Range	Formula
Very good	$x > 104.88$	$x > \mu + 1.8\ \sigma$
Good	$84.96 \leq x \leq 104.88$	$\mu + 0.6\ \sigma < x \leq \mu + 1.8\ \sigma$
Fair	$65.04 \leq x \leq 84.96$	$\mu - 0.6\ \sigma < x \leq \mu + 0.6\ \sigma$
Poor	$45.12 \leq x \leq 65.04$	$\mu - 1.8\ \sigma \leq x \leq \mu - 0.6\ \sigma$
Very poor	< 45.12	$x < \mu - 1.8\ \sigma$

Information:
X = average score from the study / empirical score

The data were analyzed using theoretical mean and standard deviation formulas to classify scores and describe the feasibility of the Arduino Uno-based circulatory system teaching aid (Azwar, 2014).

The following percentages indicate the teaching aid's practical results, which can be interpreted using the feasibility criteria listed in Table 2.

Table 2 Feasibility criteria for teaching aid

Category	Mean Range Score	Formula
Highly feasible	$x > 58$	$x > \mu + 1.8\ \sigma$
Feasible	$46 \leq x \leq 58$	$\mu + 0.6\ \sigma < x \leq \mu + 1.8\ \sigma$
Fairly feasible	$34 \leq x \leq 46$	$\mu - 0.6\ \sigma < x \leq \mu + 0.6\ \sigma$
Less feasible	$22 \leq x \leq 34$	$\mu - 1.8\ \sigma \leq x \leq \mu - 0.6\ \sigma$
Not feasible	$x < 22$	$x < \mu - 1.8\ \sigma$

Information:
X = average score from the study / empirical score

The data were analyzed using the theoretical average and standard deviation to classify scores, explaining the practicality of the Arduino Uno-based teaching aid for the human circulatory system (Azwar, 2014).

Table 3 Student practicality test criteria for teaching aid

Category	Mean Range Score	Formula
Highly feasible	$x > 75,6$	$x > \mu + 1.8\ \sigma$
Feasible	$61,2 \leq x \leq 75,6$	$\mu + 0.6\ \sigma < x \leq \mu + 1.8\ \sigma$
Fairly feasible	$46,8 \leq x \leq 61,2$	$\mu - 0.6\ \sigma < x \leq \mu + 0.6\ \sigma$
Less feasible	$32,4 \leq x \leq 46,8$	$\mu - 1.8\ \sigma \leq x \leq \mu - 0.6\ \sigma$
Not feasible	$x < 32,4$	$x < \mu - 1.8\ \sigma$

Information:
X = average score from the study / empirical score

RESULTS AND DISCUSSION

Based on the suitability evaluation results, the developed teaching aid received a "very appropriate" response, as indicated by a score of 113.56, placing it in the "very good" category. The suitability instrument consisted of 7 assessment aspects with 25 sub-aspects, covering the learning objectives, content, relevance to teaching materials, language, presentation format, media, and the author's ability to develop a teaching aid for the circulatory system based on *Arduino Uno*. According to Thiagarajan et al. (1974), the purpose of a suitability test is to evaluate how well the learning material aligns with the learning objectives that students are expected to achieve. The summary of the evaluation results for the *"Appera"* teaching aid based on *Arduino Uno* can be seen in Table 4.

Table 4 The evaluation results for the *"Appera"* teaching aid based on *Arduino Uno*

No.	Aspect	Score			Average score
		A1	A2	A3	
	A. Learning Objectives				
1.	Relevance of the stated learning objectives	5	4	4	4.33
2.	Learning objectives are meaningful for teachers	5	4	4	4.33
3.	Learning objectives are meaningful for students	5	5	4	4.66
4.	Clearly derived sources and learning objectives	5	5	4	4.66
5.	Objectives align with the teaching aid	5	5	5	5.00
	Total Score				22.98
	B. Content				
6.	Content relevance to learning objectives	5	4	4	4.33
7.	Theoretical content presented completely	5	5	4	4.66
8.	Definitions and explanations are complete	4	4	5	4.33
9.	Use of technical terms and symbols ide complete	5	5	5	5.00
	Total Score				18.32
	C. Relevance to Learning Material				
10.	Necessary for teaching the sub-concept of the human circulatory process	5	5	5	5.00
11.	Clarity of objects and phenomena in the aid aligns with the sub-concept material	5	5	4	4.66
	Total Score				9.66
	D. Language				
12.	Sentence structure in the teaching aid	4	5	4	4.33
13.	Sentence effectiveness in the teaching aid	3	5	5	4.33
14.	Use of standard language in the teaching air	5	4	5	4.66
15.	Language suits students' cognitive development	4	4	5	4.33
16.	Conformance with PUEBI (Indonesian Grammar Rules)	4	5	5	4.66
	Total Score				22.31
	E. Format				
17.	Presentation of material in the teaching aid	4	4	5	4.33
18.	Format of the teaching aid components	4	4	5	4.33
19.	Teaching aid includes usage instructions	4	5	5	4.66
	Total Score				13.32
	F. Media				
20.	Layout elements of the teaching aid	5	4	4	4.33
21.	Colors and images of the teaching aid	4	5	5	4.66
22.	LED display of the teaching aid	4	5	5	4.66
23.	Color accuracy in visual presentation	4	4	4	4.00
24.	Typography elements	4	5	5	4.66
	Total Score				22.31
	G. Author's Ability				
25.	Author's ability to develop the teaching aid	4	5	5	4.66
	Total Score	**111**	**115**	**115**	**113.56**
	Conclusion	**Very Appropriate**			

