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Development of an Arduino-Based Water Rocket Launcher in Physics Experiments

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RINGKASAN PENELITIAN

The effective science education requires methods that allow students to practice and explore in-depth in complex physics concepts. One promising approach is the use of physics experiment as an interactive media. This research focuses on the development of water rocket launcher using an Arduino as an innovative and effective equipment in physics experiment.

This equipment is a combination of Arduino microcontroller technology and water rocket launcher. Arduino in water rocket launcher is used for making the precise control and relevant measurement in physics experiments especially in water rocket launcher, such as angle of projection, speed of launch, maximum altitude of launch, and air pressure. Beside creating an interactive physics experiment, this study is to stimulate the students' interest in physics experiment and increasing the students' understanding in physics experiment.

This development study involves hardware, software, prototype, work testing, and user's instruction. Beside developing the equipment, this study is going to determine the relation between the use of water launcher in Arduino-based and students' level of understanding toward physics concept and physics experiment.

The findings of this study are developing an interactive water rocket launcher with Arduino-based, being source of material to teach physics experiment about projectile motion in fun way, enriching students' knowledge and experience in interactive experiment, and increasing the students' understanding of physics.

Kata Kunci :
Launcher, Water Rocket, Arduino, Experiment

BAB 1. PENDAHULUAN

1.1. Latar Belakang

Mechanics is one of the main materials in physics which is the beginning of the history of the development of the laws of physics. While rocket motion is one of the applications of mechanics concepts that apply many laws of physics such as Newton's law of motion, the concept of momentum and conservation of momentum, and the concept of projectile motion [1]. The working principle of rocket propulsion is an application of Newton's third law and conservation of momentum. The working principle of this rocket is the same as that used by squids or octopuses to propel themselves. They expel water from their bodies with enormous force, and the expelled water acts an equal and opposite force on the squid or octopus, propelling it forward. A rocket gets a boost by burning fuel and exhausting the gases formed through the back. The rocket exerts a force on the exhaust gas, and from Newton's law III, the gas exerts an equal and opposite force on the rocket [2].

Researchers intend to develop an Arduino-based water rocket launcher in physics experiments is a topic that has received significant attention in the world of science education. Through the integration of microcontroller technology such as Arduino in physics learning, students can understand physics concepts practically and interactively. Basically, water rocket launching experiments are an effective method to teach various physics concepts, including Newton's laws of motion, the action-reaction principle, and air pressure [3].

As technology advances, the use of Arduino in the development of water rocket launchers has become increasingly popular. Arduino is an affordable and programmable hardware platform that can be used to control a wide variety of experimental tools, including water rocket launchers. With Arduino, teachers can program the device to measure physics parameters during the rocket launch, such as angular projection, velocity, altitude, and air pressure, so that students can see and analyze the experimental results directly [4].

Project-based physics learning allows students to research, plan, design and reflect on the creation of their technology projects. This type of learning not only stimulates student creativity but also requires different assessments. Projects will provide information about students' understanding and knowledge of the learning process, their ability to apply knowledge, and their ability to communicate information. Recent research in this field has shown that the use of Arduino-based water rocket launchers can improve students' understanding of physics concepts. In addition, the use of this technology also stimulates students' interest in science and technology. This is particularly relevant in the face of modern educational challenges where students often struggle to understand abstract physics concepts [5].

In addition, the development of an Arduino-based water rocket launcher also opens up the potential for distance teaching or self-directed learning. The COVID-19 pandemic has accelerated the adoption of technology in education, and this tool can provide an effective alternative for physics learning outside the traditional classroom. In this context, this research aims to develop an effective and safe Arduino-based water rocket launcher for use in physics experiments. The tool will be designed to suit the needs of physics lecturers and students at various levels of education. With the development of an appropriate tool, it is expected to enhance physics learning and strengthen students' experimental interest in science and technology [6].

1.2. Perumusan Masalah

The development of Arduino-based water rocket launchers in physics experiments is an interesting and relevant topic in improving physics learning in an educational environment. In this context, the formulation of the research problem is important to direct the research effort appropriately. Therefore, the following is a complete formulation of the research problem: **"How to develop an effective and safe Arduino-based water rocket launcher for use in physics experiments, and how can this tool improve students' understanding of fundamental physics concepts?"** To answer this problem formulation, the research needs to consider the technical aspects of developing a water rocket launcher, including optimal hardware and software design. In addition, the research should also measure the impact of using this tool in improving students' understanding of physics through experiments. Other factors such as safety, reliability, and resource availability also need to be considered in the problem formulation

1.3. Tujuan Penelitian

This research aims to achieve a number of important objectives that will make a positive contribution to the development of physics experiments using Arduino-based water rocket launchers. The objectives of this research are:

1. Developing an Effective Arduino-based Water Rocket Launcher: This research aims to design and develop an experimental tool that can launch water rockets accurately and efficiently. It will use Arduino technology to control the entire launch process, including the measurement of relevant physical parameters.
2. Improving Understanding of Physics Concepts: The main objective is to improve students' understanding of fundamental physics concepts such as Newton's laws of motion, the principle of air pressure, and the action-reaction principle through practical experiments using a water rocket launcher. The device will be designed to allow students to directly observe and measure physical effects.
3. Measuring Tool Performance and Safety: This research will conduct intensive testing of the developed Arduino-based water rocket launcher to ensure reliable performance and a high level of safety in its use by lecturers and students.
4. Increasing Interest in Science and Technology: This research also aims to stimulate students' interest in science and technology by incorporating elements of modern technology such as Arduino in physics learning. It is expected that the use of technology will make learning more interesting and relevant for students.
5. Contribution to Educational Development: This research seeks to contribute to the world of education by creating experimental tools that can be used by physics lecturers to improve their teaching methods. The results of this research can be used as a model for the development of similar learning tools in the future.

1.4. Batasan Penelitian

Research on the development of Arduino-based water rocket launchers in physics experiments has certain limitations that need to be considered. The following are the limitations of relevant research:

1. Scope of Physics Experiments: This research will focus on physics experiments that involve launching water rockets. While there are many physics concepts that can be taught through this experiment, this research will limit the discussion to concepts directly related to water rocket launching, such as Newton's laws of motion, air pressure, and the action-reaction principle. While the tool will include measurements of several physics parameters such as velocity, altitude, and air pressure, this research will limit the number and type of parameters measured according to the more general purpose of the physics experiment.

2. Arduino Technology: This research will use Arduino ATmega 328 technology as the tool development platform. However, this research will not consider alternative microcontroller technologies or other hardware platforms. Although Arduino will be used in this research, in-depth and complex Arduino programming will not be the main focus. This research will focus on the hardware development and basic use of Arduino for the control of the water rocket launcher.
3. Rocket Size and Scale: This research will limit the size and scale of the water rocket to be used in the experiments. The water rocket developed will be of a size that is safe and practical for use in an educational environment. Testing of the developed device will focus on performance and safety aspects. This research will not include testing of actual physics experiments by students, but will focus more on technical testing of the tool.
4. Educational Context: This research will focus on developing a physics experiment tool for use in an educational setting. It will be a tool for lecturers and students in learning physics at the tertiary level.

