Energy education: adapting to learning preferences and pedagogical strategies

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ABSTRACT

Addressing diverse learning needs in energy education is vital for fostering environmental awareness and sustainability. This study aims to identify students' learning preferences, the challenges teachers encounter when teaching energy-related topics, and the most effective pedagogical strategies to address these challenges. Using a mixed-methods approach, quantitative surveys were administered to 163 15-year-old students in Bintulu, Sarawak, to assess learning preferences, demographic characteristics, and the difficulty level of various science topics, complemented by qualitative semi-structured interviews with three experienced science teachers. Quantitative data were analyzed using descriptive statistics to reveal trends and patterns, while thematic analysis of interview data provided deeper insights into teaching challenges. The study found "energy and sustainable life" to be the most challenging theme while teachers highlighted four major obstacles: i) abstract concepts; ii) weak mathematical skills; iii) terminology confusion; and iv) resource constraints. Effective strategies identified include incorporating digital learning tools, interactive and real-world applications, and enhanced teacher support. These findings underscore the need for tailored instructional approaches that leverage technology and address diverse learning preferences to improve student engagement and comprehension in energy-related topics. Future research should focus on developing innovative teaching methods and evaluating their long-term impacts on student learning and environmental consciousness.

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1. INTRODUCTION

In an era of rapid technological advancement and growing environmental challenges, robust energy education is more crucial than ever. As the world grapples with issues related to climate change, energy security, and sustainable development, fostering a deep understanding of energy concepts among learners is paramount [1]. Energy literacy-encompassing the comprehension of energy principles, awareness of energy issues, and the ability to make informed decisions about energy use-is essential for nurturing responsible and informed global citizens [2]. However, traditional educational approaches often fall short in engaging students and facilitating a profound understanding of energy topics [3]. These approaches tend to emphasize rote learning and passive consumption of information, which may not resonate with the diverse learning preferences of contemporary students.

Given the complexity of energy issues, it is crucial to tailor educational strategies to how students learn best, thereby enhancing engagement, comprehension, and knowledge retention [4]. This article delves into the relationship between learning preferences and pedagogical strategies in energy education, offering insights on aligning educational practices with students' learning styles to optimize teaching and learning. Through a rigorous need analysis, we aim to uncover insights that will inform the development of more effective and responsive energy education programs. The necessity of tailored educational strategies is underscored by the diversity of learning preferences among students. Learning preferences are influenced by a myriad of factors, including cognitive styles, prior knowledge, cultural backgrounds, and personal interests [5]. Recognizing these differences can significantly enhance the educational experience, leading to a deeper understanding of energy concepts and meaningful application of knowledge [6].

Energy education covers a broad spectrum of topics, from basic principles of energy forms and transformations to the complex socio-economic and environmental implications of energy use [7]. Teaching these topics effectively requires a multifaceted approach that considers the diverse ways students process and assimilate information. For instance, some students may thrive in hands-on, experiential learning environments, while others may benefit more from visual aids or collaborative discussions [8], [9]. To address these varying needs, our study employs a mixed-methods approach, combining surveys of students and interviews with teachers to capture a comprehensive understanding of learning preferences and experiences in energy education. The significance of this research lies in its potential to bridge the gap between educational theory and practice. By understanding how students prefer to learn and what teaching methods are most effective, educators can design and implement instructional strategies that are both engaging and educationally sound [10]. This is particularly important in the context of energy education, where the stakes are high, and the need for informed and engaged citizens is critical.

The study seeks to contribute to the discourse on effective energy education by providing evidence-based insights into learning preferences and pedagogical strategies. By tailoring educational practices to meet the diverse needs of students, we can enhance energy literacy and empower learners to navigate the complex energy landscape of the 21st century. The current needs analysis was developed to answer the main research questions: i) what are the students' learning preferences, particularly in energy-related topics? ii) what specific challenges do teachers face when teaching energy-related topics? and iii) what pedagogical strategies are most effective in addressing the diverse learning preferences of students? This investigation aims to identify and evaluate approaches that can effectively address diverse learning preferences and teaching challenges, ultimately enhancing students' understanding of energy concepts in science education.

