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Microcontroller-Based Mechanics Experiments in Physics Learning: Systematic Literature Review Using PRISMA

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Abstract: Microcontrollers are capable of digitizing conventional equipment so that it will make it easier for practitioners to carry out experiments. The aim of this research is to determine the use of microcontrollers in physical mechanics experiments using the Systematic Literature Review method. The data collected was in the form of national and international journal articles from accredited and indexed electronic databases and then extracted. The research results show mechanical experiments using microcontroller-based experimental tools, supporting sensors used in these tools, the learning models applied, learning achievements that can result from activities and the types of research used to discuss these experimental tools.

Keywords: Microcontroller; Physics mechanics; PRISMA; Systematic literature review

Introduction

Physics is a branch of natural science that studies natural phenomena or phenomena. Natural phenomena in physics can be reviewed theoretically or experimentally. Experiments are carried out to prove the truth of a theory, while theory is used to guide the course of an experiment (Radiyono et al., 2022). Referring to Ledermaan's statement, that "Science is a collection of knowledge, methods, and ways of understanding or values and beliefs about scientific knowledge and its development. Thus, it can be interpreted that in addition to solving mathematically, students are expected to be able to understand, analyze, and construct existing knowledge using the scientific method by conducting experiments (Dewi et al., 2018).

Experimental tools are a set of practical tools used to prove concepts. Everything that is still conceptual can be understood and proven through experimental tools so that it can be reached with a simple mind and can be seen, viewed and felt. Experimental tools are a set of experimental tools that are important to use in learning physics. Physics is a type of physical material that has abstract concepts and requires experiments to prove the concept. The experimental method is a way of presenting physics in which students actively experience and prove for themselves what they are studying and draw their own conclusions about an object or physical phenomenon so that it is suitable to be applied to physics learning (Qomariyah et al., 2020).

The success of experimental activities in physics learning is influenced by the availability of adequate practicum tools and materials, one of which is teaching aids (Masyruhan et al., 2020). In the experiment, a visual aid is needed which functions to reduce the abstractness of a concept or theory in order to clarify the theory more easily understood, interesting and easy to understand (Prihatiningtyas & Putra, 2018). Teaching aids in physics experiments are learning media which aim to provide illustrations and convey the characteristics of the

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concepts and theories being studied (Kause, 2019; Fauza et al., 2021a).

Important experiments are carried out especially in basic physics courses. The purpose of this experiment is for students to be able to understand lessons based on symptoms that occur through direct observation. The existence of physics experiments is expected to give birth to important discoveries. A very important role to get good research results requires experimental sets. Many physics experiment sets have been developed and circulated in the market. However, many of these experimental sets are still operated manually. This manual system still has several weaknesses, including research results that require quite a long processing time to test the correctness of experimental results and require several people to carry out experiments. For example, measuring the travel time of an object using a stopwatch certainly has a relatively large error because the object's speed is very fast. The function of teaching aids for students is to provide learning motivation so that learning is more varied and so that students are able to understand learning theories better (Fauza et al., 2023). Students need an intermediary or tool that facilitates understanding. This is expected by the teacher to help students in capturing the concept of learning even better (Ariani et al., 2023).

The digitization system will be able to overcome these weaknesses. A digital system using a microcontroller will make it easier for practitioners to conduct experiments. Self-designed experimental tools can reduce the size of the budget when using digital products on the market. Previously there was a digital product that made this experimental set, namely Pasco. However, because the purchase cost is quite expensive and maintenance is complicated because when damage occurs it will be very difficult to repair. So that schools and teaching staff choose to deliver teaching materials by showing videos or virtual labs. Products on the market are also only able to display one set of experiments. So, if there are 5 experiments, then there must be 5 experimental sets, so the cost of buying experimental sets is getting more expensive. In this study the researchers made a set of integrated mechanics experiments in a set of tools. This experimental set is expected to be more practical and efficient. Microcontroller-based mechanical experimental tools can explain mechanical concepts, namely particle dynamics, rigid body dynamics, simple planes and rectilinear motion. For this microcontroller-based mechanical experiment, a sensor is needed to determine the parameters of travel time, object distance and other quantities in this experiment. More accurate data can prove students' understanding of physics concepts in learning basic physics experiments (Fauza et al., 2022).

