Wind, solar and water-powered renewable energy prototypes for STEM learning: testing their efficiency and feasibility

Nadi Suprapto†, Iqbal A. Rizki‡, Rahmatta T. Lintangesukmanjaya† & Imam Sya'roni*

State University of Surabaya, Surabaya, Indonesia†
Victoria University of Wellington, Wellington, New Zealand‡
National Taiwan University of Science and Technology, Taipei, Taiwan*

ABSTRACT: This research aims to test the efficiency of wind, solar and water-powered renewable energy prototypes and examine experts' and practitioners' responses to the prototype for STEM education purposes. There are a total of three experiments in this research; namely, evaluating the amount of electrical energy generated from changing propeller angles in wind turbines, the effect of the cross-sectional area and slope on electrical energy in solar panels, and the generation of electricity from water using proton exchange membranes in miniature cars. Ten experts and practitioners assessed the three prototypes. The experiments demonstrated their effectiveness in teaching renewable energy principles, with significant findings on the blade's type and angle for the wind energy STEM kit (WESK), and consistent hydropower output for the multi energy car STEM kit (MECSK). Expert evaluations confirmed the prototypes' feasibility, highlighting their user-friendliness, accuracy and motivational impact on students. These findings imply that such prototypes can significantly enhance STEM education and support sustainable development goals by promoting knowledge and interest in sustainable energy technologies.

INTRODUCTION

Science, technology, engineering, mathematics (STEM) education is increasingly being recognised for its ability to foster collaboration in education; it offers a harmonious approach to the education of students, balancing social life and scientific understanding [1]. The four components of STEM subjects are science, the study of the natural world, which has a bearing on the application of accumulated facts, principles and concepts; technology is specified to mean any human-made things; engineering refers to the development of machines and designs; mathematics is the study of the relationships between quantities, numbers and space. Recently, most countries have incorporated learning in STEM fields into their curriculum [2]. For example, Taiwan introduced the STEM curriculum in problem-based learning [3]. The United States implemented STEM learning in 2011 in curricula integrating knowledge from those fields which has improved their educational rankings [4].

Also Australia has been focused on STEM integration since 2016, and the outcomes of this strategy positioned Australia as a competitive player in the global STEM environment, underpinned economic growth, and helped address a number of the fundamental challenges, such as technological advancement and sustainability [5]. Comparisons of innovations across different countries including the impact of STEM learning have been by carried out in several studies [6]. STEM learning is important for the enhancement of students' knowledge and educational outcomes and it can be adjusted to various teaching approaches which might be used to present concepts to students.

Inevitably, education has to be aligned with technological development, and contribute to the developmental speed of the technology industry. Communication is inseparable from any process of knowledge transfer, which, obviously, stems from certain core learning in the sphere of STEM. The Programme for International Student Assessment (PISA) is one of the ways to evaluate how education around the world is progressing. One of the main features of PISA concerns the transfer of knowledge, thus, communication in education. In the 2022 PISA results, Indonesian students' scores were low, especially in higher-order thinking skills. STEM education is considered a way to improve the quality of education in Indonesia, complemented by enhancing instructional strategies through learning technologies [7].

Especially the use of prototypes as technical tools is advocated in STEM learning [8]. The tools facilitate experimentation processes while showing the effects of STEM in real life. All-rounded learning tools can combine qualitative and quantitative data to enhance students' ability to see and get formulas in real-life applications. Students benefit a lot when traditional media that involve a manual setting are changed to technologically transformed media that require an automatic setting. For example, conventional media are not very useful when trying to explain energy conversion comprehensively, whereas modern, user-friendly media can be successfully used for effective coverage of complicated energy topics. Advanced learning technologies help establish new educational models and efficient resource sharing, thus realising collaborative learning [9].

