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Analysis of Physics Learning on Circular Motion Material Based on Microcontroller: A Systematic Literature Review Using PRISMA

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A B S T R A C T

A microcontroller is an electronic device that can digitalize experimental tools, making them more practical and easier to use. The method used in this research is a Systematic Literature Review using PRISMA. The purpose of this study is to identify learning models, learning media, and the utilization of microcontrollers in teaching circular motion physics in schools. The collected data consists of national journal articles from accredited and indexed electronic databases, which are then extracted for content analysis. The data is subsequently analyzed and interpreted in tabular form. The findings of this study explain the learning models, learning media, and the application of microcontrollers in physics education.

1. Introduction

Physics is a subject taught to high school students to train them in critical thinking and problem-solving in everyday life. This discipline explores various natural phenomena and objects within them through an empirical, logical, systematic, and rational approach, involving scientific processes and attitudes (Suarti et al., 2024).

Physics learning is often less appealing to students because the methods and media used by teachers tend to be monotonous, necessitating a more engaging approach. Unfortunately, many educational institutions, especially in remote areas or those with limited resources, struggle to provide effective learning media to enhance students' understanding of key physics concepts(Suwandi et al., 2024).

Due to the limited availability of teaching tools, many teachers still rely on conventional methods such as lectures and discussions (Firdaus & Syahrial, 2024).

The level of understanding of physics concepts has a significant impact on students' ability to solve everyday problems. The better their understanding, the easier it is for them to tackle various challenges. However, the comprehension of physics concepts in schools, including at UPT SMA Negeri 4 Pangkep, remains relatively low. Based on an interview with a physics teacher, this low understanding is attributed to students' lack of interest in reading learning materials, limited hands-on practical experience, and the restricted use of teaching aids in lessons (Suarti et al., 2024).

Education in technology, physics, and science is increasingly adopting innovative approaches by leveraging advanced technology such as microcontrollers. One of the factors contributing to the low quality of education in Indonesia is students' lack of interest in learning, particularly in subjects that are difficult to understand, such as physics. Simplifying physics material can enhance student interest and accelerate their comprehension. The use of physics learning media serves as an effective solution to address this issue, although its distribution remains limited (Suwandi et al., 2024). The physics learning process requires media that not only convey information but also support diverse learning styles, including visual, auditory, and kinesthetic approaches. This is crucial for increasing learning engagement and efficiency (Rahim et al., 2022),

The experimental method plays a vital role in physics, as it is an experimental science. The development of physics is based on measuring physical quantities and conducting experimental observations (Firdaus & Syahrial, 2024). The experimental method allows students to be more active and directly observe physics phenomena. However, the limited availability of physics teaching aids in schools poses a major challenge in implementing the experimental method to optimally convey physics concepts. This issue can be addressed by equipping students with the ability to create and manage simple experiments, not only utilizing available teaching aids but also modifying them as needed for learning. This approach aligns with technological advancements to provide added value for students (Qomariyah et al., 2020).

The limitations of teaching aids in schools can be addressed through the development of microcontroller-based experimental sets that are easy to use and widely applicable. Integrating sensors with instrument modules and the ability to operate them in simple experiments are crucial preparations for implementing this method. The microcontroller-based experimental approach is expected to enhance the quality of learning in schools (Qomariyah et al., 2020). One of the most commonly measured physical quantities in experiments is time, but manual measurement is often inaccurate due to reliance on subjective observation, such as manually starting and stopping a stopwatch (Firdaus & Syahrial, 2024). Microcontroller-based experimental tools are highly effective in explaining various concepts in physics mechanics, including particle motion, rigid body dynamics, and circular motion. These tools utilize sensors to measure key parameters such as travel time and object distance, providing more accurate data in the learning process (Fauza et al., 2023).

Uniform circular motion is a motion in which the trajectory forms a circle with a constant linear velocity, despite continuous changes in velocity direction. Objects undergoing this motion will continue to move along the circular path. The phenomenon of uniform circular motion is a fundamental topic in mechanics and serves as a basis for understanding various other physics concepts. Examples of uniform circular motion phenomena include a spinning compact disc (CD), rotating wheels of a motorcycle or car, a merry-go-round, the Earth's orbit around the Sun, and electrons orbiting an atomic nucleus. Therefore, to gain a deeper understanding of this concept, observation, measurement, and application of uniform circular motion phenomena are necessary (Budiman et al., 2020).