1.5. Kaitan Penelitian dengan Road Map Penelitian Pribadi dan Road Map Penelitian Fakultas

This research has a significant connection with the researcher's personal research roadmap on "Development of Arduino-based water rocket launchers in physics experiments." namely: This research is the first step in the development of more innovative and interactive educational technology. The use of Arduino in making water rocket launchers is a concrete example of how technology can enrich physics learning. In the researcher's roadmap, this research will be the foundation for the development of other learning tools that use modern technology to teach scientific concepts. Water rocket launching experiments are a particularly effective type of project-based learning [7]. This research will provide important insights on how to design educational projects that actively engage students in the exploration of physics concepts through hands-on practice. In the researcher's roadmap, it is planned to continue developing similar project-based learning methods for other physics concepts. This research is directly related to teaching science and technology, which is a major focus in the researcher's personal research roadmap. Through physics experiments and the use of Arduino technology, this research will assist students in understanding the basic principles of science and technology, which is in line with my efforts in improving science and technology literacy. Therefore, this research is not only an important starting point in my personal research roadmap, but also the basis for further efforts in developing better education, technology, and learning methods. This topic is also in line with the faculty roadmap in the field of green energy and green energy engineering.

BAB 2. TINJAUAN PUSTAKA

A. Development of Water Rocker Launcher

Water rocket experiments have long been an effective approach to physics learning. A study showed that water rocket experiments can improve students' understanding of physics principles, especially the laws of motion. Technology in Water Rocket Experiments: The use of technology in the development of water rocket launchers has improved the accuracy and functionality of experiments [8]. Characterized the use of sensors and automated control systems in water rocket launchers to improve the quality of experimental data [9].

Water Rocket Launcher Design and Construction: The study highlights the importance of proper design in the construction of water rocket launchers. Factors such as stability, materials, and ease of use contribute to the success of the experiment. Measurement of Physical Parameters: One of the main objectives of water rocket experiments is to measure physics parameters such as air pressure, launch velocity, and maximum altitude [10]. Describes various methods of measuring these parameters in water rocket experiments. Design and Construction of Water Rocket Launcher: Water rocket experiments require proper design and construction of the launcher. Discusses various designs of water rocket launchers and the factors that affect their performance. Materials and Components: The use of the right materials in the construction of water rockets and launchers is key to successful experiments. Examined the use of plastic bottles and other components in the manufacture of water rockets [11].

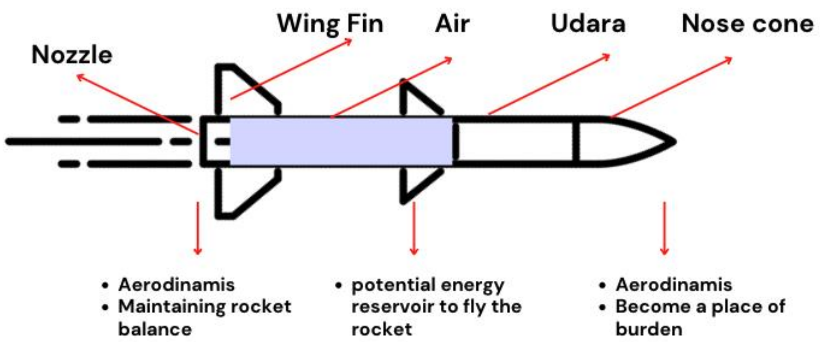


Fig. 1. Rocket parts and functions.

Application in Education: Water rocket experiments have also been integrated into the educational curriculum. Discussed the positive impact of using water rocket experiments in increasing students' interest and understanding of physics. Safety in Water Rocket Experiments: In the development of water rocket launchers, the safety aspect is a crucial factor. A study by the National Association of Rocketry presents guidelines for safety in water rocket experiments and engaging students safely. Environmental Influences on Water Rocket Experiments: Environmental factors such as wind, weather, and launch terrain can affect the outcome of experiments. Examined the influence of environmental factors on water rocket performance [12].

Water Rocket Development as Career Inspiration: Reviewed how water rocket experiments can be an effective incentive for students to explore careers in science, technology, engineering and math (STEM). This literature review shows that the development of water rocket launchers involves aspects such as design, technology, physics measurement, safety, and applicability in education. As a result, the water rocket experiment is not only an effective physics learning tool but can also motivate students to explore further in STEM fields [13].

B. The Use of Arduino in Research and Education

Arduino is an affordable and easy-to-use hardware platform developed to enable the development of various electronic projects. Arduino is based on the AVR microcontroller and has a simple and user-friendly software development environment. Arduino has become a popular tool in education. Studies show that the use of Arduino in science and technology teaching can improve students' understanding of concepts and interest. Arduino is often used in the development of robots and autonomous vehicles [25]. Previous research illustrates the use of Arduino in the development of robots that can be used in a variety of applications, including the maintenance of civil structures. Arduino can be used to control and process data from various sensors. The study discusses the use of Arduino in the measurement of environmental parameters such as angle, temperature, humidity, and air pollution. Arduino has an important role in supporting STEM (Science, Technology, Engineering, and Math) education [13]. Illustrates how Arduino can be used to facilitate practical learning in STEM subjects. Arduino-based Educational Tool Development is used in the development of interactive educational tools. The study designed an Arduino-based teaching tool to help students understand physics and math concepts.

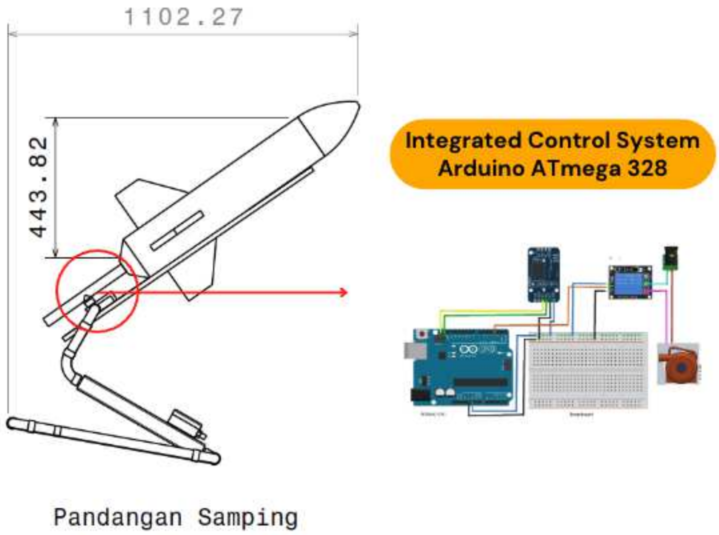


Fig. 2. Use of Arduino integrated control system on water rocket launcher.

This literature review reflects the diverse applications and contributions of Arduino in various aspects of education and research. From STEM teaching to the development of educational tools and scientific projects, Arduino has opened up a wide range of opportunities in the exploration of technology and science.

C. Working Principle of Rocket Water Propulsion

1. Newton's second law

Kinetics of a water rocket can be investigated by analyzing the forces that affect rocket motion, which include forces due to aerodynamic drag, gravity, and thrust from water being expelled. Newton's second law, Bernoulli's principle, and adiabatic expansion of air concepts are used to develop the equations of motion of a water rocket. As water is expelled from a water rocket, the thrust force it generates is given by

$$F_{Thrust} = u_{exit} \frac{dM_{\exp w}}{dt}, \tag{1}$$

where u_{exit} is the velocity of the water at exit relative to the rocket and $d\ M\exp\ \mathrm{w}/dt$ is the mass flow rate of the expelled water.

The gravitational force is given by

$$F_{Gravity} = M_R g, \tag{2}$$

where M_R is equal to the mass of the rocket (including water) and is a function of time. The gravitational constant is denoted as g.

The aerodynamic drag of the rocket is given by

$$F_{Gravity} = \frac{1}{2} \rho_{air} C_D A |v_R| v_R \tag{3}$$

where the density of air is ρ_{air}, the drag coefficient is C_D, and A is the frontal area. The velocity is $v_R$and the absolute value of the velocity $|v_R|$ is necessary to account for the sign change of the velocity during descent.