Currently, technological developments are developing rapidly, but limited laboratory facilities are not an obstacle to carrying out experiments. Many electronic components can be used to make simple practical devices that can explain certain physical matters. One electronic component that can be used in physics experiments is the Arduino Uno microcontroller (Tina et al., 2021). The microcontroller is capable of digitizing conventional equipment, of course this increases the effectiveness and efficiency of the use of teaching aids in experimental activities (Masyruhan et al., 2020).

The fact that the Arduino software and hardware are open source is supported by a block-based code program that provides access to a wide range of applications without much coding knowledge. This makes Arduino widely used in learning environments (Ocak, 2018). This is in line with what has been expressed by Çoban et al. (2023). Arduino is easily accessible to all people and it makes physics experiments that have never been done before because of limited funds can be carried out at a lower cost using Arduino.

Learning as a process carried out by each individual to get changes in his personality which is shown in the form of increasing the quality and quantity of behavior such as increasing skills, knowledge, attitudes, habits, understanding, skills, thinking and various abilities. Learning is a process that is built by the teacher to students which aims to improve students' thinking skills and efforts to increase mastery of something being taught to achieve certain goals. Physics is a science that studies natural symptoms and phenomena that are commonly encountered in everyday life. Physics is a branch of science whose application can develop children's analytical thinking abilities. This analytical thinking ability can be developed by using various examples of natural phenomena as a form of implementation of physics (Fauza et al., 2021b).

The essence of learning physics as an attitude. The way of thinking is the essence of physics where creative ideas, or ideas to explain a natural phenomenon, can be prepared. This attitude is able to underlie every measurement, investigation and experimental activity. This attitude includes self-confidence and curiosity. Physics as an attitude is a scientific attitude which consists of an attitude of curiosity, caring, responsibility, honesty, openness, and working together. The essence of physics is a science that studies phenomena through a series of processes known as scientific processes which are built on the basis of a scientific attitude and the results are manifested as scientific products which are composed of three elements, namely in the form of concepts, principles and theories that apply universally.

The development of microcontroller technology has now reached microcontrollers with the Arduino Uno open source program. Arduino is an open-source electronics prototyping platform based on hardware and software that is flexible and easy to use. It is meant for artists, designers, hobbyists, and anyone else interested in creating interactive objects or environments. Arduino can sense the environment by receiving input from its various sensors and can control its surroundings using lights, motors, actuators and others.

Based on this explanation, the researcher wants to explain how to use Arduino microcontroller-based experimental tools in learning physics mechanics. The study begins by explaining what materials have developed Arduino microcontroller-based teaching aids and the results that can be seen from learning using microcontroller-based experimental tools using various sensors.

Method

The method used in this research is Systematic Literature Review (SLR). With a survey-based quantitative descriptive approach. The survey was conducted on secondary data, namely the results of development and implementation research on microcontroller-based mechanics experiments in learning. Research stages include data collection, data analysis, and drawing conclusions. The data collected is in the form of primary research that has been published in national and international journal articles, data is collected from electronic databases registered and indexed by Scopus, Google Scholar, publish or perish, science direct, ERIC, and direct URL. Next, all articles found were extracted. Only articles that are relevant and meet the inclusion criteria are included in the analysis stage.

Inclusion criteria to obtain data that is in accordance with the research objectives. The following inclusion criteria were used: (1) Evaluation studies in the field of physics; (2) The study analyzes experimental equipment, especially microcontroller-based (3) research targets from elementary school (SD) to tertiary education (PT); (4) experimental tools used on the topic of mechanics (7) studies must contain the approach or method used; (8) the study must contain the material used in the research. Primary studies that did not meet the inclusion criteria in the study selection process were excluded from the systematic review study process.

The research instrument was in the form of observation sheets or protocols related to inclusion and exclusion criteria with criteria based on the year of publication, study level, number of samples, research locations, journal indexers and materials used. The protocol that the author uses is the PRISMA Protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyzes). The primary study selection process is carried out through four stages which refer to PRISMA, namely; identification, screening, eligibility, and inclusion.