2. METHOD

This study employed a mixed-methods research design to rigorously examine the challenges and needs associated with teaching and learning energy-related topics in science education. The research commenced with a comprehensive needs analysis, which sought to identify the specific difficulties encountered by both students and teachers. This analysis served as a critical precursor to determining the most effective instructional strategies, media, and resources, tailored to the characteristics and learning requirements of students. In the first phase, a quantitative survey was administered to 163 form three students (typically aged 15 years old in the Malaysian education system) from schools in Bintulu, Sarawak. In the first phase, a quantitative survey was administered to 163 form three students (typically aged 15 years old in the Malaysian education system) from schools in Bintulu, Sarawak.

The survey aimed to assess students' perceptions of the difficulty of various science topics, while simultaneously gathering data on demographics, competencies, and learning styles. The survey addressed four educational themes encompassing ten science topics within the form three science curriculum. Students were asked to rate the difficulty of each theme on a scale from 1 (most challenging) to 4 (least challenging). Additionally, the survey collected data on student demographics, including gender, ethnicity, and smartphone ownership. The quantitative data were analyzed using SPSS version 29.0, employing descriptive statistics to uncover patterns and trends in student responses. This analysis provided a foundational understanding of the challenges students face in science education, particularly in relation to the complexity of different science subjects. The themes and topics assessed in the survey are detailed in Table 1.

In the second phase, semi-structured interviews were conducted with three experienced science teachers, each possessing over a decade of teaching experience. These interviews aimed to gain in-depth insights into the pedagogical challenges of teaching complex science topics. The qualitative data obtained from these interviews were analyzed using NVivo, a qualitative data analysis software. The analysis involved transcribing the interviews verbatim, followed by open coding to identify key themes and concepts. These themes were then organized through axial and selective coding to form a coherent framework directly linked to the research questions. By integrating the quantitative data from student surveys with the qualitative insights from teacher interviews, this study offers a holistic understanding of the challenges faced in science education.

The combination of SPSS for numerical data analysis and NVivo for qualitative data analysis allowed for a comprehensive exploration of both overarching trends and nuanced individual experiences. This dual approach effectively informs the development of tailored instructional strategies aimed at enhancing student engagement and comprehension in energy-related topics.

Table 1. Themes and topics in science form 3

Theme	Topic
Maintenance and continuity of life	Stimuli and responses
	Respiration
	Transportation
Exploration of elements in nature	Reactivity of metals
	Thermochemistry
Energy and sustainable in life	Electricity and magnetism
	Energy and power
	Radioactivity
Exploration of earth and space	Space weather
	Space exploration

3. RESULTS AND DISCUSSION

This section presents the results and findings of our comprehensive analysis aimed at understanding the difficulties faced by students in learning various science topics, the challenges encountered by teachers in teaching these subjects, and the characteristics of students that influence their learning experiences. These findings offer significant perspectives on the educational needs and preferences of students.

3.1. Difficulty level according to themes in science subject

The survey results indicated that "energy and sustainable life" was perceived as the most challenging theme, with 65 students (39.88%) identifying it as difficult. This theme encompasses topics that require a solid understanding of abstract concepts and mathematical calculations, such as electricity, magnetism, and radioactivity. The inherent complexity and abstract nature of these topics likely contribute to the higher difficulty level reported by students. Following "energy and sustainable life," the second most challenging theme was "maintenance and continuity of life," with 52 students (31.90%) indicating difficulty. This theme involves understanding intricate biological processes and systems, which can be complex and require detailed memorization and comprehension. "Exploration of elements in nature" was ranked as the third most difficult theme, with 37 students (22.70%) reporting challenges. The topics under this theme, such as reactivity of metals and thermochemistry, involve understanding chemical properties and reactions, which can be abstract and require a strong grasp of foundational chemistry concepts. The least challenging theme was "exploration of earth and space," with only nine students (5.52%) indicating difficulty. This theme generally involves more tangible and observable phenomena, which may be easier for students to grasp compared to the more abstract and calculation-intensive topics in other themes. Table 2 summarizes the difficulty rankings according to the themes.

The data highlights that topics related to energy and sustainability pose significant challenges for students and thus require additional support and resources in the teaching and learning process. These findings are consistent with previous research indicating that topics involving physical events and abstract scientific concepts are often perceived as more difficult by students [11]. To address these challenges, educators might need to implement more interactive and supportive teaching methods, such as using visual aids, hands-on experiments, and real-world applications to make these complex topics more accessible and engaging for students [12].

