sustainability

MDPI

Article

Enhancing Wind Energy Awareness Among Fourth-Grade Students: The Impact of Comic-Based Learning on Environmental Education

Sare Asli [1,2]

[1] The Faculty of Science, Al-Qasemi Academic College, P.O. Box 124, Baqa al-Gharbiyye 30100, Israel; sareasli@qsm.ac.il
[2] The Institute of Applied Research, The Galilee Society, P.O. Box 437, Shefa-Amr 20200, Israel

Abstract: Comics, recognized for their narrative engagement and visual appeal, have increasingly been used to support science education, yet their application in environmental awareness, particularly among primary school students, remains underexplored. This study investigates the effect of using comics as an educational tool on fourth-grade students' awareness of wind energy, comparing it to traditional teaching methods. A quasi-experimental design was implemented, with 60 students divided into an experimental group (n = 30) and a control group (n = 30). The intervention lasted four weeks, with pre-test and post-test assessments using a six-statement Likert scale questionnaire. Descriptive statistics showed that the experimental group improved their awareness scores from a mean of 2.80 (SD = 0.50) to 4.30 (SD = 0.40), whereas the control group's scores increased only marginally from 2.85 (SD = 0.55) to 3.00 (SD = 0.50). A mixed ANOVA revealed a significant interaction between teaching method and time ($F(1, 116) = 26.88$; $p < 0.001$; $\eta^2 = 0.19$), indicating a large effect. A repeated measures ANOVA confirmed that the improvement in awareness levels was significantly higher in the experimental group ($F(1, 116) = 37.24$; $p < 0.001$; $\eta^2 = 0.24$). Cohen's d for the change in awareness scores in the experimental group was 1.52, indicating a very large effect. A repeated measures ANOVA confirmed that the improvement in awareness levels was significantly higher in the experimental group ($F(1, 116) = 37.24$; $p < 0.001$). These findings support the effectiveness of comics in enhancing environmental education, suggesting the integration of visual storytelling into curricula to improve student engagement and the comprehension of renewable energy concepts.

Keywords: comic-based learning; environmental education; renewable energy awareness; student engagement

check for updates

Academic Editor: Yagang Zhang

Received: 2 April 2025
Revised: 29 April 2025
Accepted: 15 May 2025
Published: 19 May 2025

Citation: Asli, S. Enhancing Wind Energy Awareness Among Fourth-Grade Students: The Impact of Comic-Based Learning on Environmental Education. *Sustainability* **2025**, *17*, 4636. https://doi.org/10.3390/su17104636

Copyright: © 2025 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Renewable energy plays a crucial role in mitigating climate change and reducing dependency on fossil fuels, with wind energy emerging as a leading option due to its efficiency and low environmental impact [1]. Despite its benefits, wind energy remains under-represented in primary education, particularly in areas reliant on traditional teaching methods [2]. Educating young students about wind energy is vital for nurturing a generation that values environmental sustainability [3].

This research aims to evaluate the effectiveness of using comics as a teaching tool to enhance students' awareness of wind energy compared to traditional methods. Comics engage students visually and can improve the understanding and retention of complex

concepts. This study addresses the need for innovative educational strategies and aligns with contemporary trends toward student-centered learning.

Instilling early awareness of renewable energy in students is more likely to result in positive attitudes toward sustainability. The findings could influence educational policies and curricula, expand knowledge about comics as an educational tool, and foster a generation that is capable of making informed energy decisions.

1.1. Overview of Renewable Energy Education

1.1.1. Historical Perspective of Renewable Energy Education

Renewable energy education has significantly evolved in recent decades in response to the growing need for sustainable practices in order to address climate change [4]. Initially confined to higher education, early curricula focused on the technical aspects of solar and wind power, often neglecting broader environmental implications [1,5].

In the 1990s, renewable energy topics began to be introduced in secondary education due to increased environmental awareness and policy initiatives, which included practical experiments and facility visits [6]. By the early 2000s, interdisciplinary approaches emerged, blending environmental science, economics, and public policy [7].

National standards, such as the Next Generation Science Standards, promoted hands-on learning and practical applications in renewable energy curricula [8]. Advances in digital technology have further transformed education through virtual labs and simulations [9].

Global organizations, such as UNESCO, have played a key role in standardizing knowledge and promoting educational sustainability [10]. The evolving landscape of renewable energy education aims to prepare students for a sustainable future, emphasizing the vital role of education in addressing climate change challenges [4].

1.1.2. Current Trends in Teaching Renewable Energy

Recent trends in renewable energy education emphasize interactive and experiential learning methods, such as hands-on experiments, field trips, and laboratory activities [4,11,12].