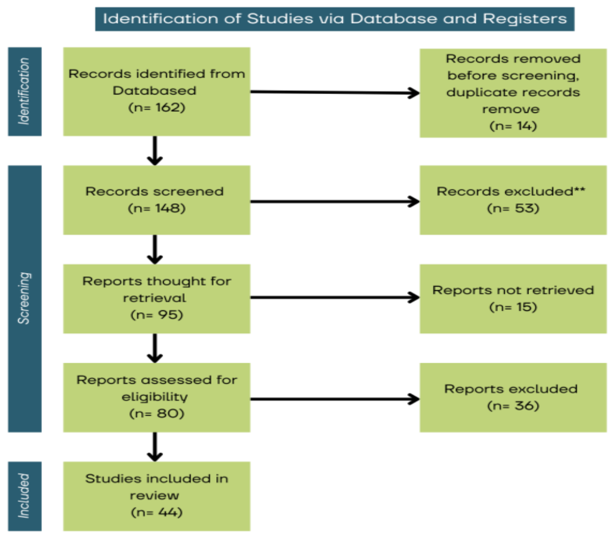

Figure 1. Literature review using PRISMA

The population in this study was all research on microcontroller-based mechanics experimental tools in learning that were published in indexed journals. Based on a search using a search engine, a sample of 80 articles was found consisting of 44 studies using qualitative and quantitative approaches. What will be analyzed in this study is only development research from the stages of design, development and implementation in learning.

Data Extraction

At this stage, data was collected from 44 articles received by reading all the articles in detail. The data presented in tabular form are: types of research, experimental tools, materials, types of sensors, learning models, learning outcomes.

Table 1. Variables Used in Processing Data

Variables	Description
Microcontroller based experimental tool	An experimental tool for physics practicum that has the advantage of obtaining data through sensors
Mechanics Material	Physics material related to motion
Learning model	A conceptual framework designed systematically in experimental learning
Learning achievement	Variables measured in learning achievement

The four variables represent research questions that answer research objectives. These variables are checked and matched with related articles. Researchers can sort out the summary according to these variables.

Result and Discussion

The Physics Mechanics Materials that can be Developed Using A Microcontroller-Based Experimental Tool

The results of this study reveal positive results in the development of experimental tools that utilize microcontrollers. The use of microcontrollers is increasing in the field of research and education, especially in physics mechanics. Researchers found some material in physics mechanics that had been developed using this microcontroller-based experimental tool and has been presented in the following figure.

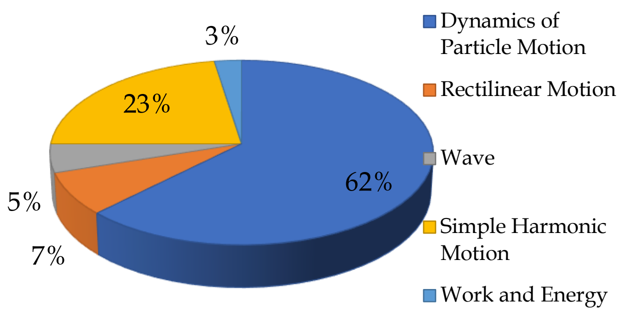

Figure 2. Graphic image of physical mechanics material

The results of the study revealed that most (62%) of these experimental tools were developed on the dynamics of particle motion, especially in the case of planes and inclined planes. One piece of evidence can be found in research results that have been developed by Dewi et al. (2018) showing that the use of a microcontroller Newton's Law experimental tool in learning is very much needed to provide direct experience for students and help students understand Newton's Law material about motion. This is in line with the results of research development conducted by Ariani et al. (2023) which revealed that the results of the development of this experimental tool were very good and received a positive response from students because it was significantly able to increase student interest and learning outcomes in physics subjects, especially in material Newton's Laws. Next on the topic of simple harmonic motion, with a percentage of 23%.

One of the research that needs to be highlighted is research that has been developed by Musik (2017) by utilizing an Arduino microcontroller connected to a computer and sensor devices to develop computer-based experimental devices (Computer-Based Experiments) for learning physics. This device is specifically designed to understand the concept of simple harmonic motion in a mass connected to a spring. Next comes rectilinear motion material (7%), and wave material (5%). However, in the context of physics mechanics, the development of experimental tools is still limited mainly to the topic of work and energy with a contribution percentage of 3%. Based on the results of research developed by Saputri et al. (2017) it shows that the average score given by media experts and material experts indicates that this mechanical energy experimental tool is suitable for use as a learning medium but still requires further revision. The following is a summary of the data regarding the physics mechanics material that the researchers have collected based on the authors who have conducted the research, the related objects are in the form of physics mechanics material and the country of origin.