In the study of circular motion, students need critical thinking skills to solve real-world problems, such as understanding the relationship between a bicycle's wheels. A lack of critical thinking skills in problem-solving often results in low scores on circular motion topics. Therefore, implementing an effective learning model is essential to help students understand and solve circular motion-related cases in everyday life (Batulieu, 2023).

Circular motion is often taught through textbook illustrations without interactive media, making it difficult for students to grasp concepts such as the relationship between wheels in circular motion (Zulhelmi et al., 2023). Diagnostic results indicate that 40.57% of students in Grade X Science at SMA Negeri 1 Simeulue Timur experience misconceptions about the dynamics of circular motion, with the most common misconception being centripetal and centrifugal forces (12.95%). Low student achievement in uniform circular motion is influenced by several factors, one of which is the lack of effective learning media (Firmansyah & Wulandari, 2016).

The media used by teachers often fail to explain circular motion effectively. This challenge arises due to inadequate laboratory equipment, teaching aids that do not cover all physics topics, and limited use of physics laboratories. In many schools, uniform circular motion is taught only through textbooks or two-dimensional images, restricting students' comprehension of the concept. Moreover, many schools still lack teaching aids for uniform circular motion as learning media, such as 60% of schools in Sukabumi and 68% of schools in East Jakarta (Sya'roni et al., 2021).

Based on these explanations, researchers are interested in reviewing the use of Arduino microcontroller-based teaching aids in physics learning, specifically in the mechanics of circular motion. This study begins by discussing various materials developed through Arduino microcontroller-based teaching aids and evaluating the results obtained from their implementation in the learning process. It also investigates the effectiveness of various learning models and media

supported by sensors to make circular motion learning more interactive and practical. The research questions addressed in this article include:
1. What are the physics learning models for Circular Motion in high schools using sensors and microcontrollers?
2. What are the physics learning media for Circular Motion in high schools using sensors and microcontrollers?
3. How are microcontrollers utilized in teaching physics, specifically Circular Motion, in high schools?

2. Methodology

This research is a literature study or systematic literature review (SLR) with a qualitative descriptive approach. The criteria for the analyzed articles include those published in nationally accredited Sinta journals from 2012 to 2024 and internationally indexed Scopus journals, with a focus on evaluating and teaching physics, specifically on circular motion. The keywords used to search for relevant journals are learning models, learning media, and the utilization of microcontrollers in teaching circular motion in physics. The number of analyzed articles consists of national journal articles (Sinta 1 to Sinta 6). The content categories analyzed include microcontroller-based circular motion physics learning, learning models, learning media, and the use of microcontrollers in physics education. The collected data is then analyzed and interpreted in the form of tables or graphs.

Specific criteria for obtaining data that align with the research objectives include: (1) Evaluation research in the field of physics; (2) Studies analyzing learning models, particularly inquiry-based (experimental) learning models using microcontrollers; (3) Research subjects ranging from high school to higher education; (4) Experimental tools used in teaching circular motion kinematics; (5) Studies that include methods, models, and approaches used; (6) Studies that specify the materials used in the research. Studies that do not meet these specific criteria are excluded from the systematic literature review process.

The research instrument used consists of observation sheets or protocols related to inclusion and exclusion criteria based on publication year, level of study, sample size, research location, journal indexing, and materials used. The systematic literature review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. The selection process is conducted in four stages according to PRISMA guidelines: identification, screening, eligibility, and inclusion.