An expression of the acceleration of the rocket can be obtained by substitution of these three equations into Newton's second law [14].

$$a_R = \frac{\sum F}{M_R} = \frac{F_{Thrust} - F_{Gravity} - F_{Drag}}{M_R} \tag{4}$$

2. Bernoulli's law and adiabatic assumption

To derive a numerical solution that predicts the kinematics of a water rocket, it is necessary to express F_{Thrust} of Eq. (4) in terms of air pressure inside the bottle. The initial value of this controlled variable to be used as a starting point for the numerical solution. To accomplish this, the mass flow rate of water term $dM_{\exp \mathrm{w}}/dt$ in Eq. (1), which is equivalent to the volumetric flow rate, can be expressed as

$$\frac{dM_{\exp w}}{dt} = \rho_w \frac{dV}{dt} = \rho_w A_{exit} u_{exit} \tag{5}$$

where ρ_w is the density of the water, dV/dt is the volumetric flow rate, and A_{exit} is the cross sectional area across which the water expels. Next, u_{exit} is expressed as a function of air pressure by using Bernoulli's principle given by

$$P_{air,1}, 1 + \frac{1}{2}\rho_{w,1}v_1^2 + \rho g h_1 = P_{air,2} + \frac{1}{2}\rho_{air,2}v_2^2 + \rho_{w,2} g h_2 \tag{6}$$

where location 1 is considered to be at the water and air interface inside the bottle and location 2 is at the exit (reference Fig. 3). Variables P, ρ, v, and h are internal air pressure, density of water, velocity of water, and height of water, respectively, at locations 1 and 2. Bernoulli's equation is simplified by approximating of $\rho g h_1 \approx \rho g h_2$ and $v_1 \ll v_2$. In addition, when changes in notations are made where $P_{air,1} = P_{air\ inside}$, $P_{air,2} = P_{exit}$, and $v_2 = u_{exit}$ Bernoulli's principle to reduces to

$$u_{exit} = \sqrt{\frac{2(P_{air\ inside} - P_{exit})}{\rho_w}} \tag{7}$$

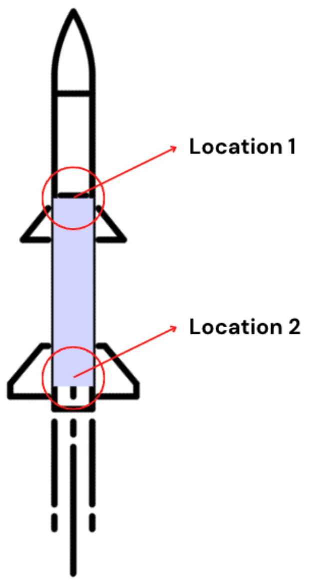


Fig. 3. Locations 1 and 2 as referenced in Bernoulli's principle (Eq. (6)).

An expression for $dM_{exp\ w}/dt$ can be obtained by substitution of Eq. (7) into Eq. (5). Theresulting expression can then be substituted into Eq. (1) to yield F_{Thrust} as a function of pressure

$$F_{Thrust} = 2(P_{air\ inside} - P_{exit})A_{exit} \tag{8}$$

Substitution of this new F_{Thrust} expression, gravitational force Eq. (3), and aerodynamic drag force Eq. (2) into Newton's second law Eq. (4) yields

$$a_R = \frac{2(P_{air\ inside} - P_{exit})A_{exit} - \frac{1}{2}\rho_{air} C_D A |v_R| v_R - M_R g}{M_R} \tag{9}$$

The changes in altitude y_R and velocity v_R of the rocket are respectively sgiven by

$$dy_R = v_R dt \tag{10}$$

and

$$dv_R = a_R dt. \tag{11}$$

Eqs. (9-11) are the kinematic equations that describe the motion of the water rocket and numerical solutions can be obtained using Euler's method of forward time differentiation using Δt = 0.001 second time steps [14].

3. Weather vanning

At launch rockets have a tendency to rotate about their center of gravity (Cg) in the presence of crosswinds. Consider rockets A and B (reference Fig. 4) which are launched with initial speeds of $v_{oÆ}$ and v_{oB}, respectively. Allow the velocities of the air moving over the rocket tobe $\bar{v}_{oÆ}$ and $\bar{v}_{oB}$. If each rocket is subjected to crosswind $\bar{v_c}_w$, then by vector addition, the resultant vectors $\bar{v}_{RÆ}$ and $\bar{v}_{RB}$ act at angles about the y-axis of each rocket as shown. This causes each rocket to rotate to an angle of attack α as shown in Fig. 4 with $\alpha_A < \alpha_B$due to the fact that $\bar{v}_{oA} > \bar{v}_{oB}$. This rotation is also known as weather vanning, and ultimately affectsthe directional stability of the rocket.

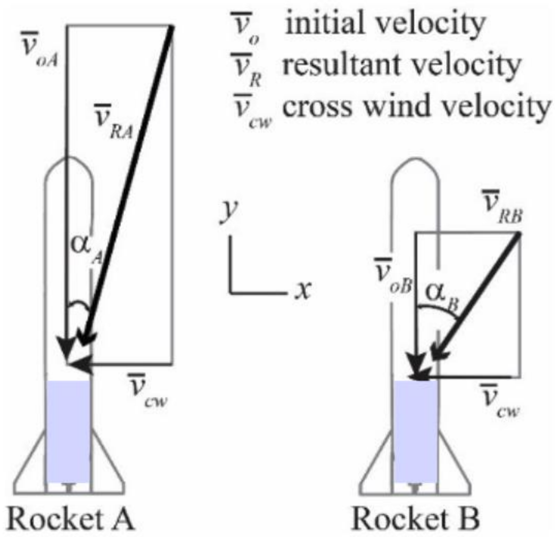


Fig. 4. Initial velocity of the rocket and crosswind velocity affects the degree at whichthe rocket will turn (or weather vane) into the wind at an angle of attack α [14].

4. Analysis of water rocket projectile motion

Motion quantities in the form of vector quantities can be decomposed into their components in each direction of their basis vectors, so that motion in two dimensions can be decomposed into a combination of two one-dimensional movements in two mutually perpendicular directions (for example in the x and y directions). Likewise, motion in three dimensions can be decomposed into a combination of three one-dimensional motions in three mutually perpendicular directions (in the x, y, and z directions). All the kinematic equations of straight motion can be used to describe motion in each direction [15]. As an example we will give the motion of a particle in two dimensions (plane) that experiences constant acceleration in the vertical direction and no acceleration in the horizontal direction. An application of this motion is the motion of a bullet, whose trajectory is a parabolic trajectory (Fig. 5).

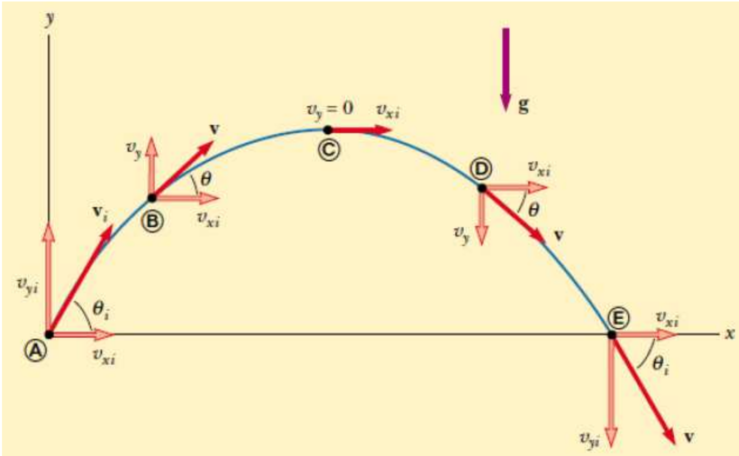


Fig. 5. Parabolic motion vector.