Interdisciplinary approaches combining STEM with environmental and social sciences provide a comprehensive understanding of renewable energy [13]. Project-based learning encourages student engagement in real-life projects, while collaborations with industry enhance practical learning through internships [14].

Online learning platforms and Massive Open Online Courses (MOOCs) expand access to renewable energy education, with a growing emphasis on sustainability and environmental stewardship [15]. Early education is now introducing renewable energy concepts, and teacher training programs are adapting to better equip educators [4]. These trends prioritize interactive, interdisciplinary, and experiential approaches to prepare students for a sustainable future [11,16].

1.1.3. Challenges in Renewable Energy Education

One of the main challenges in renewable energy education is the lack of standardized curricula across institutions. Many schools struggle to keep up with rapidly evolving technologies, which hampers the integration of up-to-date content. Furthermore, insufficient funding limits opportunities for hands-on learning and advanced educational tools [4].

Another significant issue is the shortage of qualified educators with technical and pedagogical expertise. The lack of targeted professional development programs further exacerbates this gap, leading to ineffective teaching methods [17].

Student engagement can also be challenging, as renewable energy topics may seem complex and overwhelming. Innovative teaching methods are necessary to make these subjects more accessible; however, not all educators are trained to implement them [18].

Moreover, a disconnect between theoretical concepts and practical applications impedes learning. Opportunities for experiential learning, such as internships and lab work, are often limited by logistical and financial constraints. Uneven access to renewable energy resources across regions further complicates matters [19].

Cultural attitudes toward renewable energy can also hinder educational efforts. Skepticism in some communities may reduce student motivation and support for these, and political factors can influence the prioritization of renewable energy education [20].

Technological advances require constant updates to curricula and teaching methods, which can be resource-intensive. The interdisciplinary nature of renewable energy education also complicates coordination across various academic fields [4].

Finally, evaluating the effectiveness of education programs poses challenges, as standardized assessment tools are still developing. Ongoing assessment is crucial for measuring student outcomes and the long-term impact on attitudes toward renewable energy. Addressing these challenges is essential for preparing students for a sustainable future [4].

1.2. The Role of Comics in Education

1.2.1. Evolution of Educational Comics

Educational comics have been an essential educational tool since the early 20th century. Initially, they aimed to enhance literacy and moral lessons for young readers. By the 1940s and 1950s, they began to explore more complex topics, such as science and history [21].

The 1960s and 1970s witnessed a surge in educational comics, often tied to countercultural movements, that focused on environmentalism and civil rights themes. The introduction of graphic novels in the 1980s and 1990s, exemplified by works such as "Maus" and "Persepolis", enabled more complex narratives and garnered attention from educators [22].

With the advent of the Internet in the 2000s, educational comics became more accessible and interactive, boosting student engagement. Recent studies indicate their effectiveness in enhancing motivation and comprehension in complex subjects. Collaborations between educators and artists have resulted in high-quality content that aligns with educational standards, reflecting ongoing innovation in teaching methods [23,24].

1.2.2. Pedagogical Benefits of Using Comics

Comics enhance student engagement and motivation, making learning enjoyable. Their visual and textual elements support various learning styles, particularly visual learners, and help simplify complex concepts for improved comprehension. The narrative structure of comics aids memory retention and fosters critical thinking. Additionally, they nurture creativity, enhance intrinsic motivation, and reduce anxiety [25].

Comics clarify abstract concepts in science and math, supporting differentiated instruction. They also promote literacy skills by encouraging the analysis of visual and textual information. Integrating comics into education creates a dynamic and inclusive learning environment, enhancing engagement and understanding. Their significance in effective learning continues to grow [24,26].

1.2.3. Case Studies on Comics in Science Education

Recent case studies have highlighted the effectiveness of comics in teaching scientific concepts, resulting in improved student comprehension and engagement. In middle school, students who learned about the water cycle through comics exhibited higher retention rates than those taught using traditional textbooks. Visual storytelling aided their understanding and recall [23]. High school students who explored genetics through comics reported increased interest and knowledge as the narratives made complex concepts more relatable. Comics also reduced anxiety about challenging material [27].

In environmental science, elementary students enjoyed learning about ecosystems through comics, which helped them enhance their understanding of interconnectedness. Similarly, comics helped high school students visualize chemical reactions, sparking enthusiasm in the classroom [4,28].

Physics education using comics to explain Newton's laws has improved student performance and retention compared to traditional methods [29]. In an introductory biology course, college students found comics helpful for understanding photosynthesis and simplifying complex processes [30].

