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Designing Vertical Axis Wind Turbine Prototype as Future Renewable Energy Source in STEAM Learning

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Abstract **– Vertical Axis Wind Turbine (VAWT) is a wind power plant with many advantages, especially as a renewable energy source. Through the pocket of Science–Technology–Engineering–Art–Mathematics (STEAM) learning, this study designs a VAWT and explores the potential of this tool for learning. This study used a mixed-method embedded design with an experimental and interview type. The research results show that the influence of the number of blades and wind speed on voltage, current strength, and power is directly proportional. Therefore, VAWT can also be used as one of the projects for STEAM-based learning.**

Keywords **– Vertical Axis Wind Turbine, STEAM, Learning, Renewable Energy.**

1. Introduction

Renewable Energy (RE) is significant in realizing energy security and addressing Indonesia's future environmental problems. Data from the Ministry of Energy and Mineral Resources in 2021 shows that the total potential of RE in Indonesia is enormous, reaching 417.8 Gigawatts [1]. The government targets that by 2025 the achievement of RE in Indonesia will reach 23% [2],[3].

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However, in 2020, the RE sector was also aggravated by the Covid-19 pandemic [4]. In addition, the percentage increase in the number of RE in Indonesia has also not made significant progress. It is reflected in the magnitude of the potential of 417.8 GW, only realized by 10.4 GW [5], and the mix only reaches 17.3% of the 23% target [6]. Wind energy is one of the potentials of RE that can be maximized [7].

Indonesia has sufficient wind speed, and wind speed in Indonesia with an average range of 3 to 6 m/s. Higher speeds can be obtained in the Nusa Tenggara area, ranging from 3.5 to 6.5 m/s. While islands such as Sumatra, Java, Kalimantan, Sulawesi, and Papua only have wind speeds of around 2.7 to 4.5 m/s [8]. While turbines generally refer to designs from Europe and America, which are the most considerable wind-producing continents with a speed of about 9-12 m/s. The wind speed conditions, this between wind speed conditions shows that the utilization of wind energy is very potential to be developed.

One way to harness wind energy is through wind power generation. Generally, the widely used wind turbine form is a Horizontal Axis Wind Turbine (HAWT). However, a Vertical Axis Wind Turbine (VAWT) is an alternative to produce electrical energy due to several advantages. Sargolzaei [9] states that VAWT has a low rotating speed but a high torque. Meanwhile, VAWT has advantages such as a simple design, low tip speed ratio so that it is not damaged at high speeds, and wind turbine blades that have a vertical direction where the movement of the blade is parallel to the wind direction. So the turbine will be responsive to the wind direction and does not require a turbine-directional mechanism [10]. Islam et al. [11] also predict that in the next few years, VAWT technology will support low production costs; VAWT only requires space for non-spacious installations.

In addition to solving electrical energy needs, VAWT can also be used in learning STEAM (Science, Technology, Engineering, Arts, Mathematics). Students are oriented toward the problem of limited electrical energy, and then they will find a solution by utilizing VAWT based on aspects of potential and benefits. Some researchers confirm that STEAM-based learning can improve students' critical thinking skills [12], collaborative [13], and real-life problem-solving skills [14].

Therefore, this study aims to design a VAWT and investigate the influence of the number of propeller blades on the amount of electrical energy generated. This study also analyzed the potential of VAWT in STEAM learning. This research can contribute to finding out which VAWT is the most efficient in producing electrical energy as NRE, especially in Indonesia.

2. Method

This research is included in the mixed-method design [15]. There are six stages in this research, as shown in Figure 1. The stages are preliminary study, problem formulation, instrument design, data collecting, analysis, and conclusion.