Suppose that at the origin of coordinates (0,0) a particle moves with an initial velocity of $\vec{v}_0$that forms an angle θ with respect to the x-axis. This particle experiences a gravitational acceleration of -g (in the direction of the negative y-axis). The initial velocity of the particle can be decomposed into x and y components, namely $v_{0x} = v_0 \cos\theta$ and $v_{0y} = v_0 \cos\theta$ .The motion of the particle can now be analyzed as motion with constant velocity in the x direction and motion with constant acceleration in the y direction [16]. The position of the particle in the x and y directions is given by

$$x(t) = v_{0x}t,$$

$$y(t) = v_{0y}t \text{ -}\frac{1}{2}gt^2 \tag{12}$$

The particle velocity in the x direction is fixed, $v_x t = v_{0x}$,while the particle velocity in the y direction changes as$v_y t = v_{0y} - gt$. The magnitude of the particle velocity is given by

$$v(t) = \sqrt{v_x(t)^2 + v_y(t)^2} \tag{13}$$

By substituting the time variable t in pers. (12) into pers. (13) is obtained

$$y(x) = \tan\theta x = -\frac{g}{2v_{0\,x}^2}x^2 \tag{14}$$

Equation (14) relates y to x and expresses the projectile trajectory equation, Since v_{0x}, θ_0 and g are constant, the equation can be written in the form of

$$y(x) = Bx - Cx^2,$$

is a parabolic equation, so the trajectory of the projectile is parabolic. With a little analysis, the maximum height is obtained as large as

$$y = \frac{v_0^2 sin^2\theta}{2g} \tag{15}$$

The farthest position of the particle, which is the position when the particle returns to y = 0, occurs at

$$x = \frac{2v_{0y}v_{ox}}{g} = \frac{v_0^2 sin2\theta}{g} \tag{16}$$

The travel time of the particle until it returns to position y = 0, can be written as [17].

$$t = \frac{2v_0 \sin\theta}{g} \tag{17}$$

BAB 3. METODOLOGI PENELITIAN

3.1. Waktu dan Tempat Penelitian

The research on "Development of an Arduino-based water rocket launcher for physics experiments" should be conducted within a sufficient period of time to ensure that the tools developed through this research can be improved and optimized. Suitable research time includes:

a. Initial Design and Development Phase: This initial phase of the research will involve tool design, component selection, and software development. This may require 2 months to plan properly.
b. Prototyping: Prototyping the Arduino-based water rocket launcher tool will take additional time, probably 2 months and maybe 1 additional month to ensure that the tool works as expected.
c. Performance Testing: The performance testing, data collection, and iteration stages will take significant time. It may last as long as 2 months, depending on the complexity of the tool and the number of iterations required.
d. Educational Validity Testing: Testing the tool in an educational environment will require additional time, perhaps 1 month to 2 months, depending on the length of the learning program involving students.
e. Data Analysis and Publication: Data analysis, preparation of the research report, and the publication process will also take some time, perhaps an additional few months [18].

Place of Research:

a. This research will require different places according to the research stages: Initial Design and Development: This stage can be carried out at the 3rd Floor FTI Physics Laboratory, Faculty of Industrial Technology, Trisakti University.
b. Prototype Making: Prototyping can be done at the Industrial Control and Automation Laboratory, 2nd Floor, Faculty of Industrial Technology, Trisakti University which is equipped with the necessary equipment and facilities to assemble hardware components.
c. Performance Testing: Performance testing of this tool can be done in a safe open location, such as a field or other open area, which allows safe launching of water rockets and collecting measurement data.
d. Educational Validity Testing: Testing of the tool in an educational context will be carried out in the Mechanical Engineering Physics class and the Mechanical Engineering Physics Practicum class.
e. Data Analysis and Publication: The final stage of data analysis and preparation of research reports can be done in the office or research laboratory, and publication of the results can be done through reputable scientific journals [19].

3.2. Metode Penelitian

The development research method (R&D) was used in this study to develop an innovative educational tool, an Arduino-based water rocket launcher, to be used in physics experiments. This method integrates the research steps with the tool development process, resulting in a product that can be implemented in the context of physics education. The following are the steps of the development research method in accordance with the topic "Development of an Arduino-based water rocket launcher in physics experiments":

a. Needs Identification Stage
   - The initial step in the development research method is to identify needs. This involves a literature study to understand the relevant physics concepts to be taught through the water rocket experiment.
   - Developing initial specifications for the tool, including desired features and required measurement parameters.
b. Design Stage
   - In this stage, the hardware and software for the Arduino-based water rocket launcher are designed. This includes designing a system block diagram that includes the main components such as the rocket, pressure tube, sensors, and Arduino microcontroller.
   - Selecting suitable and sufficient electronic components for the hardware.
   - Creating a software design that includes Arduino programming to control the device.
c. Development Stage
   - In this stage, the initial prototype of the water rocket launcher was developed. This involves: Physical assembly of the device based on the design.
   - Software coding and programming on Arduino to control the device.
   - Integration of sensors to measure physical parameters such as air pressure, velocity, and altitude.
d. Performance Testing Phase
   - The tool prototype will be tested to measure its performance. This includes: Launching the water rocket under various conditions and collecting performance data such as distance traveled, maximum altitude, and flight time.
   - Testing of sensors to ensure accurate measurement of physical parameters.
   - Evaluation of the reliability of the device under repeated use.
e. Revision and Improvement Stage
   - Based on the results of performance testing, the tool prototype will be analyzed and improved. Revisions may include: Hardware design modifications to improve performance or safety.
   - Improvements to the Arduino software code.
   - Improved safety of tool usage.
f. Educational Evaluation Phase
   - The tool will be tested in the context of physics learning. This involves: Testing the tool in an educational environment involving lecturers and students.
   - Data collection on students' understanding of physics concepts taught through experiments with this tool.
   - Evaluation of the effectiveness of the tool in achieving educational objectives.
g. Finalization and Dissemination Stage
   - Once the tool has been proven effective, it will be finalized. This includes: Developing a comprehensive tool usage guide for lecturers and students.
   - Preparing a research report that includes all research steps and results.
   - Promoting the research results through publication in educational scientific journals [20].

This development research method will enable the systematic and effective development of an Arduino-based water rocket launcher, which can enhance physics learning in educational environments. The research flow and component design of this tool is illustrated in the brief phase of fig. 6.