Table 2. Difficulty rankings of science themes in form 3 curriculum

Theme	Number of students	Percentage (%)
Energy and sustainable in life	65	39.88
Maintenance and continuity of life	52	31.90
Exploration of elements in nature	37	22.70
Exploration of earth and space	9	5.52

3.2. Challenges in teaching energy topics

Semi-structured interviews were performed with three experienced science teachers, each of whom had more than ten years of teaching experience at the secondary school level. The purpose of these interviews was to get a full understanding of the obstacles that are encountered when teaching energy topics. The interviews revealed several key challenges associated with teaching topics related to electricity and radioactivity, primarily due to their abstract nature and the difficulty students have in visualizing these concepts. Additionally, issues such as weak mathematical skills, terminology confusion, and resource and time constraints were identified as significant obstacles. The following sections provide a detailed analysis of these challenges based on the insights gathered from the teacher interviews.

3.2.1. Abstract concepts and visualization

One of the primary challenges identified is the abstract nature of concepts such as electricity and radioactivity. These topics involve theoretical and intangible phenomena that students often struggle to conceptualize. For example, understanding electrical circuits, electromagnetic fields, and radioactive decay requires visualizing processes that are not easily observable. Research on energy learning progressions indicates that energy is a central scientific concept, yet many students have difficulty fully grasping it. A longitudinal study covering grades 6-9 highlights the importance of effective teaching strategies to support students in developing well-integrated knowledge, which enhances their understanding [13], [14]. This abstractness poses a significant hurdle in teaching and learning, as students struggle to form concrete mental models of these concepts. Interviews with teachers provided direct insights into these challenges:

> "*When teaching about electricity, many students lose interest because they find it too theoretical. Topics like power generation, transmission, and distribution are seen as disconnected from their daily lives.*" (Teacher A)
> "*When we discuss energy transfer and conservation, students often find it hard to connect these abstract principles with practical examples. They frequently ask for real-life applications, but the theoretical nature of the topic makes it challenging for them to see its relevance outside the classroom.*" (Teacher C)

3.2.2. Mathematical skills

Another significant challenge is the weak mathematical foundation among students, which hampers their ability to master the calculations involved in energy topics. Topics like voltage, current, electrical energy, and radioactive decay require the application of mathematical formulas and principles. Many students find these calculations challenging due to a lack of proficiency in basic mathematical skills. This issue is further supported by broader research, which indicates that good mathematical skills are essential for solving day-to-day problems, succeeding in careers, and contributing to modern society [15]. Despite efforts to improve mathematics education, significant declines in performance have been observed, and traditional teaching methods often fail to equip students with practical skills needed for real-life applications. Teachers noted that this deficiency often leads to difficulties in understanding and solving problems related to energy.

> "*Chapters on electricity and magnetism, energy and power, and radioactivity involve a lot of calculations and formulas. Students often struggle with memorizing formulas and applying the correct units, which makes these topics particularly challenging.*" (Teacher B)

3.2.3. Terminology confusion

The use of similar terminology in different contexts also confuses students. Terms like "energy," "work," and "power" have specific meanings in the context of physics, which differ from their everyday use. This semantic overlap can lead to misunderstandings and misinterpretations. For instance, students might confuse the biological concept of energy, learned in earlier grades, with the physical concept of energy as the capacity to do work, leading to confusion and frustration. The difficulty of learning energy concept is reflected by a large body of research on energy learning, indicating that students often hold and use various "alternative frameworks" of energy influenced by everyday language, which are only partly compatible with the scientific view [16]. Recent research suggests that even older students struggle to apply scientific principles like the conservation of energy to everyday phenomena, highlighting the ongoing challenge of teaching energy concepts effectively.

> "*Using the same terms in different contexts is confusing for students. For example, the term 'energy' learned in biology as something derived from cellular respiration is different from the 'energy' in physics. This creates a lot of confusion.*" (Teacher C)

3.2.4. Resource and time constraints

Teachers also reported significant constraints related to resources and time. Limited access to laboratory facilities restricts the ability to conduct hands-on experiments, which are crucial for understanding complex energy concepts. Furthermore, the packed curriculum leaves little time for in-depth exploration of each topic. Teachers often find themselves rushing to cover the syllabus, compromising the depth of understanding and the quality of student engagement.

> "*Time constraints are a major issue. The curriculum is packed with content, and we also have numerous school programs. This leaves limited time to cover complex topics thoroughly. Additionally, sharing lab facilities with other classes further limits hands-on learning opportunities.*" (Teacher B)

3.2.5. Addressing the challenges

To mitigate these challenges, teachers suggested incorporating more interactive and real-world applications in the curriculum. This includes using simulations and augmented reality (AR) to help visualize abstract concepts, integrating more hands-on experiments to reinforce theoretical knowledge, and contextualizing lessons to make them more relevant to students' lives.