The learning prototypes used for delivering renewable energy topics seem very appropriate as they provide hands-on, practical experiences to help students understand complex concepts. It makes the learning process interesting, and relevant for students when they experiment and observe real-life applications of renewable energy. Besides, the prototypes can lead students to bright new ideas on the energy conversion process, such as wind and sunlight use for electricity. This strengthens understanding through a practice-oriented approach, but also at the same time increases student interest in sustainable technologies and the impact they could have. Notably, the renewable energy topic is aligned with UN Sustainable Development Goal 7 (SDG 7), which aims to *ensure access to affordable, reliable, sustainable and modern energy* [10]. If the prototypes can be incorporated into the instructional process, students may gain a deeper understanding of renewable energy technologies and their benefits, fostering a generation that is knowledgeable about and committed to sustainable energy solutions [11].

Several studies have investigated the effects of renewable energy-related teaching materials in STEM education [12][13]. However, they have not developed and implemented prototype tools that could facilitate students in hands-on and experimental learning. Machuve and Mkenda attempted to apply photovoltaic toys to enhance STEM teaching and learning that could easily and sustainably be adopted in the Tanzanian context, but the study's results only focused on student perceptions [14]. Thus, the purpose of this study was to apply renewable energy prototypes in STEM learning with a case study on wind, solar and water-powered electricity. This study provides insights into the application and effectiveness of educational tools, potentially influencing curriculum development and teaching practices to better support STEM learning and sustainability goals. It contributes to the field of STEM education by applying and testing innovative learning prototypes. In this context, the following are the research questions:

1. What is the efficiency of each prototype developed in generating renewable energy?
2. What are the experts' and practitioners' opinions on applying the prototypes in STEM learning?

RESEARCH METHODOLOGY

The research involved preparing and testing two main prototypes: the wind energy STEM kit (WESK) and the multi energy car STEM kit (MECSK), developed by Horizon Educational. The design of each prototype is depicted in Figure 1. Experimental testing was conducted on each prototype to determine the amount of electrical energy produced.

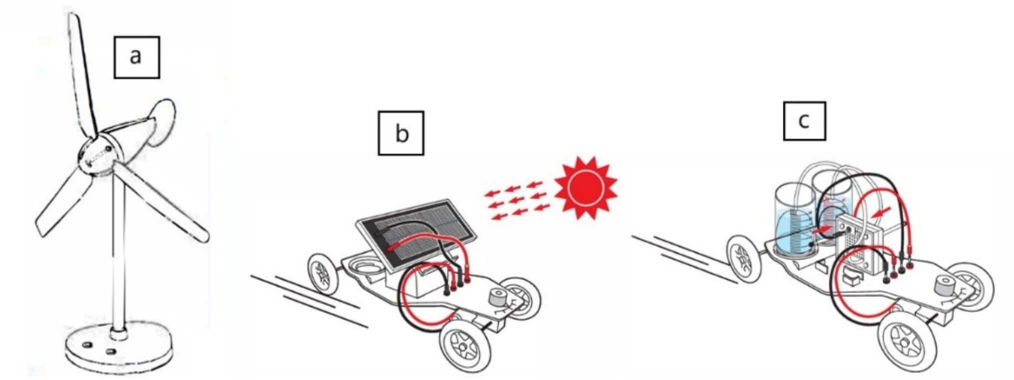

Figure 1: Prototypes' design: a) wind; b) solar; and c) water energy.

In the case of the WESK, tests were conducted by varying several variables, such as pitch degree (6°, 28°, 50°) and blade types. The differences in pitch degree and blade type are illustrated in Figure 2.

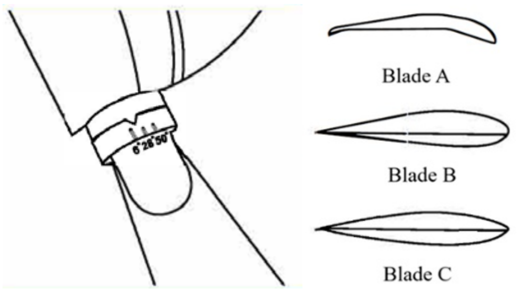

Figure 2: Differences in pitch degree and blade type.

The WESK was operated under similar conditions of wind speed (4.5 m/s), temperature (32°C), and with the same number of blades (3). The measured variables included the voltage and current strength generated in each experiment. The experimental stages were as follows: 1) placing the rotor base onto a flat surface; 2) evenly installing three profiled blades onto the rotor base; 3) positioning the blade holder atop the installed blades; 4) securing the blade assembly; 5) attaching the rotor shaft to the base; 6) installing the base assembly; 7) connecting wires to the prototype and a multimeter; and 8) conducting tests on the prototype.