Table 2. Article Material of Physics Mechanics

Author	Object	Nation
(Umamah et al., 2021)	Dynamics of Particle Motion	Indonesia
(Muchlis et al., 2018)	Dynamics of Particle Motion	Indonesia
(Islahudin et al., 2017)	Dynamics of Particle Motion	Indonesia
(Hasanah et al., 2021)	Dynamics of Particle Motion	Indonesia
(Dewi et al., 2018)	Dynamics of Particle Motion	Indonesia
(Radiyono et al., 2022)	Dynamics of Particle Motion	Indonesia
Fitriana (2020)	Dynamics of Particle Motion	Indonesia
(Andriani et al., 2022)	Dynamics of Particle Motion	Indonesia
(Subhan & Sucahyo, 2020)	Dynamics of Particle Motion	Indonesia
(Rosidi et al., 2018)	Dynamics of Particle Motion	Indonesia
(Lenisa et al., 2022)	Dynamics of Particle Motion	Indonesia
(Pratiwi & Fatmaryanti, 2020)	Dynamics of Particle Motion	Indonesia
(Çoban & Salar, 2023)	Dynamics of Particle Motion	Turkey
(Speirs et al., 2023)	Dynamics of Particle Motion	USA

Author	Object	Nation
(Promsagon & Srisittipokakun, 2022)	Simple Harmonic Motion	Thailand
(Sukmak & Musik, 2022)	Simple Harmonic Motion	Turkey
(Khotimah et al., 2015)	Simple Harmonic Motion	Indonesia
(Ariani et al., 2023)	Dynamics of Particle Motion	Indonesia
(Tina et al., 2021)	Wave	Indonesia
(Saputri et al., 2017)	Work and Energy	Indonesia
(Kause, 2019)	Straight Motion	Indonesia
(Yohanna et al., 2015)	Straight Motion	Indonesia
(Nisa et al., 2014)	Straight Motion	Indonesia
(Saiputri et al., 2021)	Dynamics of Particle Motion	Indonesia
(Afrilla et al., 2014)	Dynamics of Particle Motion	Indonesia
(Lukovic et al., 2021)	Simple Harmonic Motion	Serbia
(Kaps & Stallmach, 2021)	Simple Harmonic Motion	German
(Aminulloh & Widodo, 2018)	Wave	Indonesia
(Musik, 2017)	Simple Harmonic Motion	Thailand
(Erol et al., 2020)	Simple Harmonic Motion	Turkey
(de Castro et al., 2015)	Simple Harmonic Motion	Brazil
(Triana & Fajardo, 2013)	Simple Harmonic Motion	Colombia
(Matos & Zannin, 2021)	Dynamics of Particle Motion	Brazil
(Ferrarelli & Iocchi, 2021)	Dynamics of Particle Motion	Italy
(Addido et al., 2023)	Dynamics of Particle Motion	USA
(Wahyu & Pramudya, 2019)	Dynamics of Particle Motion	Indonesia

Sensors Work on the Experimental Equipment

In operating microcontroller-based devices, it is important to understand that the main supporting component required is a sensor. These sensors are tasked with detecting or measuring objects in various experimental contexts. In the world of research, researchers have taken steps to utilize various types and types of sensors to create more sophisticated and quality microcontroller-based experimental tools. Details regarding these types of sensors can be found in the following image.