> "*Interactive activities like project-based learning and problem-based learning are effective. These methods engage students more deeply and help them understand complex concepts through practical application.*" (Teacher A)
> "*Using digital modules with embedded videos, quizzes, and interactive content can make learning more engaging. Tools like AR (augmented reality) can be particularly useful for making abstract concepts more tangible.*" (Teacher B)
> "*We should connect classroom learning to real-world issues. For instance, teaching about energy efficiency can involve practical exercises like reading electricity bills or conducting home energy audits.*" (Teacher C)

These insights highlight the need for innovative and flexible teaching strategies to effectively engage students and enhance their understanding of challenging energy concepts. To tackle the difficulties associated with complex energy subjects, educators should contemplate the utilization of technology-enhanced educational aids [17]. Simulations and virtual labs provide students with the ability to comprehend abstract topics and carry out experiments in a safe and controlled setting. Meanwhile, AR applications enhance learning by providing interactive and immersive experiences, enabling students to better comprehend intricate concepts [18]. In addition, incorporating practical applications and problem-solving exercises can enhance the relevance and significance of the learning process [19]. Considering the significance of mathematical proficiency in comprehending energy concepts, it is advisable for instructors to integrate more opportunities for practice and assistance in this domain. Supplementing students with extra activities and lectures on mathematical principles pertaining to energy can facilitate the development of essential skills. Engaging in collaborative learning activities, wherein students collaborate to resolve issues, can further boost their comprehension and utilization of mathematical concepts [20], [21].

In order to address limitations in resources and time, educational institutions have the option to implement blended learning strategies, which involve integrating traditional face-to-face teaching methods with online educational materials [22]. This enables students to retrieve educational resources at their own preferred speed and offers additional possibilities for personalized learning. In addition, schools should give priority to allocating laboratory time and resources for doing hands-on experiments, thereby guaranteeing that students have ample opportunities to engage in practical learning experiences [23]. By addressing these identified challenges, educators can create a more supportive and enriching learning environment that fosters deeper comprehension and interest in energy topics.

3.3. Student characteristics analysis

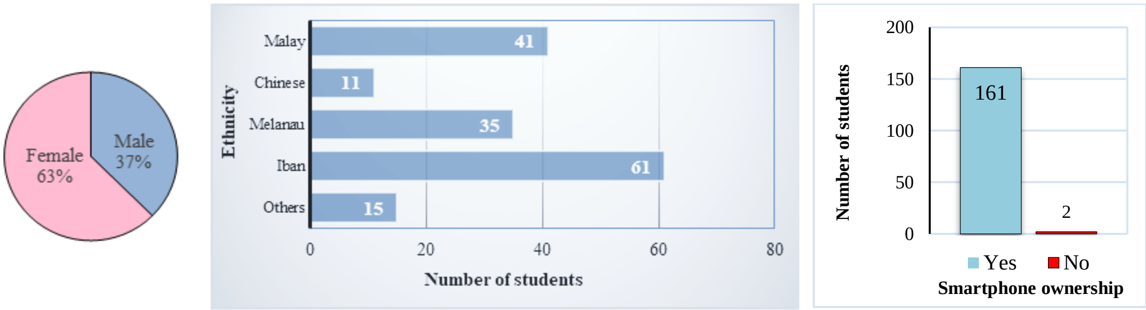
Understanding student characteristics is crucial for tailoring educational strategies to meet their diverse needs. This analysis aimed to capture detailed insights into the demographics, competencies, and learning preferences of students, which are essential for developing effective and inclusive teaching modules. The analysis included factors such as gender, ethnicity, smartphone ownership, technological skills, environmental awareness, and learning styles.

3.3.1. Demographics

The gender distribution showed a higher percentage of female students, with 62.6% (102 students) compared to 37.4% male students (61 students). This gender imbalance necessitates tailored instructional strategies to ensure engagement and inclusivity for both genders, recognizing potential differences in learning preferences and classroom dynamics. The ethnic composition of the students was notably diverse, with the largest group being Iban, comprising 37.4% (61 students) of the population. This was followed by Malay students at 25.2% (41 students), Melanau at 21.5% (35 students), Chinese at 6.7% (11 students), and a mix of other ethnicities including Kenyah, Bidayuh, and Orang Ulu, making up 9.2% (15 students). Such a multicultural classroom environment requires careful consideration of sociocultural factors in instructional design and language use. Educators must ensure that teaching materials and methods are culturally inclusive and relevant, fostering an environment where all students feel represented and respected.

