Application of GNU Octave in Simulating Dynamic Electrical Physics Concepts on BLDC Electric Motor Trainer Kits

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Abstract: The study of dynamic electrical physics among first-semester students is often unpopular because it is considered abstract and difficult to relate to real-world applications. To foster a positive attitude and interest in the subject matter, contextual and technology-based learning strategies are needed. This study aims to apply a simulation of a BLDC electric motor using the open-source software GNU Octave in the context of electric vehicles, as well as to describe students' affective responses after participating in the learning activity. The study employs a quantitative descriptive approach with participants being students from the Physics Education and Vocational Mechanical Engineering Education programs. The simulation was developed based on the mathematical model of the BLDC electric motor and visualized using numerical methods in GNU Octave. After participating in the simulation-based learning activity, students were asked to complete a questionnaire measuring affective aspects such as interest, motivation, and attitude toward physics learning based on applications. The questionnaire results indicated that the majority of students responded positively to the use of simulations. The research results indicate that over 90% of students demonstrated interest, motivation, and positive attitudes toward simulation-based physics learning on electric motors. Students also evaluated GNU Octave as an attractive, free, and relevant tool for learning needs in the digital age. Thus, the application of GNU Octave as a simulation medium not only supports conceptual understanding indirectly but is also effective in fostering students' affective aspects toward physics and electric vehicle technology learning.

Keywords: BLDC Electric Motor; Dynamic electrical; GNU Octave; Simulation.

Introduction

Technological developments in the world of transportation today show a growing trend toward the use of electric vehicles as an alternative to fossil fuel-powered vehicles. Electric vehicles such as electric motorcycles are considered capable of reducing dependence on fossil fuels and reducing carbon emissions, which are the largest contributor to global warming (Hutasoit, 2017). This is in line with global efforts to reduce carbon emissions and create more environmentally friendly technologies (Adittya, 2024). In the midst of this phenomenon, it is important for the world of education, particularly higher education in the fields of teacher training and physics, to prepare students not only in terms of understanding basic concepts but also in terms of attitude, interest, and motivation to study physics that is relevant to the times.

One essential yet often challenging concept for students is dynamic electricity, particularly as it relates to the operation of BLDC (brushless DC) motors, which are a key component in electric vehicle propulsion

systems. Dynamic electricity is typically taught conventionally through theoretical approaches, mathematical formulas, and verbal explanations that lack visual representations of the actual dynamic processes (Ni'mah & Widodo, 2022; Rizaldi et al., 2020). As a result, many students, especially in their early semesters, find it difficult to understand the relevance and practical application of these concepts. This often leads to low affective aspects of students' learning of physics, such as low interest, motivation, and positive attitudes toward the material and learning process.

This situation calls for innovative approaches to teaching that can bridge the gap between abstract physics concepts and their real-world applications. One promising approach is the use of open-source software-based simulations, such as GNU Octave, which offers numerical and visualization capabilities comparable to MATLAB but is freely accessible to students (Purnama et al., 2021). GNU Octave enables the visualization of dynamic processes in physical systems through programming, allowing students to not only memorize concepts but also directly observe how a physical system, such as a BLDC motor, operates based on the physical laws they have learned.

In the context of physics education, the use of GNU Octave-based simulations can serve as an innovative tool that not only stimulates students' cognitive abilities but also enhances affective aspects, such as interest in learning, motivation to study, and a positive attitude toward the application of physics in real-life situations (Astuti, 2021; Lusiana & Setyansah, 2020; Salwa Hidayatullaily et al., 2022). This is particularly important for first-year students who are establishing their scientific attitudes and perceptions of physics courses and their relevance in the modern era.

Previous research has shown that the use of simulations in science education has a significant impact on student engagement and improves their perception of the importance of physics in everyday life (Ika et al., 2025). In addition, the numerical modeling-based approach provides a more interactive and meaningful learning experience, as students can change parameters, run simulations, and see changes in the system directly. This can encourage students to be more active and think critically, while building connections between theory and practice.

Based on this background, this study was conducted to apply GNU Octave-based simulations in teaching dynamic electrical concepts in BLDC motor systems, which are directly related to electric vehicle technology. This study specifically aims to describe the affective responses of second-semester physics education students, including their interest, motivation, and attitudes after participating in learning using these simulations. By understanding how simulations can influence students' affective aspects, it is hoped that this approach can be adopted as part of a more contextual and relevant physics learning strategy in line with contemporary needs.