The MECSK, on the other hand, involved two experiments: solar energy and water. The solar energy experiment began with the installation of the solar panel support onto the car, ensuring a secure connection. Subsequently, the solar panel was placed on the support, and the necessary cables were connected. Notably, the angle of the solar panel can be adjusted to (60°, 75°, and 90°). Outputs included voltage and current strength, while the car's travel time was also calculated by setting a distance of 300 cm for measurement, enabling the calculation of the car's speed. Another variable change in the solar-powered car was the cross-sectional area exposed to sunlight, resulting in variations of 2 × (5 cm^2, 7 cm^2 and 9 cm^2).

For water-powered cars, a proton exchange membrane (PEM) was utilised to convert water into hydrogen. Required instruments include water and hydrogen tanks, water and oxygen tanks, a battery pack, silicon tubes, syringes, pins, wires, AA batteries and water. Initially, a syringe was inserted to inject water into the PEM, and the hole was sealed with pins. The water tank was then attached to the car frame's tank base by pressing downward into round slots and twisting it into place. Inner gas tanks were placed into the outer water tanks, ensuring that gaps were not blocked by inner plastic rims. The water tanks were filled with water up to 40 mL, ensuring no air remained in the tanks. Subsequently, the PEM was fitted onto the car frame in front of the containers, with the top nozzles of the inner gas tanks connected to the H_2 and O_2 sides of the PEM. To initiate the electricity generation process, electrolysis of water was conducted to produce hydrogen as an energy source. This was achieved by electrifying the fuel cell until bubbles emerged from the inner tank, indicating the tank was filled with gas. Finally, the PEM was connected to the car dynamo using a cable with the correct polarity until it could run. The measured variables included voltage, current strength and travel time. Figure 3 presents the ready-to-implement prototypes.

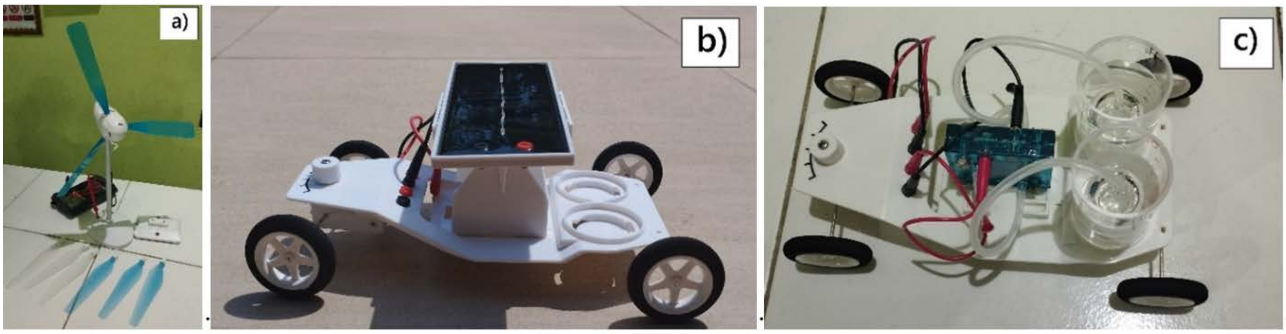

Figure 3: Final prototypes: a) wind; b) solar; and c) water energy.

Lastly, ten experts and professionals, involving one physicist, one science education expert, one physics education expert, two physics teacher, one mechanical engineering teacher, and four basic physics laboratory assistants, evaluated the feasibility of the three prototypes through two types of testing: validity and reliability. To measure, they utilised a questionnaire comprising ten questions rated on a Likert scale ranging from 1 to 4. Analysis was conducted using the following scale: 1.00 - 1.74 (highly disagree), 1.75 - 2.49 (disagree), 2.50 - 3.24 (agree), 3.25 - 4.00 (highly agree) [15]. Subsequently, the questionnaire responses were aggregated, and the Cronbach's α value was calculated to assess the reliability of the assessments. A Cronbach's α value greater than 0.7 indicates high reliability in the assessment results [16]. Hence, if the prototypes met both valid and reliable criteria, they were considered feasible for practical use in STEM learning processes.