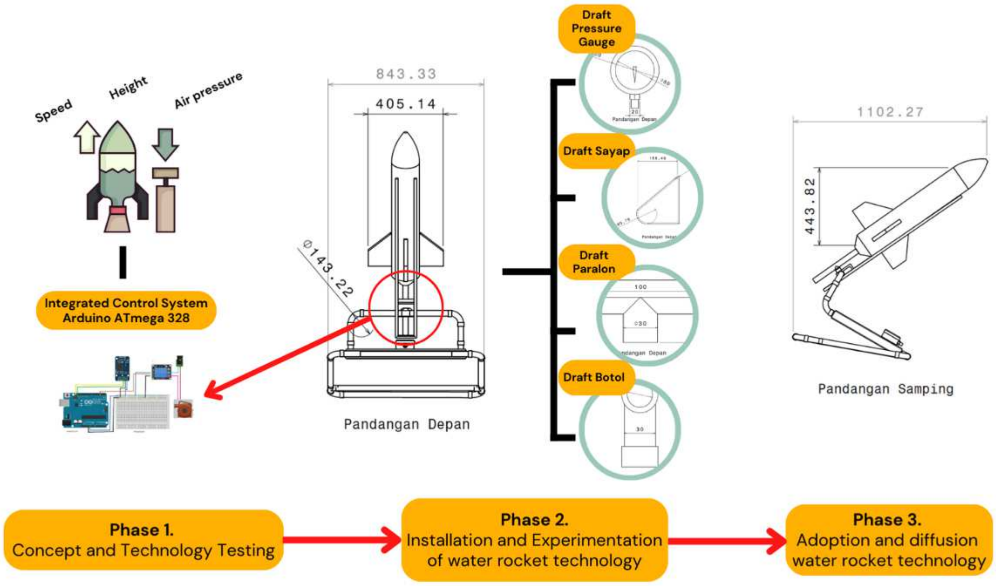


Fig. 6. Research flow and tool component design.

3.3. Metode Analisis

A suitable analysis method for the research "Development of an Arduino-based water rocket launcher in physics experiments" will include a number of important phases that allow evaluation and measurement of the effectiveness of the developed experimental tool. The following is Table 1 of analysis methods suitable for this topic:

Table 1. Analysis methods

No	Fase	Objective
1.	Hardware Design Analysis	First, an in-depth analysis of the hardware design of the Arduino-based water rocket launcher will be conducted. This includes examining the physical components, construction, and technical specifications of the device. The purpose of this analysis is to ensure that the design meets safety, efficiency, and reliability standards.
2.	Pengujian Kinerja Performance Testing	Experimental testing will be conducted to assess the performance of the device. This includes testing the launch of water rockets using the developed tool under various conditions. Parameters such as distance traveled, altitude, flight time, and measurement accuracy will be recorded and analyzed [21]

3.	Measurement of Physical Parameters	During the water rocket launch experiment, relevant physical parameters such as launch velocity, air pressure and altitude will be measured using sensors attached to the device. Analysis of these measurement data will help understand the relationship between these physical parameters.
4.	Subjective Data Collection	In addition to quantitative measurements, subjective data will be collected from the students involved in the experiment. This includes their insights into the use of the tool, their learning experience, and the extent to which the tool helps their understanding of the physics concepts being taught [22]
5.	Evaluation of Education	This research will analyze the impact of using this experimental tool in physics learning. This may include comparing students' understanding of physics concepts before and after the use of the tool, as well as evaluating how the tool can be used by lecturers in their teaching.
6.	Safety Analysis	The safe use of the tool will be a particular focus of analysis. This involves identifying potential risks or safety issues that could arise during tool use and efforts to mitigate those risks.
7.	Cost Analysis	The analysis method will also include the estimated costs of developing, producing and maintaining the experimental tool. This will help in evaluating the sustainability of using the tool in an educational context [23].

This method of analysis will provide a comprehensive understanding of the effectiveness and functionality of the Arduino-based water rocket launcher in physics experiments. The results of this analysis will help in the better development of the experimental tool as well as identify areas that can be improved for better learning purposes [24].

3.4. Indikator Capaian Penelitian

To measure the success of this research achievement indicators are summarized in Table 2 as follows:

No	Type of outcome	Planned title
1	International Journal Targets : Journal of Engineering Education Transformations (JEET) Q4 – Indexing Scopus	Development of an Arduino-Based Water Rocket Launcher in Physics Experiments.
2	Intellectual Property Rights (HKI)	The power point material contains the steps of a water rocket physics experiment.

BAB 4. HASIL DAN PEMBAHASAN

STEM which consists of Science, Technology, Engineering, and Mathematics (STEM) is a very important part of education in Indonesia. This research aims to develop an Arduino-based water rocket launcher in physics experiments. Through the integration of microcontroller technology such as Arduino in physics learning, students can understand physics concepts practically and interactively. Moreover, water rocket launching experiments are an effective method to teach various physics concepts, including Newton's laws of motion, the action-reaction principle, and air pressure.

As technology advances, the use of Arduino in the development of water rocket launchers has become increasingly popular. Arduino is an affordable and programmable hardware platform that can be used to control a wide variety of experimental tools, including water rocket launchers. With Arduino, teachers can program the device to measure physics parameters during the rocket launch, such as angular projection, velocity, altitude, and air pressure, so that students can see and analyze the experimental results directly.

Project-based physics learning allows students to research, plan, design and reflect on the creation of their technology projects. This type of learning not only stimulates student creativity but also requires different assessments. Projects will provide information about students' understanding and knowledge of the learning process, their ability to apply knowledge, and their ability to communicate information. Recent research in this field has shown that the use of Arduino-based water rocket launchers can improve students' understanding of physics concepts. In addition, the use of this technology also stimulates students' interest in science and technology. This is particularly relevant in the face of modern educational challenges where students often struggle to understand abstract physics concepts.

Therefore, the following is a complete formulation of the research problem: **"How to develop an effective and safe Arduino-based water rocket launcher for use in physics experiments, and how can this tool improve students' understanding of fundamental physics concepts?"** To answer this problem formulation, the research needs to consider the technical aspects of developing a water rocket launcher, including optimal hardware and software design. In addition, the research should also measure the impact of using this tool in improving students' understanding of physics through experiments. Other factors such as safety, reliability, and resource availability also need to be considered in the problem formulation.

This study uses the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) method. During the Analysis stage, an open interview was done to physics teachers to gather information about their insights in the water rocket activity. Consequently, this research was undertaken to create a an Arduino-based water rocket launcher so that teachers can focus more in the physical concepts rather than the launcher assembly itself. During the Design stage, the launcher underwent a 3D designing, and its parts were chosen to ensure the quality of the kit. Components were sourced from inexpensive and readily available materials to ensure it is affordable. Then in the Develop stage, a prototype of the kit was assembled and validated by experts in learning media experts [4]. This validation includes content and face validity of the kit. The validity is assessed with a 4-point Likert scale ranging from "totally disagree" to "totally agree". Content validity was determined using the content validity index (CVI), while face validity was determined based on expert consensus percentage.

During the Implement stage, the kit underwent a pilot test involving 30 Engineering Students in Trisakti University in Jakarta, Indonesia. Semi open-ended questionnaires were distributed to these participants to evaluate their perceptions of the kit. Lastly in the Evaluate stage, the questionnaires result from the pilot test is analyzed and any suggestions from the respondent was discussed to improve the kit in another development cycle.

Findings

Launcher Design

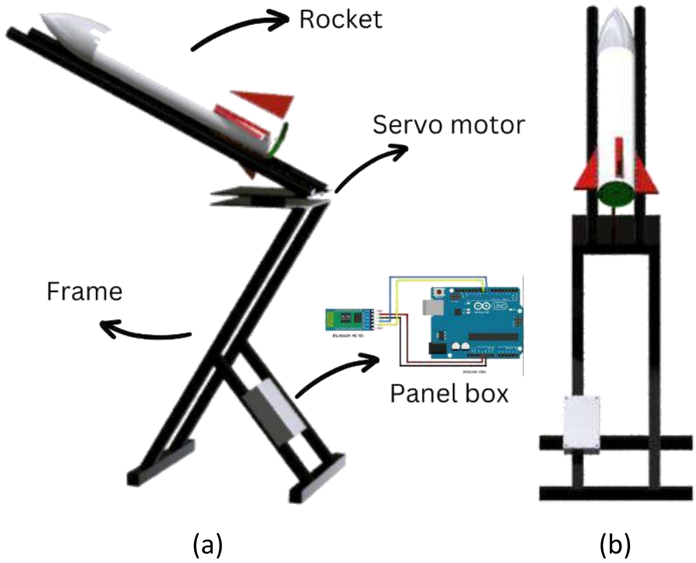


***Figure 7**. (a) Parts of Arduino-Based Water Rocket Launcher and (b) back view of the launcher.*

The components of the launcher are shown in Figure 1. The main raw material of the kit is hollow aluminium pipe and 3 mm iron plates. Hollow pipe was cut into several pieces, then iron plates were cut into 20 × 20 cm size. Researcher also welded the hollow pipes into L-shape. After that researcher drills some hole for motor servo installation later, then welded iron plates to the hollow pipes and installed ball bearings between the plates. After the frame is fixed, researcher installed servo motors and the Arduino. The installation documentation is shown in Figure 2.