Method

This study is a quantitative descriptive study that aims to describe the affective aspects of students after participating in dynamic electricity learning using GNU Octave simulation. The affective aspects measured include learning interest, motivation, and attitudes toward simulation-based physics learning. The subjects of this study were students from the Physics Education Program and the Vocational Education Program in Mechanical Engineering at Universitas Sarjanawiyata Tamansiswa. A total of 54 students participated in the study, all of whom were active students. The learning was conducted in the form of simulation-based activities using GNU Octave, as shown in Figure 1.
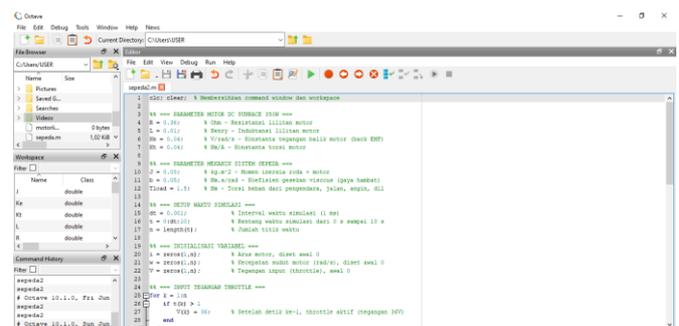

Figure 1. GNU Octave BLDC Motor Simulation Program Display

Table 1. Student Affective Questionnaire

Statement Affective Aspect	Statement	Affective Aspect
I became interested in studying dynamic electricity after seeing the simulation.		Interest
Learning with GNU Octave made me more enthusiastic about studying.		Motivation
The DC motor simulation helped me imagine the application of physics in the real world.		Attitude toward learning
I want to try creating my own physics simulations in GNU Octave.		Interest
I feel more motivated to study physics because the material feels real.		Motivation
Simulative learning like this makes physics more enjoyable.		Attitude toward learning

Statement Affective Aspect	Statement	Affective Aspect
I understand the benefits of learning dynamic electricity for the future.		Attitude toward learning
GNU Octave is an interesting tool for physics learning.		Attitude toward learning
I feel more engaged during learning using simulations.		Motivation
I hope more courses adopt a simulation-based approach.		Attitude toward learning

Students are encouraged to understand the basic concepts of BLDC motors as an application of dynamic electricity, then run BLDC motor simulation scripts using GNU Octave. Activities include an introduction to dynamic electricity and BLDC motors, a demonstration of how to use GNU Octave, practice running simulations and interpreting the results of voltage, current, and motor speed graphs, joint reflection, and discussion to reinforce concepts.

The primary instrument used in this study was a student affective aspect questionnaire, designed in the form of a 4-point Likert scale. The questionnaire consists of 10 statements covering three main indicators: learning interest, learning motivation, and attitude toward application-based learning, as shown in Table 1.

The questionnaire was validated by two expert lecturers to ensure the clarity and readability of the items. Data was collected through an online questionnaire after the simulation-based learning activity was completed.

Result and Discussion

Research related to simulation-based learning approaches using GNU Octave examines students' affective responses, including their interest, motivation, and attitudes during the learning process. These three aspects are crucial in understanding how students perceive, respond to, and emotionally engage with innovative learning methods. Therefore, a questionnaire was designed to explore these affective dimensions through validated statements based on the Likert scale.

The interest aspect refers to the extent to which students feel interested and motivated to explore dynamic electricity material through the use of GNU Octave simulations. This aspect reflects students' initial attraction and curiosity toward the material presented visually and interactively. Furthermore, the motivation aspect focuses on students' internal drive to continue learning, try things out for themselves, and explore the application of physics concepts through simulation technology. Meanwhile, the attitude aspect describes students' general views on the use of GNU Octave as a learning medium, including the extent to which they accept and appreciate this method as part of the educational process. Research related to physics learning simulation programming has also been conducted by Riskawati (2025). The study shows that

the use of simulation in learning not only aids cognitive understanding but also promotes affective aspects.