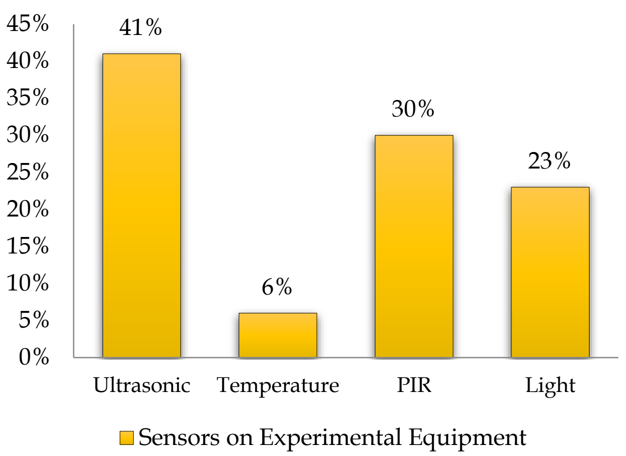

Figure 3. Graph of sensors working on experimental equipment

Figure 3 shows the percentage of sensors working on the Arduino microcontroller-based experimental device. Research reveals that most (41%) of this experimental tool uses ultrasonic sensors. Ultrasonic sensors are used to detect objects by measuring their distance (Saputri et al., 2017). One type of ultrasonic sensor that is commonly used is the HCSR-04 type. This sensor can measure the distance of objects around 2 cm to 450 cm using two digital pins to transmit and receive signals. The working principle of this ultrasonic sensor involves sending an ultrasonic pulse of around 40 kHz which then reflects the echo pulse and measures the time required in microseconds (Puspasari et al., 2019). The next sensor most often used is the PIR (Passive Infrared Sensor) or better known as an infrared sensor (30%). PIR is used to reduce errors in calculating time compared to measuring time using a stopwatch because measurements using a stopwatch can occur less accurately when starting the measurement (Subhan & Sucahyo, 2020). The maximum distance that can be detected by PIR is 6 meters. When the sensor detects it, the microcontroller will process the data and send the data to RS-232 then the RS-232 interface will provide a signal to the cell phone or computer installed on the device (Desmira et al., 2020). Then tools that use light sensors (23%), and followed by temperature sensors (6%). In addition to the pictures, in an attempt by researchers to describe the sensors that work on this microcontroller experimental device, researchers have compiled a table based on the authors who have conducted the research, the objects in the form of sensors used and the country of origin.

Table 3. Sensor Articles that Work in Experimental Equipment

Author	Object	Nation
(Lenisa et al., 2022)	Ultrasonic Sensor	Indonesia
(Hahn et al., 2019)	Ultrasonic Sensor HC-SR04 Temperature Sensors DS18 B20	Portugal
(Ariani et al., 2023)	Ultrasonic Sensor	Indonesia
(Saputri et al., 2017)	Ultrasonic Sensor HC-SR04	Indonesia
(Kause, 2019)	Ultrasonic Sensor Passive Infrared Sensor	Indonesia
(Matsun et al., 2022)	Ultrasonic Sensor HC-SR 04	Indonesia
(Subhan & Sucahyo, 2020)	Passive Infrared Sensor	Indonesia
(Rosidi et al., 2018)	Passive Infrared Sensor	Indonesia
(Sukmak & Musik, 2022)	Passive Infrared Sensor	Turkey
(Musik, 2017)	Passive Infrared Sensor	Thailand
(de Castro et al., 2015)	Light Sensor	Brazil
(Muchlis et al., 2018)	Light Sensor	Indonesia
(Radiyono et al., 2022)	Light Sensor	Indonesia
(Erol et al., 2020)	Light Sensor	Turkey

Learning Models Can be Applied in Experiments Using Microcontroller-Based Experimental Tools

After the researcher realizes that the development results from previous research have confirmed their validity and are feasible to be applied in a learning context, the next step is to find out a learning model that can be applied to be tested in experiments using this microcontroller-based tool. As explained by the researcher in the following figure, the main goal is to understand and describe a learning model that can provide the best results in the use of experimental tools in the form of percentages.

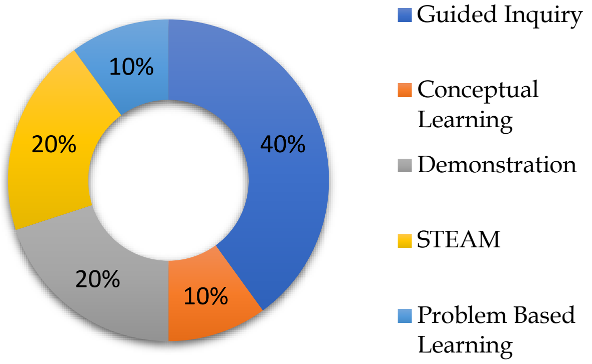

Figure 4. Graphical image of the learning model

In Figure 4, research using the guided inquiry learning model has a high percentage (40%) because the application of this learning model provides opportunities for students to learn actively. Students are able to find learning resources independently while the teacher acts as a facilitator and provides guidance to students who experience difficulties in building knowledge. The learning activities carried out by these students are more meaningful so that long-term memory is stored (Sundari et al., 2017). The next learning model is followed by the STEAM learning model (Science, Technology, Engineering, Arts, and Mathematics) and demonstrations with each percentage (20%), for this STEAM learning model can also be used in experimental activities because this model is believed to be able to help develop knowledge, help answer questions based on investigations and be able to help students to increase creativity in learning (Nasrah, 2021).