RESULTS

Testing the Prototypes' Efficiency for STEM Learning

In this section, the experimental results are divided into three: the WESK with modified blade types, the MECSK with a modified solar panel area, and the MECSK with a water fuel cell. Based on the results obtained through experiments using the WESK prototype, testing was carried out by varying several variables to produce electrical voltage values through a simple circuit. Table 1 below shows the blade experiment.

Table 1: Blade experiment.

Blade type	Angle (°)	Output voltage (V)	Output current (mA)	Output power (W)	Control variables
A	6	0	0	0	Number of blades: 3 Wind speed: 4.5 m/s Distance: 0.6 m Temperature: 32 °C
	28	3.47	24.18	0.0838	
	50	1.41	8.54	0.0120	
B	6	2.82	20.48	0.0578	
	28	4.72	29.09	0.1373	
	50	0	0	0	
C	6	8.32	68.20	0.5674	
	28	2.62	20.22	0.0529	
	50	1.21	6.59	0.0084	

As illustrated in Table 1, the experiment revealed that the blade type producing the largest voltage is blade type C, particularly when positioned at an angular tilt of 6°. This is influenced by several factors, primarily the shape of the blade and its effectiveness in rotating the propeller, which generates different speeds. The speed of the propeller when rotating is affected by the amount of air resistance, causing each blade type to experience varying degrees of friction. In-depth physics-based modelling of propeller components conducted during the design of the blade shape, affects the speed of the propeller [17].

In addition to the difference in blade shapes, the angle at which the propeller is installed affects the amount of stress experienced. For blade type C, the angle significantly impacts the voltage, with the angle being inversely proportional to the voltage. This is consistent with Ohm's law, which describes a linear relationship between current and voltage, leading to a significant increase in voltage [18].

However, this inverse relationship does not apply to other blade types. Observations show that larger angles generally produce higher stress, but for blade types A and B, an angle of 28° generates the highest stress compared to other angles. This indicates that the propeller installation angle influences the change and speed of rotation, which in turn affects the friction against the air [19]. Then, the faster the propeller rotates, the greater the voltage generated. This is because variables, such as the number of propellers, fan blades and capacitance can affect the voltage output.

The voltage generated in this WESK prototype produces corresponding current strength and output power. According to Ohm's law, voltage is proportional to current strength, and the output power is directly proportional to current strength at a constant voltage. The use of wind energy conversion through propellers, similar to those used in developed countries in Europe and America, demonstrates these systems' practical application and efficiency over certain distances [20].

Based on the results obtained through experiments using the MECSK prototype tool for energy utilisation from solar panels, testing was carried out by changing several variables: the angle and cross-sectional area of the solar panel. In the solar panel experiment with angle manipulation, it was found that the angle of 60°, 75° and 90° on the MECSK can affect the amount of voltage generated (Table 2).

Table 2: Solar panel experiment with manipulating the angle.

Angle (°)	Output voltage (V)	Output current (mA)	Output power (W)	Period (s)	Control variables
60	2.926	8.87	0.0259	3.32	Resistance: 330 Ω Distance: 300 m Panel's area: 27 cm^2
				3.30	
				3.18	
75	2.972	9.006	0.0268	2.65	
				3.01	
				2.72	
90	3.040	9.212	0.0280	3.47	
				3.33	
				3.27	

Solar panels can absorb a natural amount of solar energy when facing the sun at the right angle [21]. The 90° angle can absorb the amount of solar energy optimally compared to other angles, as seen in the amount of voltage produced. From the results of solar energy absorbed through solar panels, which is then converted into electric power in the form of voltage, it can move the multi energy car with the help of a motion dynamo connecting device.

If the period of motion of the car at each measured voltage is averaged, the voltage will be directly proportional to the period of motion of the car. This is in accordance with the theory that the conversion of incoming energy (electrical energy) is always proportional to the energy produced (motion energy).