The data presented in the following tables is a summary of students' responses to statements representing these three aspects. Analysis of this data provides deep insights into how simulation-based approaches can influence students' emotional engagement and perceptions of physics learning. These results also form the basis for recommending the integration of similar methods into science and engineering curricula.
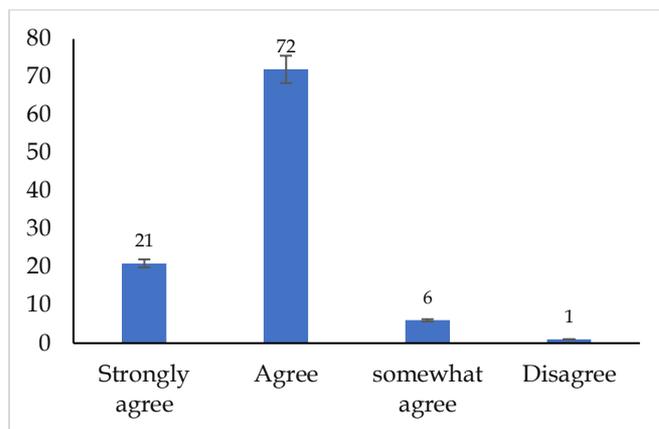

Figure 2. Student Interest in the Application of GNU Octave on BLDC Motors

The application of GNU Octave software in the simulation-based learning of brushless DC (BLDC) motors has had a significant impact on students' interest in understanding applied physics concepts (Chasiotis & Karnavas, 2018; Kardile, 2023). This is clearly reflected in the percentage distribution graph illustrating students' responses to this approach. The graph shows that the majority of students demonstrate high enthusiasm for simulation-based learning using GNU Octave, 72% of students stated "Agree," indicating they felt the tangible benefits of applying BLDC motor simulation using GNU Octave. Additionally, 21% of students even stated "Strongly Agree," indicating that nearly all respondents (93% in total) have a positive perception. This figure suggests that the visual, numerical, and interactive approach offered by GNU Octave can enhance students' interest and engagement in the learning process (Krishnamoorthy, 2025).

Conversely, only a small portion of students provided less supportive responses to this method. Six percent of students stated "Somewhat Disagree," and

only 1% stated "Disagree." These values are relatively very small and can be interpreted as individual barriers or technical discomfort, such as difficulty operating the software, rather than rejection of the learning approach itself. The dominance of positive responses confirms that the integration of simulation-based technology can be a solution in addressing abstract learning challenges such as dynamic electrical concepts (Hazizi et al., 2025; Saiteja et al., 2024).
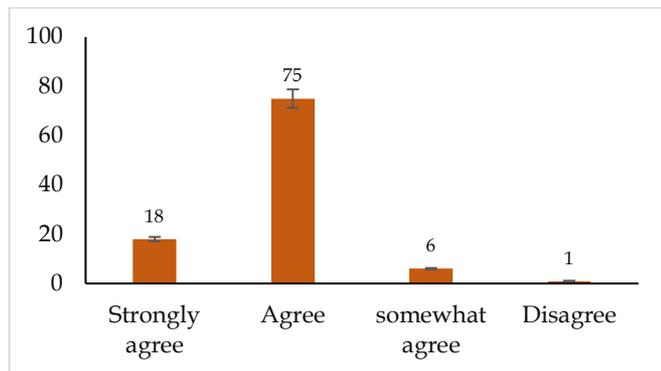

Figure 3. Student Motivation for the Application of GNU Octave in BLDC Motors

The graph shows the level of student motivation in participating in simulation-based learning using GNU Octave, specifically in the context of brushless DC (BLDC) motor material in applied physics learning (Khan et al., 2020). Motivation is an important aspect of the affective domain that determines the extent to which students are internally driven to understand the material and actively engage in the learning process. Therefore, this data is a crucial indicator of the effectiveness of the learning approach applied.

Based on the graph, it appears that the majority of students (75%) responded "Agree" to the use of GNU Octave as a learning medium. This indicates that they feel more motivated to learn when physics material is presented through simulations that can be visualized directly. Additionally, 18% of respondents stated "Strongly Agree," reinforcing that some students experienced a significant increase in motivation due to this interactive approach. Overall, 93% of students demonstrated positive motivation, reflecting the success of the learning strategy in enhancing their learning drive.

On the other hand, 6% of students stated "Somewhat Disagree" and only 1% "Disagree." These numbers are relatively small and insignificant compared to the majority of positive responses. However, this data still needs to be considered as an indication of minor obstacles, such as technical difficulties in using the software, lack of experience in running simulations, or personal preferences for different learning styles.