A significant finding from the survey was the high rate of smartphone ownership, with nearly all students (98.8%, 161 students) owning a smartphone. Only two students reported not having individual smartphones and instead shared them with family members. This high level of access to smartphones highlights a substantial opportunity to integrate digital learning tools into the educational process. The availability of mobile devices supports the use of educational apps, online modules, and interactive platforms, facilitating self-paced learning and providing students with access to a wealth of resources outside the traditional classroom setting [24]. The student responses based on their gender, ethnicity, and smartphone ownership are illustrated in Figures 1(a)-(c) respectively.

These demographic insights underscore the need for an inclusive educational environment that accommodates students' diverse cultural backgrounds and technological capabilities. The predominance of smartphone ownership suggests that digital learning tools can enhance educational outcomes by offering personalized, accessible, and engaging experiences [25]. By leveraging these tools, educators can create a more dynamic and responsive learning environment, tailored to the needs of a diverse student body.



(a) (b) (c)

Figure 1. Student responses based on their (a) gender, (b) ethnicity, and (c) smartphone ownership

3.3.2. Students' competency

Descriptive statistical analysis reveals that students generally exhibit strong competencies in technology use, reading, listening skills, independent learning, and environmental awareness. High proficiency in internet use (M=3.91, SD=0.74) and smartphone use (M=4.13, SD=0.73), suggests that students are well-equipped with modern communication and technology skills. This indicates that they are generally adept at navigating digital platforms and using modern communication tools effectively. These skills are crucial for the integration of technology-enhanced learning tools in the curriculum. Reading skills were found to be stronger (M=4.02, SD=0.77) compared to listening skills (M=3.58, SD=0.71). The moderate listening skills may be due to the multilingual environment, where students speak Malay along with other languages like Iban, Melanau, and Chinese. Exposure to multiple languages can lead to language interference, where linguistic features from one language unintentionally affect another, impacting the students' ability to accurately comprehend each language. Research indicates that linguistic distance between known and learned languages can influence listening skills, with greater linguistic distance presenting more challenges in auditory comprehension due to differences in structure, intonation, and pronunciation that the students' minds need to adapt to study's [26]. Additionally, the ability to understand spoken language depends on the students' background knowledge and exposure to the language in social and academic contexts [27].

Students' ability to learn independently was moderate (M=3.63, SD=0.82), while their reliance on teacher assistance was relatively high (M=4.36, SD=0.78). This highlights the importance of teacher support and the need for a balanced approach that combines independent learning with strong guidance. Students showed moderate interest in new learning methods (M=3.55, SD=0.95) but displayed a strong inclination towards using technology in learning (M=4.12, SD=0.82). This suggests a positive reception to technology-enhanced learning, but also emphasizes the need for diverse teaching methods to maintain engagement. Environmental awareness among students was relatively low (M=3.25, SD=0.83), indicating low sensitivity to environmental issues and a lack of initiative in seeking related information. However, students showed a high awareness of the negative impact of inefficient energy use on the environment (M=4.23, SD=0.82). This points to the need for integrating environmental education into the curriculum to help students better understand and address environmental challenges effectively [28]. The results of the descriptive statistical analysis are presented in Table 3.

Table 3. Descriptive statistical analysis of student competencies and environmental awareness

No	Item	Mean score (M)	Standard deviation (SD)
1	I am proficient in using the internet	3.91	0.744
2	I am proficient in using a smartphone	4.13	0.730
3	I have good listening skills	3.58	0.711
4	I have good reading skills	4.02	0.774
5	I am able to learn independently	3.63	0.824
6	I need teacher assistance to explain things when learning	4.36	0.784
7	I like using new methods to learn	3.55	0.950
8	I like learning using technology	4.12	0.822
9	I often keep myself informed about environmental issues	3.25	0.832
10	I know that inefficient energy use negatively impacts the environment	4.23	0.819

3.3.3. Students' learning styles

The analysis of learning styles revealed a relatively even distribution among visual, auditory, and kinesthetic preferences, indicating the necessity for diverse instructional strategies to effectively cater to all learning preferences. Specifically, 31.9% of the students identified as visual learners, 30.7% as auditory learners, 29.4% as kinesthetic learners, and 8.0% as multimodal learners who utilize a combination of these approaches. The distribution of learning styles among students is illustrated in Figure 2.