The renewable energy capacity of solar panel utilisation has great potential by offering stability assisted by hybrid systems on other renewable energies, including wind, hydro and fossil substitutes [22]. Furthermore, in the *solar panel experiment* with *manipulation area panel*, by manipulating the size of the surface area of the solar panel to determine the amount of voltage produced, the surface area of the solar panel has an effect in influencing the voltage produced [23].

In this second experiment using solar panels, the solar panel area was manipulated by 15 cm^2, 21 cm^2 and 27 cm^2 with the same resistance and angle. From this experiment, the greater the surface area of the solar panel, the greater the voltage (Table 3). This can happen because the wider the solar panel, the more solar energy it absorbs. The effect of height, area and volume in installing solar panels results in different solar power efficiency improvements [21].

The MECSK entirely relies on the amount of incoming energy in this experiment, the energy utilised is solar energy obtained through the solar panel. The use of solar panels as an energy alternative can be maximised during the day alongside wind power when the weather is not favourable [22].

Table 3: Solar panel experiment with manipulating the area panel.

Area (cm^2)	Output voltage (V)	Output current (mA)	Output power (W)	Control variables
15	2.814	73.3	0.2062	Resistance: 330 Ω Angle: 90°
21	2.873	75.4	0.2166	
27	2.921	77.3	0.2257	

In the MECSK experiment on saltwater fuel cell utilisation, tests were conducted to determine the voltage generated from water energy using a maximally charged saltwater fuel cell prototype. Impressively, the results (Table 4) demonstrate that hydropower can effectively produce electricity in the form of voltage. Hydrogen energy has the potential to support the integration of renewable energy into general electrical energy utilisation [24].

Table 4: Experiment with the saltwater fuel cell.

Output voltage (V)	Output current (mA)	Output power (W)	Period (s)
1.414	33.4	0.0472	5.41
			4.69
			5.24
			4.47
			4.90

The experiment showed that the MECSK could be powered by the saltwater fuel cell for an average duration of 4.942 seconds. The system harnesses excess energy by pumping water from one reservoir tube to another, generating electrical energy as the water moves between reservoirs. The tool's advantage lies in its potential as an instrument for developing alternative water energy sources to produce electrical power. The energy output remained consistent throughout the experiment, as indicated by the prototype's operation duration. However, a limitation of the prototype is the saltwater fuel cell's capacity, which is restricted to a maximum of 40 mL. This limitation results in a voltage generation cap of approximately 1.414 V.

Evaluating the Prototypes' Feasibility for STEM Learning

The prototypes were evaluated by ten professionals and experts to determine their perception and agreement on the feasibility of the prototypes to be implemented in STEM learning (see Table 5).

Table 5: The results of experts' and professionals' assessments of the prototypes.

Item	Perception	
	Average score	Criteria
WESK and MECSK as to be used as STEM kits do not require a high level of technical knowledge	3.40	Highly agree
WESK and MECSK can facilitate the absorption of the study material	3.80	Highly agree
WESK and MECSK can potentially improve students' critical thinking skills	3.70	Highly agree
WESK and MECSK can produce accurate data	3.30	Highly agree
WESK and MECSK can help learners in linking science concepts to everyday life	3.70	Highly agree
WESK and MECSK can produce valid data based on the related theory	3.50	Highly agree
Suitability of WESK and MECSK kits for the level of the education unit is high	3.40	Highly agree
In terms of construction, WESK and MECSK have an ideal size to be used as an instruction tool	3.70	Highly agree
WESK and MECSK have an attractive and aesthetic colour composition	3.20	Agree
Implementation of WESK and MECSK is predicted to increase student learning motivation	3.80	Highly agree

Note: Cronbach's α value is 0.78, meaning that the result is considered reliable [16].

Table 5 shows the experts' and professionals' assessment of the prototypes, where their perceptions are overwhelmingly positive, suggesting that the WESK and MECSK prototypes are feasible and effective tools for STEM learning. They are user-friendly and accessible, requiring no advanced technical knowledge.