The STEAM learning model is also believed to be able to encourage students to learn to explore all the abilities they have in their own way (Widarti & Roshayanti, 2021). The next method used is the demonstration method. The demonstration method is a method by demonstrating a process to students. This method is very effective because it helps students to find their own answers based on the facts that occur (Gumay & Bertiana, 2018). And the smallest is the learning model of conceptual learning and problem based learning with each percentage (10%). In the table below, the researcher presents data regarding learning models that can be applied in experiments using microcontroller-based experimental tools based on the authors who have conducted the research, the object of course being the learning model used and the country of origin.

Table 4. Article Learning Model used

Author	Object	Nation
(Umamah et al., 2021)	Guided Inquiry	Indonesia
(Fitriana, 2020)	Guided Inquiry	Indonesia
(Matos & Zannin, 2021)	Guided Inquiry	Brazil
(Ferrarelli & Iocchi, 2021)	Guided Inquiry Problem Based Learning	Italy
(Speirs et al., 2023)	Conceptual Learning	USA
(Çoban & Salar, 2023)	STEAM	Turkey
(Addido et al., 2023)	STEAM	USA
(Dewi et al., 2018)	Demonstration	Indonesia

The Learning Outcomes Using Microcontroller-Based Experimental Tools

After implementing experimental tools with various types of learning models available, researchers understand that this activity has the potential to achieve various valuable achievements. Therefore, in an effort to provide a comprehensive understanding, researchers have detailed in more depth the achievements obtained from carrying out experiments using this microcontroller-based tool. This deeper understanding will provide a more complete picture of the impact and benefits of the experiment as the researchers have explained in the Figure 5.

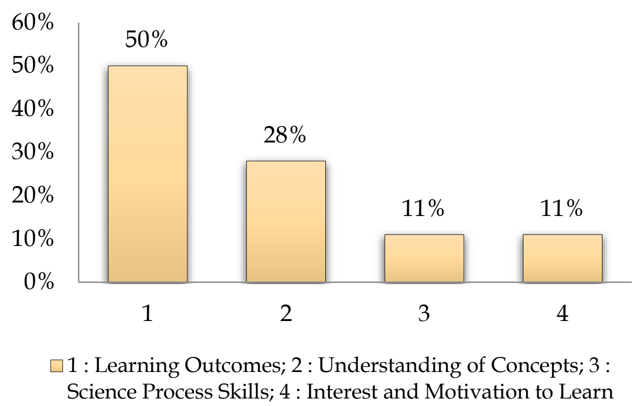

Figure 5. Graph of learning achievements

Figure 5 shows the percentage of learning outcomes obtained after applying this Arduino microcontroller-based experimental tool in learning and related articles are presented in Table 5. There are various forms of learning outcomes obtained after applying this tool, with the highest percentage being learning outcomes (50%). The results of this study include learning outcomes on cognitive aspects, psychomotor aspects, and affective aspects of students. Students were successful in carrying out all activities in the experiment by implementing experimental tools. Teachers and students feel that they are more involved in learning physics, they are also able to learn the main concepts and even have discussions so that the teacher explains that there is a significant increase in student learning outcomes and they are able to learn the physics concepts contained in the experimental tool beyond the objectives learning (Matos & Zannin, 2021). Then, the next learning outcomes are followed by a conceptual understanding of the theory with a percentage (28%), based on the results of research that has been conducted by. Finally, learning outcomes with the smallest percentage are science process skills and students' learning interest and motivation with each percentage (11%). In the following, the researcher presents a table that contains a list of researchers and their countries of origin who have conducted research on the achievement of learning outcomes using microcontroller-based experimental tools.