The Figure 4 presents data on students' attitudes toward the use of GNU Octave in learning about brushless DC (BLDC) motors. The aspects of attitude referred to in this context include students' acceptance, assessment, and general views of simulation-based learning methods using this open-source software. Attitude is an important element of the affective domain as it reflects an individual's emotional and cognitive readiness to respond to the learning approach used by lecturers or institutions.
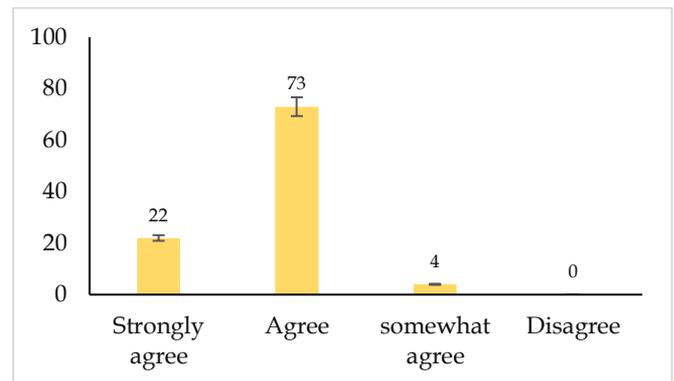

Figure 4. Students' Attitudes Towards the Application of GNU Octave on BLDC Motors

Based on the graph, it can be seen that most students gave positive responses, with 73% of respondents stating "Agree" and 22% stating "Strongly Agree" regarding the application of GNU Octave in the learning process. Combining these two categories accounts for 95% of total responses, indicating that the majority of students not only accept but also highly value this simulation-based approach. This suggests that they not only feel comfortable but also view GNU Octave as a beneficial, appropriate, and relevant learning tool for understanding applied physics concepts in a more concrete and practical manner.

Meanwhile, only 4% of students stated "Somewhat Disagree," and no respondents stated "Disagree." This very small percentage reflects that resistance to the use of GNU Octave is very low or even non-existent. It is possible that students who disagree have individual barriers such as being unfamiliar with the programming environment or preferring conventional narrative and text-based methods.

GNU Octave itself is open-source software that has the ability to visualize and process mathematical and physical data numerically. In the context of BLDC motors, simulations can help students visualize how current, voltage, and magnetic force work simultaneously. This is in line with the contextual learning approach, which aims to bring physics theory closer to real-world phenomena. When students can see the real-world connection between concepts and

applications, their motivation and interest in learning significantly increase.

From these findings, it can be concluded that GNU Octave makes a significant contribution to enhancing students' interest in learning, particularly in applied physics fields such as BLDC motors. Simulation-based learning approaches not only strengthen conceptual understanding but also enhance active participation and intrinsic motivation among students. Therefore, this approach is highly worthy of broader adoption in similar courses or other engineering fields that require an understanding of dynamic systems.
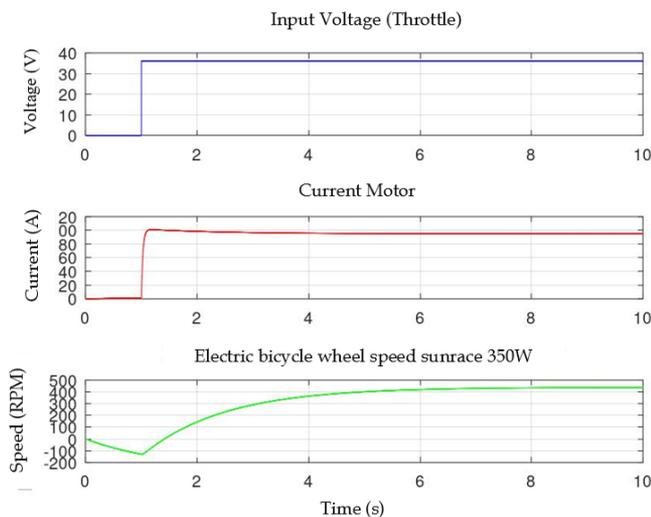

Figure 5. Simulation of Sunrace 350 Watt DC Electric Motor with GNU Octave

Figure 5 shows the simulation results of the Sunrace 350 Watt BLDC electric motor using GNU Octave. The simulation produced three main graphs, each representing the relationship between time and the relevant physical quantities in DC motor performance: input voltage, motor current, and wheel speed (RPM). Each graph illustrates the dynamic process that occurs when the motor starts operating until it reaches a steady state. The first graph shows the input voltage (throttle) over time. The voltage supplied to the motor is assumed to come from a 36-volt electric motor battery. At the start (0–1 seconds), the voltage is still 0 V because the motor has not been turned on. After 1 second, the voltage is immediately increased to 36 V and maintained constant until the end of the simulation time. This graph illustrates the real-world situation when the user begins to fully turn the electric motor throttle. This sudden voltage spike is intended to trigger current into the motor armature and generate initial torque.