The feasibility of the instructional media was assessed by a media expert who also served as a mentor during the internship and certified independent study program at PT Stechoq Robotika Indonesia. The evaluation encompassed 15 assessment criteria, using a Likert scale ranging from 1 to 5, covering aspects related to media components, visual design, and operational functionality. A summary of the expert's evaluation results is presented in Table 5.

Table 5 The expert's evaluation results

No.	Assessed Aspect	Average Score
1.	The teaching aid is organized comprehensively	5.00
2.	Availability of supplementary material relevant to the concept	4.00

3.	The teaching aid can be reused	5.00
4.	Required elements are available (Usage instructions, learning outcomes, and objectives)	4.00
5.	The scope of the learning material is provided	4.00
6.	Time allocation for using the teaching aid is provided	4.00
7.	The teaching aid can be used independently	5.00
8.	A schedule of sessions is included in the teaching aid	4.00
9.	Cost of producing the teaching aid	5.00
10.	User guide for teachers is available	4.00
11.	Procedures for using the teaching aid	3.00
12.	Ease of use of the teaching aid	5.00
13.	Specific knowledge required to operate the teaching aid	4.00
14.	Likelihood of acceptance by students	5.00
15.	Likelihood of acceptance by teachers	5.00
	Total score	66.00
	Conclusion	Very good

The practicality test questionnaire for the Arduino Uno-based human circulatory system teaching aid consisted of 18 assessment items rated from 1 to 5. The results were obtained from the evaluations of 12 students from class XI Science 1 at MA Negeri 3 Banjarmasin. Table 6 summarizes the practicality test results.

Table 6 summarizes the practicality test results

No.	Assessed Aspect	Average score
1.	No learning time is wasted when using the Arduino Uno-based circulatory system training tool.	4.66
2.	This teaching aid is intended for learners from secondary to adult levels.	4.94
3.	This teaching aid is very enjoyable.	5.00
4.	This teaching aid can be used independently.	4.77
5.	The Arduino Uno-based teaching aid is beneficial in the learning process.	4.88
6.	This teaching aid is suitable for me.	4.77
7.	Learning with this teaching aid provides a more realistic visualization compared to other media.	5.00
8.	I learned many useful things when using this teaching aid.	4.88
9.	I hope other concepts can be developed into Arduino Uno-based teaching aids.	4.77
10.	Learning using this teaching aid is engaging.	4.88
11.	If I were a teacher, I would want to use this teaching aid in learning.	4.94
12.	The Arduino Uno-based teaching aid is better than textbooks.	4.66
13.	I don't mind using this teaching aid as a learning medium.	4.94
14.	I can use this learning medium continuously.	4.50
15.	I can use the Arduino Uno-based teaching aid while still retaining the meaning of the material.	4.77
16.	Learning how to use the teaching aid can enhance a person's learning capacity.	5.00
17.	Learning with the teaching aid helps students retain information more easily.	4.94
18.	The teaching aid provides a learning experience.	4.77
	Total score	**87.07**
	Conclusion	**Very good**

The findings of this study indicate that the Arduino Uno-based "Appera" teaching aid yielded excellent results in relevance, feasibility, and practicality. These results were assessed by several experts and implemented directly during the learning process. The tangible outcomes of this study have increased student engagement. The findings show that the "Appera" teaching aid is highly feasible for use in biology education, with a relevance score of 113.56, a feasibility score of 66.00, and a practicality score of 87.07.

These results align with the study by Aisyah et al. (2018), which stated that using a circulatory system teaching aid significantly improves student learning outcomes. However, the previous study only utilized static media without integrating microcontroller technology. The strength of the current study lies in its use of the Arduino Uno microcontroller, which allows students to observe an interactive simulation of the circulatory process through red and blue LEDs. This provides added value compared to conventional media, as it enhances understanding through dynamic visualization.

In addition to relevance and practicality, evaluating the cognitive impact of the Appera teaching aid on student learning outcomes is also essential. This study did not include an in-depth analysis of the differences in student performance before and after using the aid, making it difficult to draw definitive conclusions about its effect on cognitive achievement. According to Mayer (2009), effective instructional media should enhance conceptual understanding and promote higher-order thinking skills, particularly in the cognitive domain, as classified in Bloom's taxonomy. In this context, teaching aids should encourage critical, analytical, and evaluative thinking about the studied material.