According to Heijsters et al, this is to ensure that both teachers and students can easily integrate and use them in the educational environment, hence allowing every student to benefit from educational tools irrespective of his/her technical expertise [25]. They also greatly help in ease of learning and can improve critical thinking skills when working with accurate valid experimental data. This is supported by the findings of Oyewo et al, who stated that project-based STEM learning environments, similar to what will be facilitated by the WESK and MECSK prototypes, could significantly enhance students' critical thinking, with potential improvement in learning outcomes [26].

Moreover, the kits allow students to relate science concepts to real-life situations, thereby making STEM subjects relevant and enjoyable. This can both improve understanding and retention of the material; the practical application also serves to further raise student interest and motivation to undertake further studies and to pursue a career in STEM [27].

The prototypes are of a suitable design for the target educational levels, of a practical size for classroom use, and are aesthetic, all of which helps in student engagement. Most importantly, studies indicate that they can significantly boost student motivation, leading to better participation and learning outcomes. Increased motivation also fosters a positive attitude towards learning, resulting in improved academic performance and long-term educational outcomes [28].

CONCLUSIONS

To conclude, both prototypes effectively demonstrate the principles and potential of renewable energy sources, particularly in STEM education. The WESK experiments highlighted the significant impact of blade type and installation angle on voltage generation, with blade type C at a 6° angle proving the most effective. The MECSK experiments, especially the saltwater fuel cell utilisation, showcased the potential of hydropower to generate consistent electrical energy, albeit with limitations due to the fuel cell's capacity. Additionally, expert evaluations of the prototypes' feasibility indicated high levels of agreement on their effectiveness for STEM education. The prototypes were deemed user-friendly and capable of facilitating learning, enhancing critical thinking skills, and producing accurate and valid data.

REFERENCES

1. Kelley, T.R. and Knowles, J.G., A conceptual framework for integrated STEM education. *Inter. J. of STEM Educ.*, 3, 1-11 (2016).
2. Schweingruber, H., Pearson, G. and Honey, M., *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. Washington, DC: National Academies Press (2014).
3. Ministry of Education of Taiwan, Curriculum Guidelines of 12-Year Basic Education - Science Education. Taipei: The Ministry of Education of Taiwan (2018).
4. Mullis, I.V.S., Martin, M.O., Foy, P. and Drucker, K.T., PIRLS 2011 International Results in Reading. Chestnut Hill: TIMSS & PIRLS International Study Center, Boston College (2012).
5. Xu, L., Fang, S.C. and Hobbs, L., The relevance of STEM: a case study of an Australian secondary school as an arena of STEM curriculum innovation and enactment. *Inter. J. of Science and Mathematics Educ.*, 21, **2**, 667-689 (2023).
6. Chang, C.Y., Lin, P.L. and To Khuyên, N.T., e-Learning Integrated STEM Education Center (eLISE) in Asia: a Reflection Case Study of Taiwan and Vietnam Research Project. *Revista historia de la educación latinoamericana*, 23, **36**, 15-36 (2021).
7. Solihin, R.R., Susanto, T.T.D., Fauziyah, E.P., Yanti, N.V.I. and Ramadhania, A.P., The efforts of Indonesian government in increasing teacher quality based on PISA result in 2022: a literature review. *Perspektif Ilmu Pendidikan*, 38, **1**, 57-65 (2024).
8. Hayden, K., Ouyang, Y., Scinski, L., Olszewski, B. and Bielefeldt, T., Increasing student interest and attitudes in STEM: professional development and activities to engage and inspire learners. *Contemporary Issues in Technol. and Teacher Educ.*, 11, **1**, 47-69 (2011).
9. Huang, Y., Lin, M. and Liu, X., Digital media and interactive e-learning application in art teaching process based on big data platform. *Entertainment Computing*, 100737 (2024).
10. United Nations. Department of Economic and Social Affairs. Sustainable Development. Goals. Goal 7, 8 August 2024, https://sdgs.un.org/goals/goal7
11. Abulibdeh, A., Zaidan, E. and Abulibdeh, R., Navigating the confluence of artificial intelligence and education for sustainable development in the era of industry 4.0: challenges, opportunities, and ethical dimensions. *J. of Cleaner Production*, 140527 (2024).
12. Wiyono, K., Zulkardi, Madang, K., Suhery, T., Yusup, M., Effendi, Hapizah, Anwar, Y., Meryansumayeka and Shahrill, M., The preliminary prototype of learning material based on STEM framework in renewable energy topic. *AIP Conf. Proc.*, 3052, **1**, 020053 (2024).
13. Nazhifah, N., Wiyono, K. and Ismet, I., Development of STEM-based e-learning on renewable energy topic to improve the students creative thinking skills. *Jurnal Penelitian Pendidikan IPA*, 9, **11**, 9575-9585 (2023).
14. Machuve, J. and Mkenda, E., Promoting STEM education through sustainable manufacturing: case study of photovoltaic toys. *Procedia Manufacturing*, 33, 740-745 (2019).
15. Erika, F., Prahani, B.K., Supardi, Z.A.I. and Tukiran, Development of a graphic organiser-based argumentation learning (GOAL) model for improving the self-efficacy and ability to argue of chemistry teacher candidates. *World Trans. on Engng. and Technol. Educ.*, 16, **2**, 179-185 (2018).
16. Taber, K.S., The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Educ.*, 48, 1273-1296 (2018).
17. Cole, J.A., Krebs, T., Barcelos, D. and Bramesfeld, G., Influence of propeller location, diameter, and rotation direction on aerodynamic efficiency. *J. of Aircraft*, 58, **1**, 63-71 (2021).
18. Kımuya, A., The modified Ohm's Law and its implications for electrical circuit analysis. *Eurasian J. of Science Engng. and Technol.*, 4, **2**, 59-70 (2023).