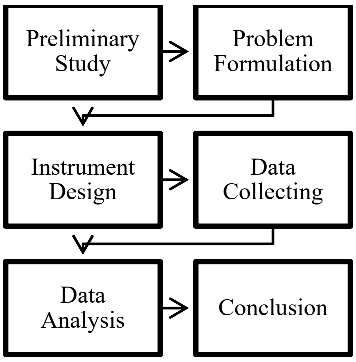


Figure 1. Research Stages

A preliminary study of expectations and reality is carried out at this stage so that a gap arises. Then, the problem is formulated based on the gap analysis to find a solution. Finally, at the instrument design phase, planning is carried out regarding the tools/VAWT to be made. The VAWT design was obtained from *Horizon Educational* (https://www.horizoneducational.com) and modified according to STEAM learning objectives. The design of the VAWT can be seen in Figure 2. After the design, the tool's construction with specifications can be seen in Table 1.

Table 1. VAWT tool specification

Component	Parameter
1 Base Body	153 mm x 107 mm
1 Wind Plate for Blades	Ø 120 mm
1 Upper Blade	120 mm
4 Blades	50 mm x 120 mm
2 Coil windings	Ø 40 mm
4 Magnets	25 mm x 40 mm x 10 mm
2 Bearings	Ø 5 mm
1 Aluminium Stator	
1 Aluminium Rotor	
2 Rubber Rings	
1 LED Base	107 mm x 85 mm
Voltage	2 V – 7 V
Current	0.09 – 0.45 mA

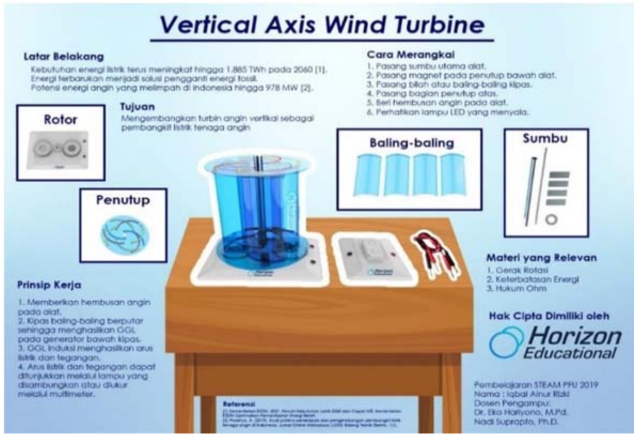


Figure 2. VAWT tool design

The stages of designing the manufacturing this tool are described as follows.

- Preparation Stage:

At this stage, preparation is carried out for the tools and constituent materials of VAWT: 4 neodymium magnets, 4 propellers, 1 LED base, Lower blade plate, upper blade plate, connecting cable, multimeter, 1 aluminum rotor and stator, blade plate lock, 1 coil winding base, fan.

- Assembly Stage:

1. Installing the rotor and stator as the central axis.
2. Installing a magnet on the lower blade plate.
3. Installing fan blades/propellers of varying numbers (2, 3, 4).
4. Installing the upper blade plate.
5. Connecting the connected wires to the multimeter.

Figure 3. VAWT tool construction

- Testing Stage:

1. Turn on the fan with low, medium, and high.
2. Measuring the wind speed magnitude using an anemometer (0.1 resolution, 0.1 thresholds, ±5% accuracy).
3. Observing the results of the voltage readings generated on the multimeter.
4. Record the data obtained.

After the VAWT design (Figure 3), the next stage is data collection. At this stage, experimental data collection is carried out through VAWT tool testing. The test was conducted at the Basic Physics Laboratory of *Universitas Negeri Surabaya* (State University of Surabaya) in May-June 2022. The experiments carried out refer to the following research variables:

- Manipulation Variable: Number of propeller blades and wind speed magnitude. The number of propellers on the VAWT will be manipulated by 2, 3, and 4. Meanwhile, the wind speed was varied as much as three times for the type of speed low, medium, and high.
- Response Variable: Electrical voltage and current. The mains voltage is generated from the tool and measured using a Multimeter.
- Control Variables: Type of power plant, room temperature, and distance between fan to VAWT. The type of power plant is VAWT and all its components. The measured air temperature during the trial was 25ºC Meanwhile, the distance between them are 30 cm.