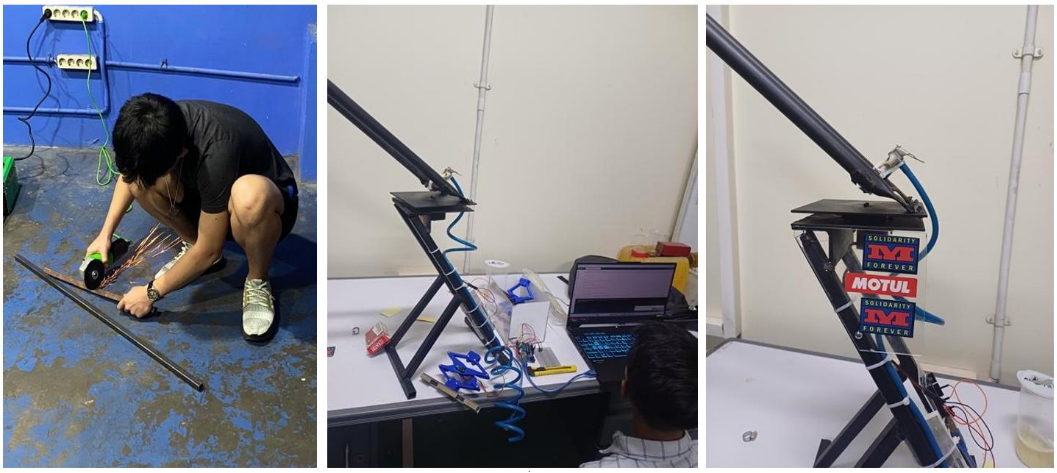
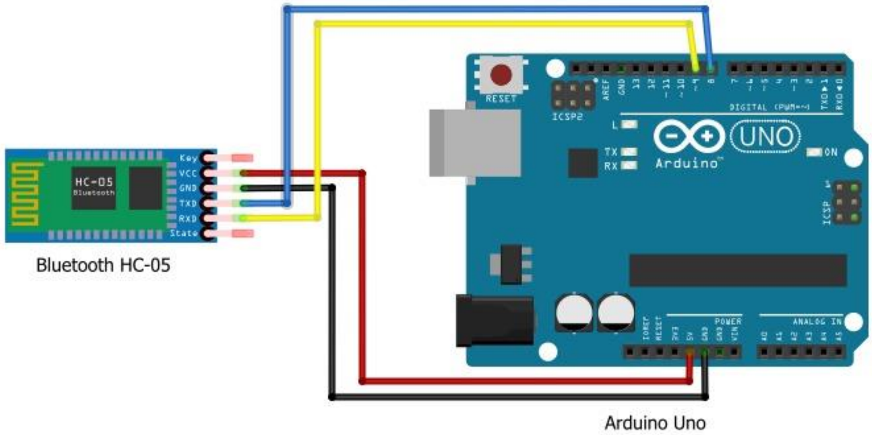


***Figure 8.** Frame assembly and installation*

Arduino Installation and Coding

The servo motor is controlled via Arduino Uno and Bluetooth module HC-05.



Researcher used Bluetooth HC-05 module, male to male cable, Arduino Uno, and a breadboard. The pins of HC-05 module are connected to the Arduino with the following configuration

- VCC : 5V
- GND : GND
- TXD :RXD
- RXD : TXD

Then, researcher installed Arduino IDE from https://www.arduino.cc/en/software, connected Arduino cable to a laptop, and run the software. The following code is written to control the servo motor.

```
#include <Servo.h>

Servo servoAxis1;  // Create servo object for first axis
Servo servoAxis2;  // Create servo object for second axis

int posAxis1 = 90;  // Initial value for first axis (90°)
int posAxis2 = 90;  // Initial value for second axis (90°)

char receivedChar;  // Variabel to receive data from Bluetooth

void setup() {
  servoAxis1.attach(9);  // Attach servo motor for first axis to pin no. 9
  servoAxis2.attach(10); // Attach servo motor for first axis to pin no. 10

  Serial.begin(9600);  // Initialize serial communication

  Serial.println("Kendalikan servo dengan tombol 'u', 'd', 'l', 'r' di ponsel
Anda melalui Bluetooth."); // Print servo motor instruction in Indonesian
}
```

```
void loop() {
  if (Serial.available() > 0) {
    receivedChar = Serial.read();

    if (receivedChar == 'u') {
      // Up botton pressed
      posAxis1 = 120;  // Adjust position increment as needed
    } else if (receivedChar == 'd') {
      // Down botton pressed
      posAxis1 = 60;  // Adjust position decrement as needed
    } else if (receivedChar == 'l') {
      // Left button pressed
      posAxis2 = 120;  // Adjust position increment as needed
    } else if (receivedChar == 'r') {
      // Right button pressed

    // Limit servo motor range
    posAxis1 = constrain(posAxis1, 0, 180);
    posAxis2 = constrain(posAxis2, 0, 180);

    // Adjust servo motor position
    servoAxis1.write(posAxis1);
    servoAxis2.write(posAxis2);
  }
}
```

After the code is installed, researcher connected their phones to HC-05 module via Bluetooth, and the Arduino can be controlled using Arduino Controller apps from Google Playstore.

Researchers use simplified approach to find theoretical value of launch data, given that the powered flight time is very short. Firstly, researchers calculate the mass flow rate, then calculate initial velocity of the rocket using the thrust and mass flow rate equations. Then, this initial velocity is used to analyse the unpowered ballistic flight using standard projectile motion equations.

Calculate Mass Flow Rate

The mass flow rate ($\dot{m}$) in a water rocket can be calculated using the discharge coefficient, the nozzle area, the density of water, and the pressure inside the bottle (Sutton & Biblarz, 2016). The formula is derived from fluid dynamics principles and is given by:

$$\dot{m} = C_d A\sqrt{2\rho P} \qquad (1)$$

where:

$\dot{m}$ is the mass flow rate (kg/s)
C_d is the discharge coefficient (average is 0.7)
A is the cross-sectional area of the nozzle (m^2)
ρ is the density of water (approximately 1000 kg/m^3)
P is the pressure inside the bottle (Pa)

Calculate Exhaust Velocity

The exhaust velocity of the water leaving the rocket nozzle can be approximated using Bernoulli's equation:

$$v_e = \sqrt{\frac{2(P_{in} \times P_{out})}{\rho}} \tag{2}$$

where:

P_{in} is the pressure inside the bottle
P_{out} is the pressure of air outside the bottle
ρ is the density of water.

Calculate Thrust

$$T = \dot{m} v_e \tag{3}$$

where:

$\dot{m}$ is the mass flow rate.
v_e is the exhaust velocity.