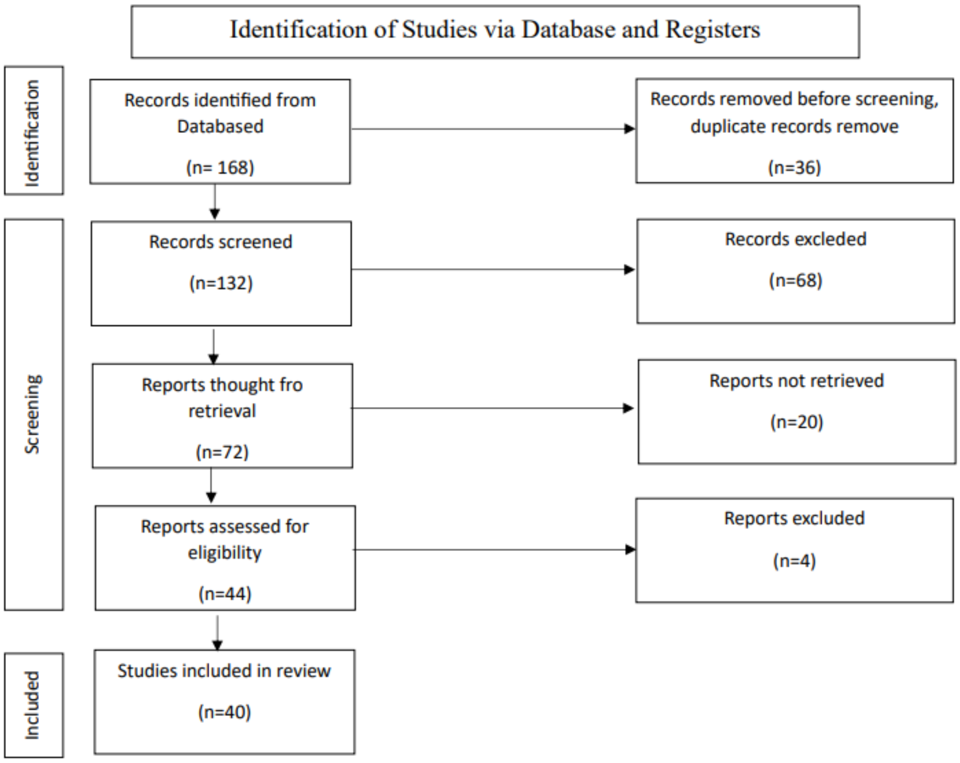

Figure 1. Systematic Literature Review (SLR) using PRISMA

The population in this study includes all research on microcontroller-based mechanics experimental tools in learning, published in indexed journals. Based on searches through search engines, a total of 40 articles were obtained as samples, consisting of research with qualitative, quantitative, and developmental approaches.

Data Extraction

At this stage, data is collected from 40 accepted articles by thoroughly reading each one. The obtained data is then presented in a table that includes: learning models, learning media, and the utilization of microcontrollers in physics education.

Table 1. Variables Used in Data Processing

Variabel	Keterangan
Microcontroller-based circular motion experiment tools	Has the advantage of obtaining data using sensors
Circular Motion Kinematics Material	Physics material related to the motion of objects
Learning Model	A systematically designed conceptual framework in experimental learning
Learning Achievement	A variable measured in academic performance

These four variables represent the research questions designed to achieve the research objectives. The variables are analyzed and aligned with relevant articles. The researcher can then compile a summary based on these variables.

3. Results and Discussion

This study proves the success of developing microcontroller-based experimental tools. The use of microcontrollers continues to evolve, especially in research and education, particularly in the field of mechanical physics, specifically on circular motion. The following table presents data on learning models, media, and the utilization of microcontrollers in physics education.

Table 2. Learning Models, Media, and Utilization of Microcontrollers in Teaching Circular Motion in Physics

No	Author(s)	Learning Model/Method	Learning Media	Microcontroller Usage
1.	(Putri & Asrizal, 2019)	Experiment	Circular Motion Modeling Tool with DC Motor Speed Control Assisted by Tracker Video Analysis	Used
2.	(Wicaksono et al., 2023)	Experiment	Rotating Wheel Motion Experiment Tool Connected to a Remote IoT Laboratory Based on WEB	Used
3.	(Gulo, 2018)	Demonstration	Simple Teaching Aid	Not Used
4.	(Batulieu, 2023)	Double Loop Problem Solving (DLPS)	Student Worksheet	Not Used
5.	(Firmansyah & Wulandari, 2016)	Generative	Animation	Not Used
6.	(Yenni Darvina, 2018)	Discovery Learning	Student Worksheet	Not Used
7.	(Surya, 2020)	Contextual Teaching and Learning (CTL)	Projector	Not Used
8.	(Sya'roni et al., 2021)	Experiment	Arduino-Based Rotating Wheels Teaching Aid	Used
9.	(Haryadi et al., 2024)	Discovery Learning Integrated with Quranic Verses	Student Worksheet	Not Used
10.	(Prastiti, 2016)	Cooperative Learning - NHT Type	Projector	Not Used
11.	(Supriyanto, 2020)	Out bond	Student Worksheet	Not Used