On the other hand, qualitative data were collected using structured interview techniques on three physics education undergraduate students (IZ, HS, FN). These three interviewees were chosen with the consideration of the first researcher's close friends so they would be more open to answering questions. In addition, three of them had also seen firsthand when researchers designed and tested VAWT. Interviews were conducted to determine their perception of using VAWT in STEAM-based learning. At first, the interviewees were given videos about descriptions, tools and materials, design, and VAWT testing. Finally, interviewees were given three questions with indicators: potential if applied to students in learning, impact on students, and future expectations of the tool.

Data analysis uses quantitative and qualitative descriptive methods. Quantitative descriptive analysis is a statistical method that provides a description or picture of the research subject based on variable data obtained from a particular group of subjects [16]. In this case, the analyzed data is the influence of the number of blades on the voltage, current strength, and electrical power generated. After an analysis of the VAWT design trial, the next analysis regarding the data of the interview results uses a qualitative descriptive model, including analyzing, describing, and summarizing various situations and conditions from multiple collected data from the interviews' results [17].

3. VAWT Design Trial Results

The data from the VAWT design trial can be seen in Table 2. It can be seen that the number of blades 2 will produce a voltage of 14.21 V, the number of blades 3 produces a voltage of 15.71 V, and the number of blades 4 produces a voltage of 16.16 V. Graph of the influence of the number of blades on the voltage can be seen in Figure 4.

Table 2. VAWT design trial results for blades number

Blade Number	Voltage (V)	Current (mA)	Power (mW)
2	14.21	0.66	9.37
3	15.71	0.83	13.03
4	16.16	0.85	13.73

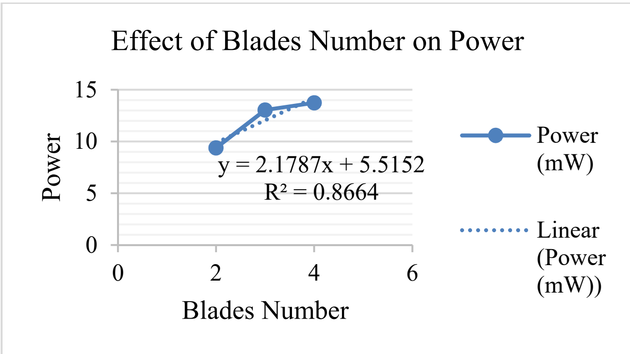


Figure 4. Graph of the effect of the number of blades on electrical power output

The influence of the blades on the voltage and current is directly proportional. The greater the number of blades used, the greater the voltage and current generated. The more blades will cause the surface area exposed to the wind push to be more so that the fan will rotate faster. Consistent with research by Wenehenubun *et al.* [18], which states that VAWT with four rotor turbines has the highest torque. As a result, the fan spins faster and produces a higher voltage.

Meanwhile, the strength of the current flowing at the resistor does not show a significant difference. The current strength is influenced by the load used, which is used as a control variable. The consequence is that the strong current does not change because the resistor is also not changed. In addition, the substantial value of the rated current is minimal because the resistor has a high resistance.

The number of blades on electrical power is also directly proportional linearly with line equations y = 2.1787x + 5.5152. The greater the number of blades, the greater the electrical power generated. It corresponds to the equation P = V.I, which shows that power is the product of the multiplication between voltage and current strength. The voltage measurement shows that it is directly proportional, so the amount of electrical power will also be directly proportional. The number of blades produces the highest amount of electrical power 13.73 mW.

Data on the test results of the influence of wind speed on voltage, current strength, and electrical power can be seen in Table 3. It can be seen that the relationship between wind speed and voltage is directly proportional. The greater the wind speed, the higher the voltage will be. This is also applied to the strength of the current, which is also directly proportional.