Calculate Initial Velocity

The initial velocity v_0 can be estimated using the thrust and the duration of the powered flight:

$$v_0 = \frac{T . t_{powered}}{m_i} \tag{4}$$

where:

T is the thrust.
$t_{powered}$ is the powered flight time
m_i is the initial mass of the rocket.

Calculate Maximum Height

We use the initial velocity v_i and launch angle θ in standard projectile motion equations (Serway & Jewett, 2014).

$$H_{max} = H_{powered} + \frac{v_0^2 \sin^2(\theta)}{2g} \tag{5}$$

Calculate Total Distance

$$D_{max} = D_{powered} + \frac{v_0^2 \sin(2\theta)}{g} \tag{6}$$

Given the short-powered flight time, the rocket's initial velocity and subsequent projectile motion can be approximated without detailed integration.

According to the mentioned equations, the theoretical value compared to the experimental value of maximum height and total distance are as following.

Table 3. Comparison between experimental and theoretical data

Number of fins	Launch Angle (º)	Experimental: Maximum height (m)	Experimental: Total distance (m)	Theoretical: Maximum height (m)	Theoretical: Total distance (m)
3	15	0.3	7.4	0.30	5.63
3	30	1.33	14.35	2.70	22.39
3	45	2.35	20.86	4.96	23.39
3	60	5.23	13.51	6.65	17.19
3	75	6.01	10.34	8.58	10.08
3	90	9.41	2.52	8.30	0.00
4	15	1.67	10.15	1.10	17.71
4	30	2.92	18.13	2.46	23.01
4	45	4.14	23.1	4.46	21.42
4	60	5.84	15.56	7.72	22.08
4	75	8.67	12.96	10.25	13.24
4	90	10.4	3.79	10.53	0.00

BAB 5. KESIMPULAN DAN SARAN

It is shown that the experimental data are different with theoretical data. These discrepancies could be caused by several factors. One of them is discharge coefficient. Researchers use the average value 0.7 due to the limitations of apparatus, while the actual number may vary from 3-fins rocket to 4-fins rockets. Another possible cause that causes the difference is the flaw in the rocket design itself, with flaws which make it not following projectile trajectory.

However, in this study the Arduino-based water rocket launcher was successfully developed with good functionality. Water rockets can be launched with automated launch angle due to Arduino programming, and the trajectory of the rocket itself does not veer too far from calculated trajectory.

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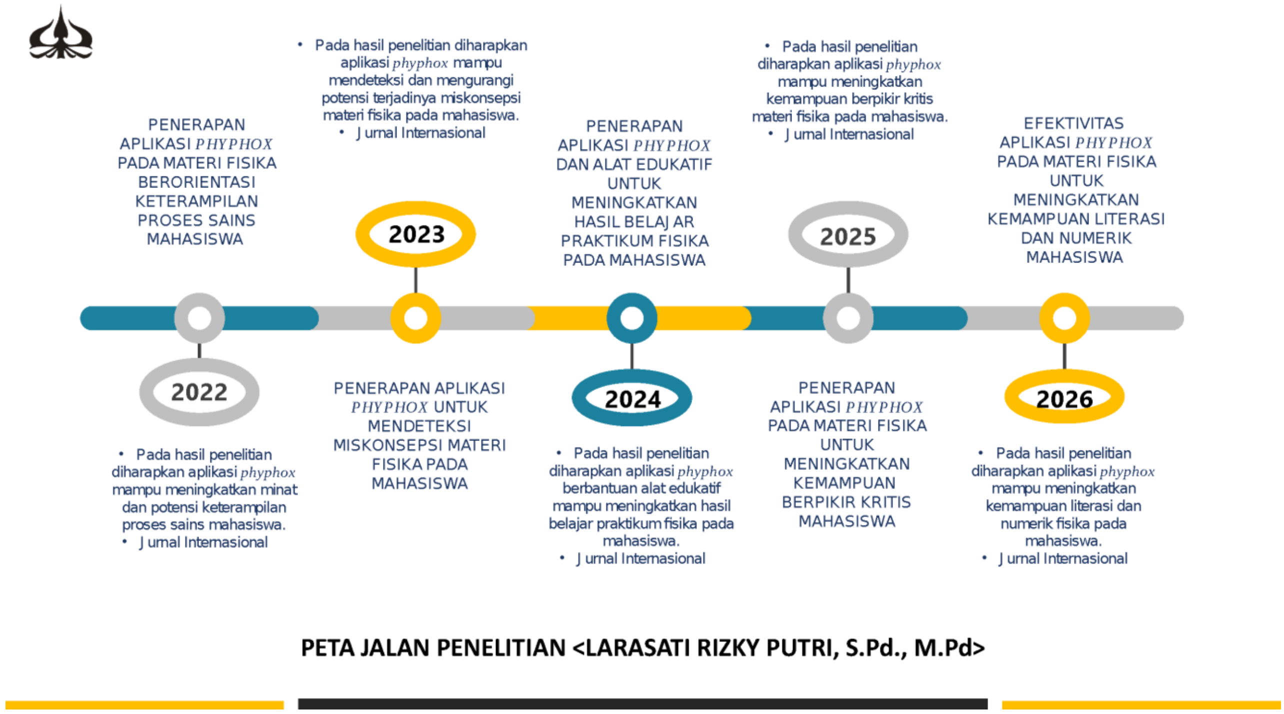
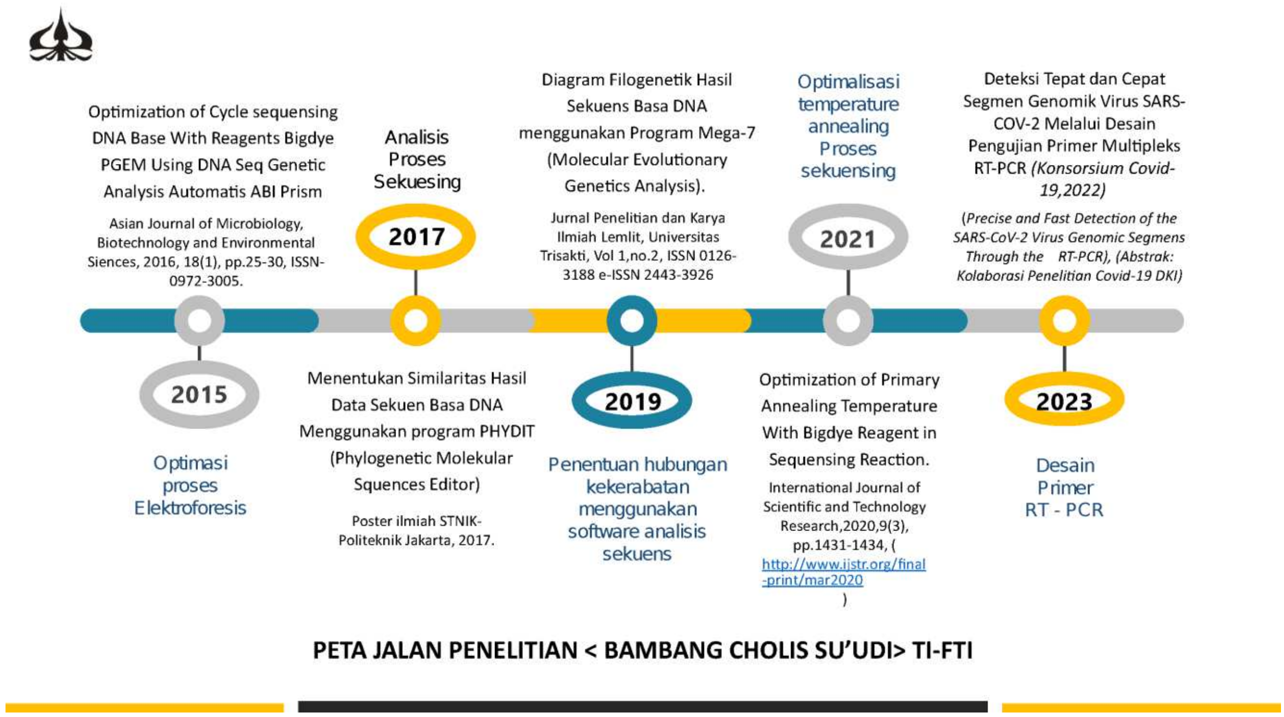
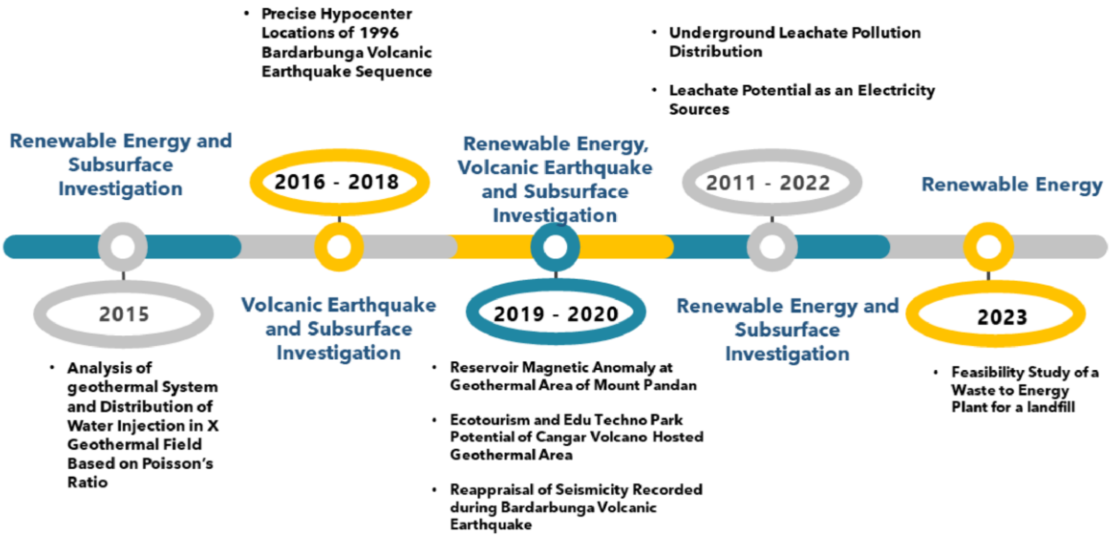
LAMPIRAN 1. ROAD MAP PENELITIAN