Table 5. Table of Learning Outcomes Articles

Author	Object	Nation
(Islahudin et al., 2017)	Learning outcomes	Indonesia
(Dewi et al., 2018)	Learning outcomes: Cognitive assessment, Psychomotor assessment, Affective Assessment	Indonesia
(Speirs et al., 2023)	Cognitive Learning Outcomes	USA
(Promsagon & Srisittipokakun, 2022)	Learning outcomes	Thailand
(Matos & Zannin, 2021)	Learning outcomes	Brazil
(Ariani et al., 2023)	Learning outcomes Interest and Motivation to Learn	Indonesia
(Addido et al., 2023)	Learning Outcomes of Understanding Concepts	USA
(Ferrarelli & Iocchi, 2021)	Understanding Concepts	Italy
Fitriana (2020)	Understanding Concepts	Indonesia
(Umamah et al., 2021)	Understanding Concepts	Indonesia
(Subhan & Sucahyo, 2020)	Science Process Skills	Indonesia
(Saputri et al., 2017)	Science Process Skills	Indonesia
(Aminulloh & Widodo, 2018)	Concept Understanding, Interest and Learning Motivation	Indonesia

In Figure 6, the percentage of research types used in the discussion regarding microcontroller-based experimental tools is shown. The figure reveals that most research (38%) focuses on experimental tool development research. The development research is a research method used to produce certain products and test the effectiveness of these products (Rustandi & Rismayanti, 2021). At the development stage, the experimental tool design resulting from each research provides an initial overview of its functionality. After going through the tool testing phase, the experimental tool was validated by experts (Ariani et al., 2023). Then the quantitative research type is in second place with a percentage of 33%. This type of research is used to collect and analyze numerical data with the aim of producing objective and measurable information. Quantitative data is often collected through various methods such as surveys, experiments or direct measurements. Furthermore, the data was analyzed using statistical techniques to identify patterns or significant relationships in the data.

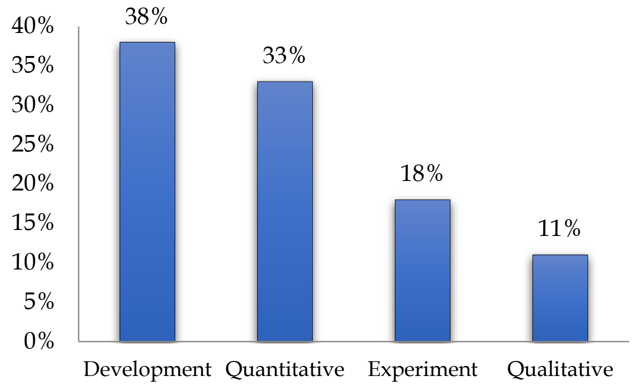

Figure 6. Graph of research types

Meanwhile, experimental research has a percentage of 18%. This type of experimental research aims to make students have the skills to find and find various answers and problem solving independently through conducting experiments. It is hoped that through this experimental experience, students will be able to hone their scientific thinking skills. Then by conducting experiments, students can directly find empirical evidence from the theory they are studying (Hendawati & Kurniati, 2017). Furthermore, the type of research that is rarely used is qualitative research with a percentage (11%).

Conclusion

This study aims to determine the utilization of microcontrollers in physics mechanics experiment tools using the PRISMA method, Systematic Literature Review (SLR) on microcontroller-based mechanics experimental tools to be extracted to obtain 44 articles. The results showed that the use of microcontroller-based mechanics experiment tools was very effective in various physics mechanics materials, some of which were in the dynamics of particle motion, simple harmonic motion, straight motion, waves, as well as work and energy. Each experimental tool is also equipped with various sensors as supporting components such as ultrasonic sensors, PIR, light sensors and temperature sensors. When implementing this experimental tool it also supports a variety of learning models such as guided inquiry learning models, STEAM, demonstrations, conceptual learning and problem based learning so that they are able to produce various aspects of learning outcomes after applying these tools such as learning outcomes, conceptual understanding, science process skills as well as interest and motivation to study physics. Then various types of research were used to discuss this microcontroller-based experimental tool, most of the research was development research, followed by quantitative research, experimental research and qualitative research.

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Author Contributions

Contribution of ideas by main writer Naila Fauza in collaboration with Fanny, Zulhelmi and Ernidawati. Fayolla assisted in finding sources and drafting articles. Ahmad amirul Latif and Khairan assisted with data extraction.

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Conflicts of Interest

All authors declare no conflict of interest.

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