19. Pranta, M.H., Rabbi, M.S. and Roshid, M.M., A computational study on the aerodynamic performance of modified savonius wind turbine. *Results in Engng.*, 10, 100237 (2021).
20. Reutter, F., Drechsler, M., Gawel, E. and Lehmann, P., Social costs of setback distances for onshore wind turbines: a model analysis applied to the German state of Saxony. *Environmental and Resource Economics*, 87, **2**, 437-463 (2024).
21. Capraz, O., Gungor, A., Mutlu, O. and Sagbas, A., Optimal sizing of grid-connected hybrid renewable energy systems without storage: a generalized optimization model. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects,* 1-34 (2020).
22. Hassan, Q., Azzawi, I.D., Sameen, A.Z. and Salman, H.M., Hydrogen fuel cell vehicles: opportunities and challenges. *Sustainability*, 15, **15,** 11501 (2023).
23. Gangwar, P., Singh, R., Tripathi, R.P. and Singh, A.K., Effective solar power harnessing using a few novel solar tree designs and their performance assessment. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 41, **15**, 1828-1837 (2019).
24. Yue, M., Lambert, H., Pahon, E., Roche, R., Jemei, S. and Hissel, D., Hydrogen energy systems: a critical review of technologies, applications, trends and challenges. *Renewable and Sustainable Energy Reviews*, 146, 111180 (2021).
25. Heijsters, F.A., van Loon, G.A.P., Santema, J.M., Mullender, M.G., Bouman, M., de Bruijne, M.C. and van Nassau, F., A usability evaluation of the perceived user friendliness, accessibility, and inclusiveness of a personalized digital care pathway tool. *Inter. J. of Medical Informatics*, 175, 105070 (2023).
26. Oyewo, O.A., Ramaila, S. and Mavuru, L., Harnessing project-based learning to enhance STEM students' critical thinking skills using water treatment activity. *Educ. Sciences*, 12, **11**, 780 (2022).
27. Maiorca, C., Roberts, T., Jackson, C., Bush, S., Delaney, A., Mohr-Schroeder, M.J. and Soledad, S.Y., Informal learning environments and impact on interest in STEM careers. *Inter. J. of Science and Mathematics Educ.*, 19, 45-64 (2021).
28. Mega, C., Ronconi, L. and De Beni, R., What makes a good student? How emotions, self-regulated learning, and motivation contribute to academic achievement. *J. of Educational Psychology*, 106, **1**, 121 (2014).