Tennyson and Park (2005) also found that interactive visual aids, such as microcontroller-based media or digital simulations, positively affect cognitive learning outcomes, especially for complex or abstract topics such as the human biological system. Therefore, it is recommended that future development include a quasi-experimental or pre-experimental design to quantitatively measure differences in student learning outcomes, providing more substantial empirical evidence of Appera's effectiveness in enhancing students' cognitive competencies.

Using the Arduino Uno microcontroller in instructional media also supports the findings of Silvia et al. (2014), who concluded that Arduino-based media are effective due to their ease of programming, flexibility, and adaptability to different learning needs. This makes Appera an educational innovation that is not only curriculum-relevant but also responsive to technological advancements. However, expert validation results indicate that Appera still requires improvement to reach optimal product quality. This aligns with Adinugraha's (2017) view that good instructional media should undergo continuous revision based on feedback from users and experts.

Although the findings show that the Arduino Uno-based Appera teaching aid is highly feasible and practical, several challenges must be addressed during its development and implementation. One of the main challenges is the need for technical knowledge of the Arduino system, both for teachers and students. This poses a barrier, especially for teachers unfamiliar with microcontroller technology, highlighting the need for initial training to ensure optimal classroom use.

Additionally, the Appera teaching aid is still semi-manual in operation. For instance, replacing components such as LEDs or connectors requires technical skills and specific tools. This supports Rohani's (2006) argument that one of teaching aids' limitations is their limited scalability for large-scale instruction and reliance on adequate facilities.

Another limitation lies in the visual design. Although it includes LED elements and an anatomical model, the aid could still be improved in aesthetics, material durability, and structural flexibility to make it more appealing and long-lasting for repeated use. These

improvements are crucial to ensure sustained use without diminishing instructional quality. Considering these limitations, further development is necessary to make Appera an innovative teaching medium and an effective and efficient tool across diverse school environments.

CONCLUSION

This study aimed to develop and evaluate the feasibility and practicality of the Arduino Uno-based teaching aid "Appera" as an instructional medium for teaching the human circulatory system to Grade XI students at Islamic Senior High Schools (MA). Utilizing the 4D development model, the findings indicate that Appera represents an innovative and interactive alternative to traditional learning media, particularly in facilitating the visualization of abstract biological concepts.

The integration of Appera in the learning process demonstrates the potential to enhance students' learning experiences through hands-on engagement and concrete visualization, which may contribute to improving conceptual understanding. This study's practical implications suggest that incorporating microcontroller technology into instructional media can effectively increase student engagement and enrich interaction during classroom activities.

For future research and development, it is recommended that a quantitative evaluation of Appera's impact on student learning outcomes, particularly in the cognitive domain, be conducted. Furthermore, improvements in visual design, material durability, and teacher training should be prioritized to ensure broader implementation and sustainable use of the teaching aid across diverse educational settings.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTION

The author was fully involved in all stages of the research, including idea conception, instrument design, teaching aid development, data analysis, and the preparation of the research report and this scientific article. The author also coordinated with subject matter experts and media specialists during the validation process and facilitated the practicality testing with students. Additionally, the author ensured that all data and findings were presented objectively and were academically accountable.

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Muhammad Hasyim Muzadysaha is a Biology Education Study Program student at the Faculty of Teacher Training and Education, Lambung Mangkurat University, Banjarmasin, Indonesia. As a prospective biology educator, Hasyim is deeply interested in developing technology-based learning aids to support a more effective teaching and learning process. He actively researches and develops teaching aids, especially those related to the human circulatory system. In addition, Hasyim is also interested in biology education and educational technology and is committed to creating a more interesting and interactive learning environment for students.

Kaspul is a lecturer at Lambung Mangkurat University, focusing on biology education. Demonstrating consistent contributions in scientific publications. His research focuses on innovations in biology learning, especially developing technology-based teaching media and strengthening critical thinking skills. One of his most cited publications discusses using Google Sites as a learning medium for protist concepts. He is also involved in cross-disciplinary collaboration. Kaspul helped develop e-modules and worksheets for high school students, which were scientifically validated and effective in improving learning outcomes. His work reflects concern for the quality of biology learning.

Nurul Hidayati Utami is a lecturer at Lambung Mangkurat University who is active in biology education, science learning, and developing context-based teaching models. The main focus of her research lies in the innovation of teaching media and the application of the STEM (Science, Technology, Engineering, and Mathematics) approach integrated with local wisdom. One of her contributions is the development of e-booklets as a biology learning medium for high school/vocational high school students, especially on biodiversity material. In addition, she also plays a role in assisting science teachers in designing STEM-based learning in the city of Banjarmasin, demonstrating her involvement in empowering education at the local level. Through collaboration with academics and education practitioners, Nurul actively combines research with community service activities. Her consistency in publishing scientific works and her contribution to the development of learning.