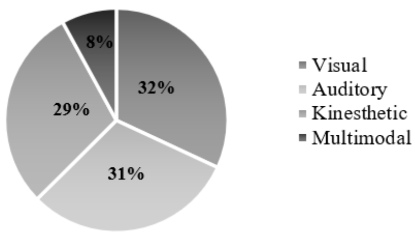


Figure 2. Distribution of learning styles among students

To cater to the varied learning preferences identified in the student competency analysis, it is essential to employ a diverse range of teaching methods [29]. Visual learners, who represent a significant portion of the student population, benefit greatly from the use of diagrams, charts, videos, and other visual aids [30]. These tools simplify complex concepts and make them more accessible. For instance, visual representations of scientific processes, such as the water cycle or electrical circuits, aid in comprehension and retention. Interactive whiteboards and visual storytelling can further enhance the learning experience for these students, making abstract concepts more concrete and understandable. Auditory learners thrive in environments where information is delivered through discussions, lectures, and audio materials. These students are more likely to engage and retain information when they can hear and discuss it. Educators can leverage this by incorporating more group discussions, debates, and audio recordings into their lessons. Podcasts and recorded lectures are valuable resources, allowing auditory learners to revisit and reinforce the material at their own pace [31]. Additionally, using rhythmic or musical mnemonics can help these students memorize complex information more effectively, making learning more enjoyable and memorable. Kinesthetic learners, who learn best through hands-on activities and movement, require a more interactive approach [32]. Practical experiments, model building, and role-playing activities make learning more tangible and engaging for them. For example, conducting science experiments that allow students to physically manipulate materials and observe results can deepen their understanding of scientific principles. Incorporating physical activities, such as laboratory work or field trips, provides real-world applications of theoretical knowledge, enhancing kinesthetic learners' comprehension and retention. Multimodal learners benefit from a combination of visual, auditory, and kinesthetic approaches, allowing them to adapt to various instructional methods [33]. By employing a mix of visual aids, interactive discussions, practical experiments, and multimedia resources, educators can ensure that all learning styles are addressed. This diverse approach not only accommodates different learning preferences but also makes learning more dynamic and engaging for all students, leading to better educational outcomes.

4. CONCLUSION

Based on the analysis of student characteristics, this study recommends several strategies to enhance instructional methods and optimize learning outcomes. The findings emphasize the importance of integrating digital learning tools into the curriculum to align with students' high proficiency in internet and smartphone use. This includes educational apps, online modules, and interactive platforms that enable self-paced learning and provide access to diverse resources, aligning education with students' digital fluency. However, while fostering independent learning, it is essential to maintain adequate teacher guidance. Students' reliance on teacher assistance indicates the need for a balanced approach, combining opportunities for self-directed learning with structured support through regular feedback and personalized assistance. This balance helps students develop self-regulation skills without feeling overwhelmed. Furthermore, making learning relevant to real-world applications, particularly environmental issues, can enhance student engagement and comprehension. For example, teaching about energy efficiency can involve practical exercises such as analyzing household energy consumption or exploring renewable energy solutions, thus making learning more relevant and impactful.

Moreover, to accommodate diverse learning preferences, a variety of instructional techniques should be employed. The needs analysis bridges the gap between educational theory and practice by identifying effective teaching approaches that are engaging and pedagogically sound. This comprehensive strategy ensures that students' educational needs are met, leading to improved learning outcomes and a more effective educational experience overall. Future research should focus on developing and evaluating innovative teaching methods that incorporate new technologies and address diverse learning preferences. Longitudinal studies on the long-term effects of these strategies on student learning and behavior, as well as research on effective teacher training programs and resource allocation, are crucial for the successful implementation of personalized energy education initiatives. Additionally, investigating the impact of energy education on students' career choices and engagement in energy-related fields can yield valuable insights. By implementing these recommendations, educators can create more effective and inclusive energy education programs, helping to create a more energy-literate and environmentally aware society.

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C : **C**onceptualization
M : **M**ethodology
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Fo : **Fo**rmal analysis
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D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research involving human participants complied with all relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration. Research permission for this study was obtained from the Educational Planning and Research Division (EPRD), Ministry of Education Malaysia, and the Sarawak State Education Department.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [KO], upon reasonable request. The data are not publicly available to protect the privacy of research participants.

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