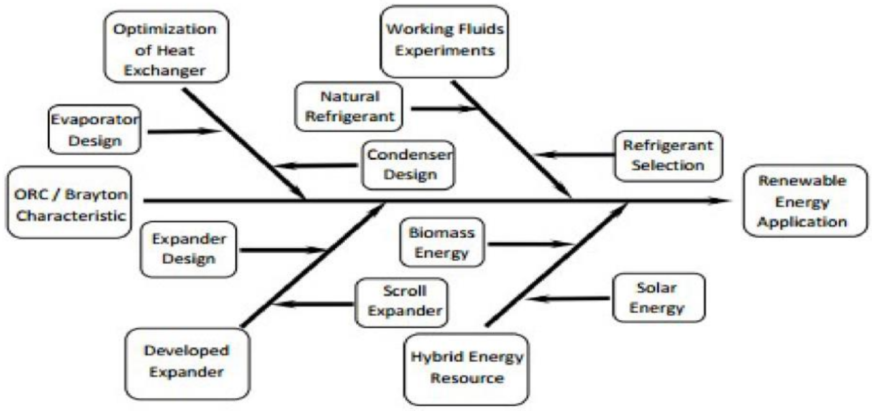


RESEARCH ROAD MAP IKA WAHYU UTAMI, S.SI., M.SC.

Road Map Penelitian

Dr. Sentot Novianto, A.Md., S.T., M.T.

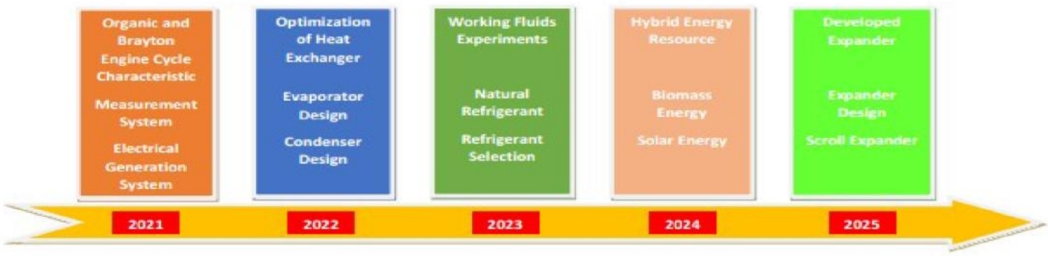
Penelitian Energi Terbarukan dengan Siklus Organic Rankine dan Brayton Engine Cycle



Gambar Fish Bone Energi Terbarukan Dengan Organic Rankine dan Brayton Cycle

Road Map Penelitian

Dr. Sentot Novianto, A.Md., S.T., M.T.



Peta Jalan penelitian Energi Terbarukan dengan *Organic Rankine* dan *Brayton Cycle*:

- *Set up Organic Rankine* dan *Brayton cycle* di laboraturium prestasi mesin Trisakti.
- Mengoptimasi *heat exchanger* dengan melakukan perancangan dan pembuatan *heat exchanger* yang lebih efisien dan efektif.
- Penelitian penggunaan *working fluids* dengan menginvestigasi *performance working fluids* terhadap kinerja sistem
- Penelitian pemanfaatan sumber energi, dari mulai penggunaan *heater* dalam skala lab, kemudian dilanjutkan dengan sumber energi matahari atau *biomass* serta *hybrid* (gabungan keduanya)
- Mengembangkan turbin (*expander*) dari model *scroll* hingga pengembangan *design expander* yang lebih tinggi efisiensinya

LAMPIRAN 2. LUARAN PENELITIAN

<u>LUARAN 1 :</u>
Kategori Luaran : Hak Kekayaan Intelektual
Status : Tercatat/Tersedia
Jenis HKI : Hak Cipta
Nama HKI : Modul Percobaan Fisika: Roket Air
No. Pendaftaran : EC00202481393
Tanggal Pendaftaran : 2024-05-03
No. Pencatatan : 000656737
Penulis (Tim Peneliti) :

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3. Dr. Sentot Novianto, A.Md., S.T., M.T.
4. Drs. Bambang Cholis Su'udi, M.Sc.
5. Jeevan Kristori

Penulis (Di Luar Tim Peneliti) :

1. Kiar Vansa Febrianti

<u>LUARAN 2 :</u>
Kategori Luaran : Publikasi di Conference Series Bereputasi
Status : Submitted
Tingkat Forum Ilmiah : Internasional
Nama Conference : Journal of Engineering Education Transformations (JEET)
Lembaga Penyelenggara : Rajarambapu Institute Of Technology
Tempat Penyelenggaraan : India
Tanggal Penyelenggaraan : 02/09/2024 - 28/09/2024
Lembaga Pengindek : https://www.scopus.com/sourceid/21100890669
Url Website Conference : https://journaleet.in/
Judul Artikel : Development of an Arduino-Based Water Rocket Launcher in Physics Experiment
Penulis (Tim Peneliti) :

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