Table 3. VAWT design trial results for wind speed

Wind Type	Wind Speed (m/s)	Voltage (V)	Current (mA)	Power (mW)
Low	2.40	5.37	0.35	1.88
Medium	3.60	8.23	0.70	5.76
High	5.00	10.45	0.92	9.61

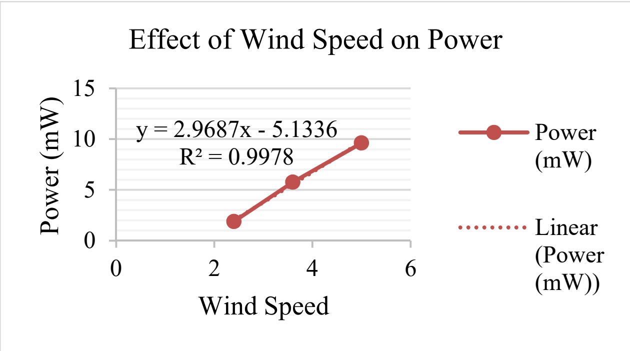


Figure 5. Graph of the effect of wind speed on electrical power output

Figure 5 shows a graph of the effect of wind speed on electrical power. It can be seen that the wind speed is directly proportional to the electrical power linearly with line equations y = 2.9687x – 5.1336. Research by Korprasertsak & Leephakpreeda [19] and Pourrajabian *et al.* [20] corroborates this finding where the greater the wind speed, the angular speed and torque of the turbine will be greater so that the output electrical power is also greater so that it has enough force to rotate the axis of the generator to increase the value of the mains voltage generated. This finding is consistent with research by Naseem et al. [21] which shows that the greater the wind speed, the greater the electrical power both computationally and experimentally.

4. VAWT in STEAM Learning

The VAWT provides an activity that allows the students to experience and sense the STEAM education in physics learning. Through some STEAM' activities, students got the meaning of being a STEAM member. "By implementing the learning model of guided inquiry, the students understood the essence of STEAM, the interconnection among science in energy, math in efficiency, technology, and engineering in tool construction" [14]. The guided inquiry was chosen as a learning model because of senior high students' educational level, with the main character being the transition from concrete to abstract thinking.

Furthermore, the results of the interviews of three interviewees are explained as follows. The first question is about the potential application of VAWT in STEAM-based physics learning. This question aims to provide a response of pre-service physics teachers to the potential of the tool if applied in learning.

"*VAWT can be applied in STEAM-based physics learning, but with a note, students must know the physics concepts presented in the tool, such as the process of converting energy from mechanical to electrical or the comparison of electrical efficiency.*" – HV

"*I think VAWT is very good if applied in physics learning because it contains specific and clear physics content. In addition, VAWT can also have a positive influence because its working principles can be seen directly by students*" – IZ

"*VAWT has the potential to be applied in physics learning because it is highly relevant to 21st-century skills and makes students understand the importance of renewable energy to the earth.*" – FN

It can be seen that general thinking of VAWT tools is excellent if implemented in physics learning because this tool can include physics content. If explored further, the physics content that can be studied through VAWT is the angular velocity, classical mechanics, efficiency, energy, Ohm's law, electrical power, and rotational mechanics. Consistent with [22], [23] research that develops STEAM-based learning relevant to physics. The main goal of this context-based STEM Education Learning activity is to apply physics and other disciplines to design, create, or make something related to solving energy problems using renewable energy.

The second question is about the effect of applying VAWT on students in general. Here is their answer.

"*I think VAWT can provide innovation in physics learning.*" – HV

"*I am very sure because the application of VAWT can provide novelty in learning and improve skills, motivation, and understanding of the concept.*" – IZ

"*Of course, I believe because this tool already encompasses Science, Technology, Engineering, Arts, and Math in an integrated manner so that it has a good effect on students.*" – FN

According to HV and IZ, the application of VAWT is innovative and novelty in learning, especially in physics. This can increase the potential for VAWT implementation in STEAM learning because it positively influences students, ranging from motivation, understanding, and skills. STEAM-based learning is also supported by constructivism learning theory that the learning process begins with cognitive conflicts. Finally, students build knowledge through experience and interaction with the surrounding environment. In addition, some empirical studies also state that STEAM learning can improve students' critical thinking skills [12], collaborative [13], real-life problem-solving skills [14], and learning motivation [24].