The second graph illustrates the motor current response over time. When the voltage is suddenly applied at the 1-second mark, the current immediately spikes sharply. This is a characteristic of DC motors, where inrush current occurs due to the armature's inductance and the initial imbalance between voltage and electromagnetic back EMF. A high initial current is required to overcome the inertia moment and start the wheel rotation. However, after a few seconds, the current begins to decrease and reaches a stable condition around 110 amperes. This decrease in current indicates that the motor load has started to move and the required torque is lower than when it is stationary. This condition reflects that the DC motor system has reached a balance between the electromotive force and the shaft speed.

The third graph shows the wheel speed response in RPM (rotations per minute). Initially, the wheel speed is zero because the motor has not yet received a voltage supply. However, as soon as the voltage is applied at 1 second, the wheel begins to rotate, marked by an exponential increase in RPM. The speed increases gradually because the torque from the motor begins to move the system load (wheel), which has inertia. After a few seconds, the speed reaches a value close to 520 RPM and remains stable, indicating that the motor has reached a steady state, i.e., when the speed is constant and the torque is sufficient to overcome the load and friction forces.

These three graphs provide a highly informative representation of the dynamics of a DC motor in light electric vehicles such as electric motorcycles. The relationship between voltage, current, and speed can be observed directly and simultaneously, showing how the electro-mechanical system responds to user input (throttle). With this visualization, physics education students can better understand that a DC motor is not merely an electric device that rotates but a complex system involving the interaction of electrical laws (Ohm's law, electromagnetic induction), rotational mechanics, and control systems.

In an educational context, this simulation can also be used to develop students' affective aspects, such as interest in the application of physics in the real world and awareness of the importance of environmentally friendly technology (Hariyanto et al., 2024). By linking this simulation to the topic of electric vehicles, students not only understand the theory but are also inspired to explore sustainable technology. Simulations based on GNU Octave or MATLAB provide students with the opportunity for experiential learning, testing various parameters, and analyzing the effects of parameter changes on system behavior directly (Bali & Mughal, 2025; Lotfi et al., 2021). The simulation code is shown in Figure 6.

This simulation begins by clearing the GNU Octave work environment using the clc; clear command. The purpose is to ensure that no old data or output interferes with the new simulation process. After that, the

important parameters of the Sunrace 350W DC motor are determined, such as resistance (R), inductance (L), back-EMF constant (Ke), and motor torque constant (Kt) (Al Hossain, 2023; Safi, 1994). These values describe the electrical characteristics of the motor to be simulated and are crucial in calculating the motor's dynamic response to input voltage.

```
clc; clear;  % Membersihkan command window dan workspace

%% === PARAMETER MOTOR DC SUNRACE 350W ===
R = 0.36;      % Ohm - Resistansi lilitan motor
L = 0.01;      % Henry - Induktansi lilitan motor
Ke = 0.04;     % V/rad/s - Konstanta tegangan balik motor (back EMF)
Kt = 0.04;     % Nm/A - Konstanta torsi motor

%% === PARAMETER MEKANIK SISTEM MOTOR ===
J = 0.08;      % kg.m^2 - Momen inersia roda + motor
b = 0.05;      % Nm.s/rad - Koefisien gesekan viscous (gaya hambat)
Tload = 1.5;   % Nm - Torsi beban dari pengendara, jalan, angin, dll

%% === SETUP WAKTU SIMULASI ===
dt = 0.001;        % Interval waktu simulasi (1 ms)
t = 0:dt:10;       % Rentang waktu simulasi dari 0 s sampai 10 s
n = length(t);     % Jumlah titik waktu

%% === INISIALISASI VARIABEL ===
i = zeros(1,n);    % Arus motor, diset awal 0
w = zeros(1,n);    % Kecepatan sudut motor (rad/s), diset awal 0
V = zeros(1,n);    % Tegangan input (throttle), awal 0

%% === INPUT TEGANGAN THROTTLE ===
for k = 1:n
  if t(k) > 1
    V(k) = 36;     % Setelah detik ke-1, throttle aktif (tegangan 36V)
  end
end

%% === SIMULASI SISTEM MENGGUNAKAN METODE EULER ===
for k = 1:n-1
  % Hitung perubahan arus berdasarkan persamaan KVL motor DC
  % di/dt = (V - Ri - Ke*w) / L
  di = (1/L)*(V(k) - R*i(k) - Ke*w(k));
  i(k+1) = i(k) + dt*di;  % Update arus dengan metode Euler

  % Hitung torsi motor (proposional terhadap arus)
  T = Kt * i(k);

  % Hitung perubahan kecepatan sudut (hukum Newton rotasi)
  % dw/dt = (T - b*w - Tload) / J
  dw = (1/J)*(T - b*w(k) - Tload);
  w(k+1) = w(k) + dt*dw;  % Update kecepatan sudut
end

%% === KONVERSI KECEPATAN SUDUT KE RPM ===
% 1 rad/s = 9.5493 RPM
rpm = w * 9.5493;

%% === PLOT HASIL SIMULASI ===
% Grafik Tegangan Input terhadap Waktu
figure;
subplot(3,1,1);
plot(t, V, 'b');
ylabel('Tegangan (V)');
title('Input Tegangan (Throttle)');
grid on;

% Grafik Arus Motor terhadap Waktu
subplot(3,1,2);
plot(t, i, 'r');
ylabel('Arus (A)');
title('Arus Motor');
grid on;

% Grafik Kecepatan Motor terhadap Waktu (dalam RPM)
subplot(3,1,3);
plot(t, rpm, 'g');
ylabel('Kecepatan (RPM)');
xlabel('Waktu (s)');
title('Kecepatan Roda Motor Listrik Sunrace 350W');
grid on;
```