12.	(Chodijah et al., 2012)	Guided Inquiry	Module and Student Worksheet	Not Used
13.	(Hidayat et al., 2018)	Experiment	Microcontroller-Based Circular Motion Practicum Media	Used
14.	(Refiana et al., 2016)	Problem Solving	Student Worksheet	Not Used
15.	(Damayanti et al., 2019)	Experiment	ESP32-Based Circular Motion Learning Media with Android Display	Used
16.	(Yandari et al., 2016)	Cooperative Problem Solving	Student Worksheet	Not Used
17.	(Sitania et al., 2022)	Inquiri Learning	Student Worksheet	Not Used
18.	(Elfiati, 2022)	Demonstration	Simple Teaching Aid	Not Used
19.	(Desy et al., 2015)	Experiment	Circular Motion Physics Teaching Aid	Used
20.	(Sudiatmika, 2023)	Problem Based Learning	Projector	Not Used
21.	(Fathiyaturrahmani, 2021)	Cooperative Learning - STAD Type	Projector	Not Used
22.	(Aflah et al., 2019)	Guided Inquiry	Student Worksheet	Not Used
23.	(Ningsih et al., 2017)	Group Investigation-Guided Inquiry	Simple Practicum and Student Worksheet	Not Used
24.	(Pujiyanti et al., 2021)	Problem Based Learning	Teaching Aid to Enhance Interest and Learning Outcomes	Not Used
25.	(Mahyana & Rosi, 2023)	Multiple Intelligences	Projector	Not Used
26.	(Kurnia & Ramli, 2020)	Problem Based Learning	Textbook with Comprehensive Intelligence Content	Not Used
27.	(Pratama et al., 2020)	Guided Inquiry	Student Worksheet	Not Used
28.	(Pranita et al., 2016)	Reciprocal Teaching	Projector	Not Used
29.	(Suminem, 2016)	Lesson Study	Student Worksheet	Not Used
30.	(Lestari, 2019)	Assisted Bicycle Riding	Bicycle	Not Used
31.	(Astuti et al., 2024)	Remediation	Refutation Text-Based E-Module with KREC Framework	Not Used
32.	(Azizahwati et al., 2020)	Experiment	Circular Motion Experiment Tool Using Arduino Uno Microcontroller	Used
33.	(Mardiana, 2021)	Discovery Learning	Student Worksheet	Not Used
34.	(Norhasanah et al.,	Direct Teaching	Whiteboard and	Not Used

	2013)		Marker	
35.	(Nurmala, 2021)	Learning Start With A Question (LSWQ)	Textbook or Teaching Module	Not Used
36.	(Rizki et al., 2022)	Direct Instruction	Teaching Material and LKPD	Not Used
37.	(Raharja et al., 2020)	Experiment	Smartphone-Based Circular Motion Experiment Tool	Used
38.	(Simarmata, 2019)	Discovery	Student Worksheet	Not Used
39.	(Nurhayati et al., 2023)	Scientific	Interactive Electronic Module	Not Used
40.	(Wati & Misbah, 2021)	Scientific	Physics Teaching Material with Authentic Learning Content	Not Used

Based on the data presented above, research shows that the experimental learning model is the dominant approach in physics education, accounting for 20%, particularly in circular motion topics. Researchers such as Putri and Asrizal, as well as Wicaksono and colleagues, actively use this model as it is considered effective in enhancing students' understanding through hands-on practice. Additionally, cooperative learning models, such as STAD and NHT, and problem-based approaches, such as Problem-Based Learning (PBL), are frequently used because they effectively promote collaboration and problem-solving in real-life contexts. The distribution of learning models or methods used in teaching circular motion is as follows:

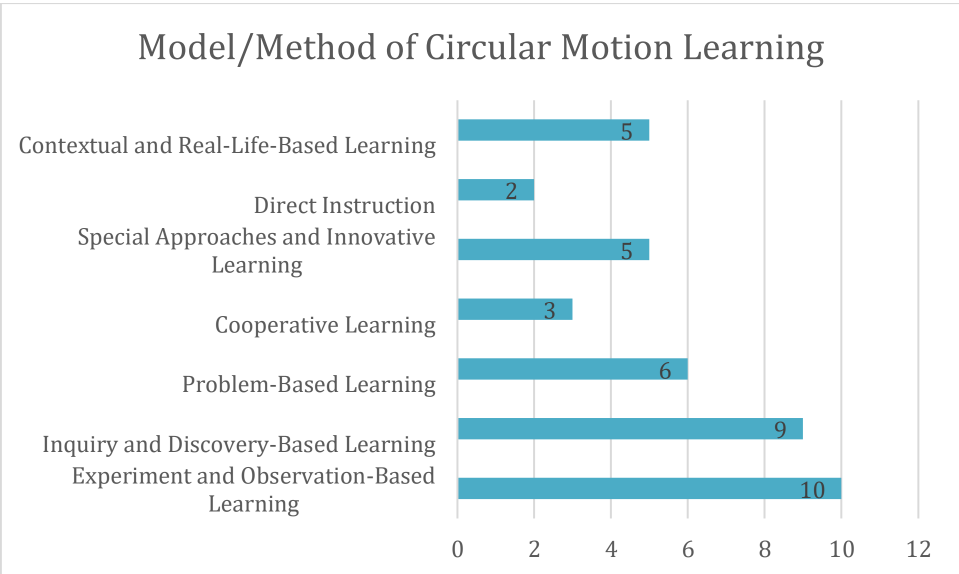

Figure 2. Distribution of Learning Models or Methods for Circular Motion

The graph above explains that the learning models or methods used in teaching circular motion topics are generally categorized into seven groups: experiment- and observation-based learning, inquiry- and discovery-based learning, problem-solving-based learning, cooperative learning, contextual and real-life-based learning, direct instruction, and specialized or innovative learning approaches. The percentage distribution of these learning models or methods for circular motion is as follows.

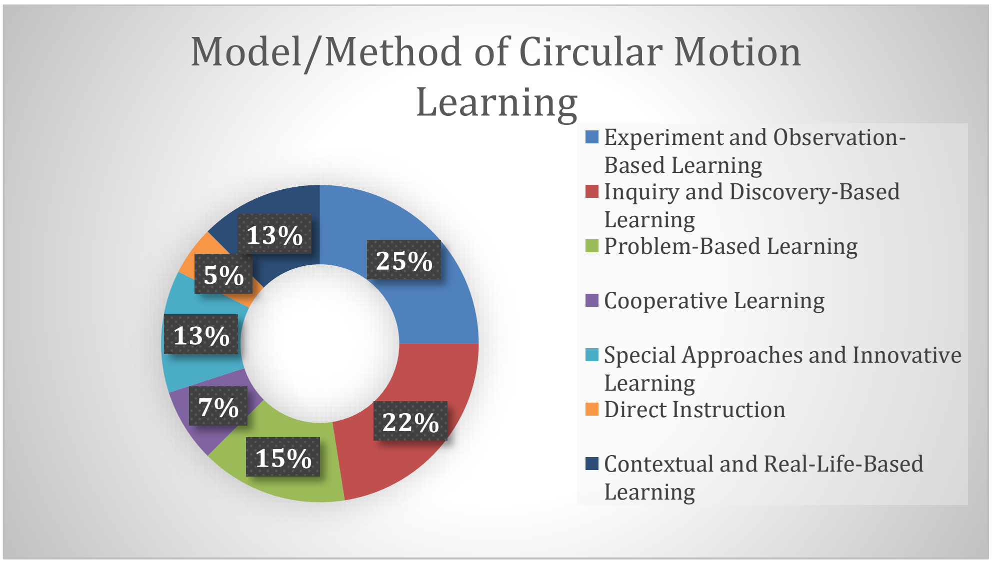

Figure 3. Percentage of Learning Models or Methods for Circular Motion

Based on the graph displayed above, it can be concluded that the most dominant learning method is experiment- and observation-based learning, with a percentage reaching 25%. This is followed by inquiry- and discovery-based learning, which accounts for 22%, indicating that this approach is quite effective in developing students' analytical and discovery skills. Meanwhile, problem-solving-based learning accounts for 15%, highlighting the importance of critical thinking skills in overcoming challenges. Cooperative learning, which emphasizes collaboration among students, only reaches 7%, suggesting that this approach may not yet be fully embraced or optimally implemented. Contextual and real-life-based learning, which connects material to everyday experiences, accounts for 13%, whereas direct instruction only reaches 5%, indicating that this method tends to be less preferred or perceived as less effective by students. Lastly, specialized approaches and learning innovations account for 13%, demonstrating the ongoing need for innovation to enhance learning effectiveness.