Table 4. STEAM Aspects in VAWT

STEAM Aspects	Description
Science	Covers the scientific concepts of physics: energy, electricity, and mechanics
Technology	Generator technology, electromagnetic induction, converts the wind's kinetic energy into electricity.
Engineering	Designing the kit so that it can be used to convert wind kinetic energy into electricity.
Arts	Aesthetic value on tools that have been constructed.
Mathematics	Calculation of the amount of electrical energy produced, and the influence of the number of fan blades on electrical energy.

Meanwhile, FN revealed that VAWT already covers each aspect of STEAM. Therefore, researchers tried deciphering each aspect of STEAM on VAWT as in Table 4. In the Science aspect, VAWT can explain many physics concepts accordingly in the first question. In the Technology aspect, VAWT is equipped with generators and electromagnetics so that later students can explain how the energy conversion process occurs. In the Engineering aspect, students are required to design this fan starting from a separate component to ready for testing. In the Arts aspect, students must design the tool so that it has aesthetic value and is comfortable to look at but does not reduce its function. Finally, in the mathematics aspect, students can analyze predetermined variables regarding the number of blades, electrical power, and voltage.

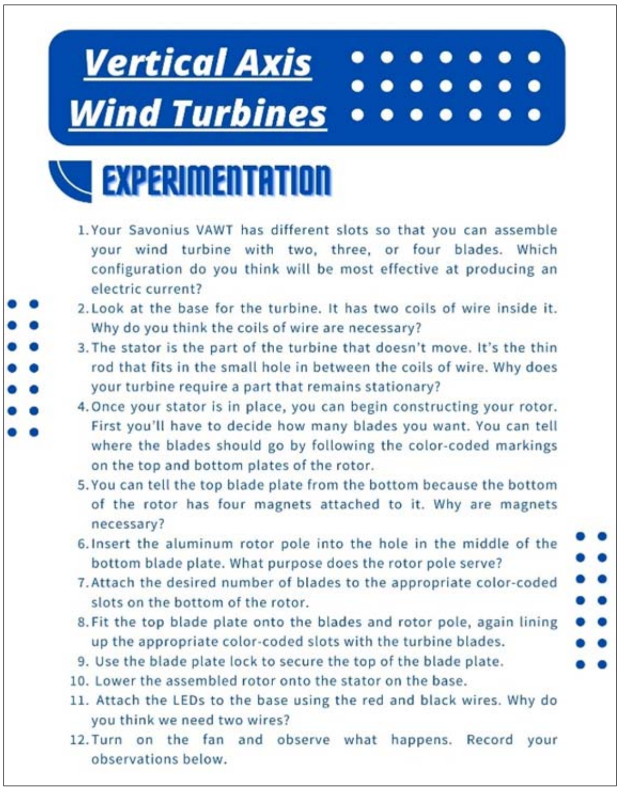
The last question is about future expectations about VAWT in STEAM learning. Here are their answers.

"*I hope VAWT can be implemented as a renewable energy power plant in remote areas. In physics learning, this tool is also expected to have a positive influence in academic terms.*" – HV

"*The hope is that if this tool is indeed applied, it should be equipped with a worksheet that contains mini-research by students.*" – IZ

"*Because physics is one of the difficult subjects and tends to be abstract, this tool physics learning course will become more motivating according to the worksheet and can achieve learning objectives*" – FN

It can be seen that HV hopes that this STEAM project, in addition to being applied in learning, is also applied directly to overcome energy problems, especially those that occur in remote areas with the use of its independent power generation system [25]. Meanwhile, IZ and FN argue that there is a need for a worksheet that can direct students to do mini-research on VAWT. An example worksheet containing the procedure can be seen in Figure 6 and a worksheet containing an experimental data table in Figure 7.