Figure 6. GNU Octave Simulation Coding

Next, the mechanical parameters of the electric bicycle system are defined. These parameters include the system's moment of inertia (J), which indicates resistance to rotational changes, the viscous friction coefficient (b), which indicates mechanical resistance force, and the load torque (Tload) caused by external factors such as rider weight, road incline, or air resistance (Sayed et al., 2024). These parameters are used in Newton's laws of rotation to calculate changes in the motor's angular velocity during the simulation.

The simulation time range is set from 0 to 10 seconds with a time interval of 1 millisecond. This generates thousands of data points, enabling smooth and detailed numerical analysis. Three main variables are initialized: motor current (i), angular velocity (w), and input voltage (V). All three are updated at each time step based on the physical equations used. The input voltage is set to 0 for the first second to simulate the condition of the motor not yet activated. After that, the voltage is suddenly increased to 36 volts, as occurs when the user fully twists the throttle of the electric bicycle.

The simulation was run using the Euler method, a numerical approach to solving differential equations iteratively over time. In each time step, current changes were calculated based on Kirchhoff's Voltage Law (KVL), and velocity changes were calculated based on Newton's law of rotation. Through this process, the system can model how the motor responds to voltage changes in the form of initial current surges, torque generation, and acceleration until it reaches a steady-state condition.

After all calculations are complete, the motor's angular velocity in radians per second is converted to RPM (rotations per minute) for more familiar interpretation. The simulation results are visualized in three graphs: the first graph shows input voltage over time, the second graph shows motor current changes over time, and the third graph shows motor speed in RPM over time. These graphs clearly illustrate the operational dynamics of an electric motor from a stationary state to constant-speed operation. Students can clearly observe how the interaction between voltage, current, and speed occurs simultaneously.

Conclusion

The application of GNU Octave in BLDC electric motor simulation learning has been proven to have a positive impact on students' affective aspects in understanding dynamic electrical concepts. This simulation successfully connects abstract physics theory with real-world applications in electric vehicle technology, particularly electric motors. Research results show that more than 90% of students demonstrate

interest, motivation, and positive attitudes toward physics-based simulation learning in electric motors. The numerical visualizations generated by GNU Octave not only clarify the operational dynamics of electric motors but also enhance students' engagement and enthusiasm toward applied physics. Therefore, the GNU Octave simulation-based approach is highly suitable for integration into science and engineering education to foster conceptual understanding and positive attitudes among students toward physics and sustainable technology.

Author Contributions
This article was written by four authors, namely JA. K., A. Y. P., R., and A. M. A. All authors contributed to each stage of the implementation of the activities until this article was completed.

Conflicts of Interest
The authors declare no conflict of interest.

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