Learning media also play an important role in supporting the success of learning models. Researchers have developed various media, ranging from simple teaching aids, as used by researchers like Gulo and Desy along with their colleagues, to advanced technology-based tools, such as microcontroller-based media using Arduino, utilized by Azizahwati and Sya'roni with their teams. These technology-based tools, including Arduino-based rotating wheels and ESP32-based devices with Android displays, help improve the accuracy and appeal of learning circular motion concepts.

However, challenges in implementing learning media are still frequently encountered. Researchers such as Norhasanah and her colleagues, as well as

Nurmala, have noted that many schools still rely on traditional media, such as whiteboards, markers, and textbooks, which are less effective in explaining abstract concepts like circular motion. This limitation indicates that modern technology has not yet been evenly adopted in physics education across schools. The use of microcontrollers in the innovation of physics learning media for circular motion material is presented as follows.

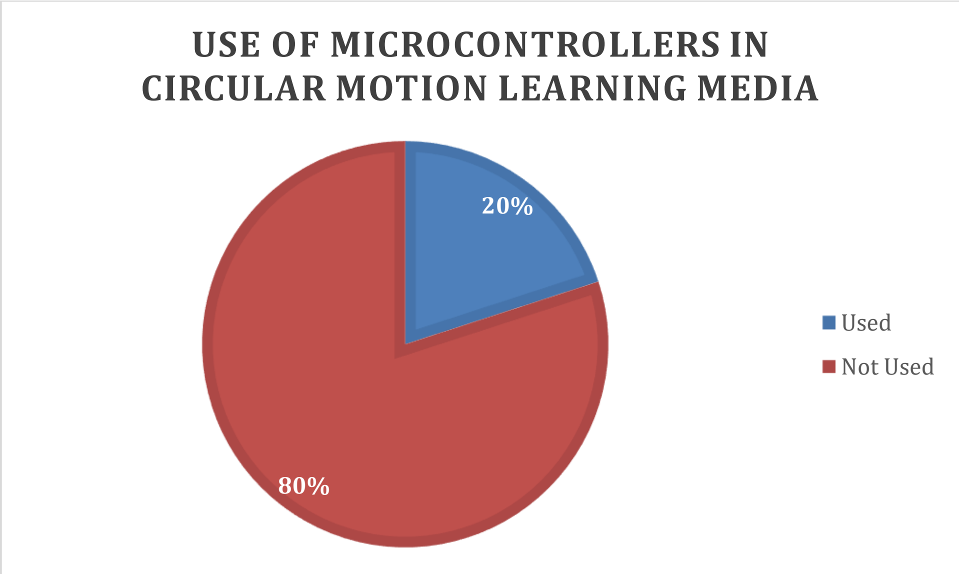

Figure 4. The Use of Microcontrollers in Circular Motion Learning

The diagram above shows that the use of microcontrollers in circular motion learning media reaches 20%, while 80% of other learning media still rely on conventional methods without microcontrollers. This indicates that the innovation of using microcontrollers in circular motion learning media is still limited and not yet widely implemented. In fact, microcontrollers have great potential to enhance interactivity and students' understanding of circular motion concepts, particularly in visualizing phenomena more accurately and engagingly. However, the low adoption of microcontrollers may be due to limited access to technology, a lack of teacher knowledge in applying this technology, or relatively higher costs compared to traditional methods. Therefore, efforts are needed to introduce and integrate microcontroller technology into learning to encourage more effective and efficient learning media innovations.

To overcome these challenges, the development and utilization of microcontroller-based technology in learning media must be further enhanced. Researchers such as Hidayat and colleagues, as well as Damayanti and colleagues, have proven that this technology can improve students' understanding of circular motion material. Additionally, teacher training should be optimized so that they can effectively implement technology-based learning media.

Thus, the use of technology-based teaching aids like microcontrollers provides an innovative solution to improve the quality of physics learning. This initiative needs to be expanded so that more students can understand physics concepts, particularly circular motion, more effectively and enjoyably.

4. Conclusion

This study aims to analyze the utilization of microcontrollers in circular motion laboratory equipment using the PRISMA method and Systematic Literature Review (SLR). From the analysis, 40 relevant articles were obtained. The results indicate the successful development of microcontroller-based experimental tools, which continue to expand in research and education, particularly in the field of mechanical physics, especially in circular motion topics. Technology-based teaching aids such as microcontrollers have proven to be an innovative solution for enhancing the quality of physics learning. Therefore, the application of this technology needs to be further expanded to enable students to understand physics concepts, particularly circular motion, more effectively and enjoyably.

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