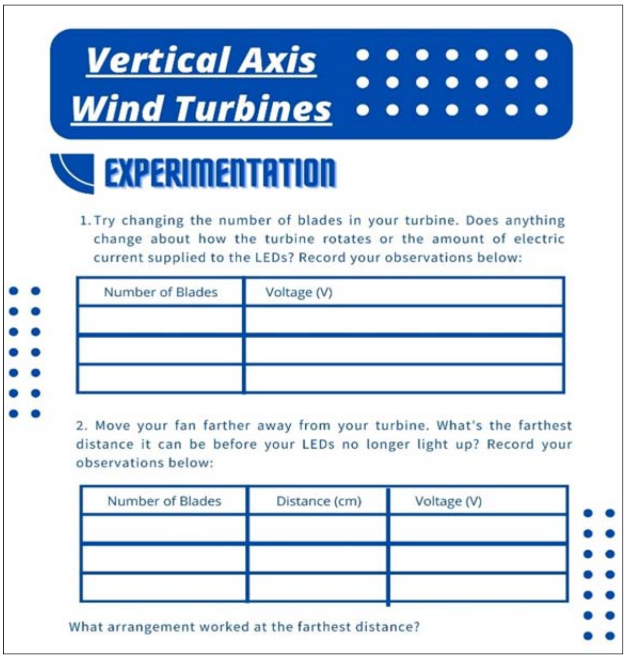

Vertical Axis Wind Turbines

EXPERIMENTATION

1. Your Savonius VAWT has different slots so that you can assemble your wind turbine with two, three, or four blades. Which configuration do you think will be most effective at producing an electric current?
2. Look at the base for the turbine. It has two coils of wire inside it. Why do you think the coils of wire are necessary?
3. The stator is the part of the turbine that doesn't move. It's the thin rod that fits in the small hole in between the coils of wire. Why does your turbine require a part that remains stationary?
4. Once your stator is in place, you can begin constructing your rotor. First you'll have to decide how many blades you want. You can tell where the blades should go by following the color-coded markings on the top and bottom plates of the rotor.
5. You can tell the top blade plate from the bottom because the bottom of the rotor has four magnets attached to it. Why are magnets necessary?
6. Insert the aluminum rotor pole into the hole in the middle of the bottom blade plate. What purpose does the rotor pole serve?
7. Attach the desired number of blades to the appropriate color-coded slots on the bottom of the rotor.
8. Fit the top blade plate onto the blades and rotor pole, again lining up the appropriate color-coded slots with the turbine blades.
9. Use the blade plate lock to secure the top of the blade plate.
10. Lower the assembled rotor onto the stator on the base.
11. Attach the LEDs to the base using the red and black wires. Why do you think we need two wires?
12. Turn on the fan and observe what happens. Record your observations below.

Figure 6. Sample of procedure in a VAWT experiment in the student worksheet (Adopted from Horizon Educational)

Some of the student activities that can be done on VAWT STEAM learning are investigating the most efficient number of fan blades, explaining the role of coils on the base, investigating the fan's speed and/or distance to the most efficient turbine, and the function of the rotor and stator. This student activity has an essential role in making it easier for students to learn and maximize aspects of STEAM and achieve learning goals [26], [27].



Vertical Axis Wind Turbines

EXPERIMENTATION

1. Try changing the number of blades in your turbine. Does anything change about how the turbine rotates or the amount of electric current supplied to the LEDs? Record your observations below:

Number of Blades	Voltage (V)

2. Move your fan farther away from your turbine. What's the farthest distance it can be before your LEDs no longer light up? Record your observations below:

Number of Blades	Distance (cm)	Voltage (V)

What arrangement worked at the farthest distance?

Figure 7. Sample of a data table in a VAWT experiment in the student worksheet (Adopted from Horizon Educational)

5. Conclusion

VAWT is one of the prototypes in STEAM learning. It is a wind power plant that can be one of the solutions to overcome energy limitations. The influence of the number of blades on voltage, current strength, and power is directly proportional. In addition, the effect of wind speed on electrical power is also directly proportional. The highest electrical power generated is 11.31 mW with four blades. In addition, VAWT can also be used as one of the projects for STEAM-based learning because it has fulfilled every aspect of STEAM. This research implies that it can be an alternative solution to STEAM learning in high school as well as a future renewable energy source.

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