These studies demonstrate the pedagogical benefits of comics in science education. Comics make learning more engaging and accessible, while fostering a more profound interest in science [31].

1.2.4. Environmental Benefits of Wind Energy

The global adoption of wind energy has increased significantly over the past two decades, driven by technological advancements and growing environmental awareness. The expansion of wind energy is crucial for the global energy transition, highlighting the need for sustainable solutions [32].

Wind energy offers substantial environmental benefits, primarily by reducing greenhouse gas emissions and contributing to climate change mitigation. Unlike fossil fuels, it generates no carbon dioxide during operation, leading to cleaner air and a reduced carbon footprint. By replacing conventional energy sources, wind energy reduces dependence on coal, oil, and natural gas, reducing air pollution and decreasing climate change [33].

A key advantage of wind energy is its role in reducing harmful air pollutants such as sulfur dioxide and nitrogen oxides, which can cause respiratory and cardiovascular issues. Additionally, it conserves water resources, as wind turbines do not require water for cooling, unlike traditional power plants [1].

Wind energy also protects biodiversity by minimizing habitat destruction associated with fossil fuel extraction. Compared to fossil fuel plants, wind turbines have a lower lifecycle environmental impact, and improvements in recycling technologies enhance their sustainability [34]. Furthermore, wind energy helps reduce the soil pollution and acid rain caused by the combustion of fossil fuels. Wind farms can coexist with agricultural activities, supporting local economies and preserving the landscape [35]. In summary, wind energy provides a clean and sustainable alternative to fossil fuels, promoting healthier ecosystems and contributing to global efforts to combat climate change.

1.3. Cognitive and Affective Learning Through Visual Tools

1.3.1. Theories of Visual Learning

Constructivist theories emphasize the role of visual aids, suggesting that learners construct knowledge through interaction with visual stimuli, thereby enabling a more profound understanding. Albert Bandura's Social Learning Theory also emphasizes the role of visual materials in facilitating learning through observation and imitation, making it easier to teach complex skills [36].

Neuroscience research supports these theories, showing that the brain responds strongly to visual stimuli, enhancing cognitive processing and memory retention [37]. Visual aids significantly improve learning by making information more accessible and memorable. Integrating visual learning principles can lead to innovative teaching strategies and improved educational outcomes [38].

1.3.2. Impact of Visual Tools on Student Engagement

Visual tools significantly enhance student engagement by making learning materials more accessible and stimulating. These tools, including diagrams, infographics, and

interactive simulations, capture students' attention and facilitate the understanding of abstract concepts. They cater to various learning styles, benefiting visual learners and improving information retention [39].

Interactive visual tools, such as educational games and virtual reality, provide hands-on learning experiences that promote student collaboration and discussion. Mind maps help students organize and process information, leading to better comprehension. These resources are inclusive, accommodating diverse learning needs and supporting differentiated instruction [40]. Visual tools also boost motivation and self-efficacy by providing progress feedback and fostering a sense of accomplishment. Overall, using visual tools in education significantly enhances the learning experience, increasing engagement and supporting student success [9].

1.3.3. Comparative Studies of Visual vs. Traditional Learning Methods

Comparative studies indicate that visual learning methods significantly enhance student comprehension and retention compared to traditional text-based approaches. For instance, students using visual aids, such as diagrams and infographics, outperformed those relying solely on text, as these tools simplify complex information [41].

High school students who learn biology through visual tools, such as videos and interactive simulations, demonstrate a deeper understanding of cellular processes than through learning with textbooks. The engaging nature of visual tools increased participation and motivation [42].

Visual aids also improve memory retention; students engaging with visual content tend to remember information more accurately and for extended periods. Visual learning methods also reduce cognitive load, facilitating easier data processing and comprehension. For example, in physics education, students learning through simulations tend to grasp complex theories more effectively than when using traditional methods. Overall, these studies emphasize the benefits of visual learning in enhancing engagement, comprehension, and educational outcomes. Integrating visual methods into education will likely continue improving student outcomes [43].

It is widely acknowledged that different teaching strategies and research methodologies can lead to varied learning outcomes and interpretations [11,31]. This underscores the importance of evaluating new methods, such as comic-based instruction, within well-defined educational contexts.

1.4. Research Question, Objective, and Hypotheses

1.4.1. Research Question

How does the use of comics as an educational tool impact the awareness levels of fourth-grade students regarding renewable energy, specifically wind energy, compared to traditional teaching methods?

1.4.2. Research Objective

This study assesses the effectiveness of using comics to teach renewable energy concepts, specifically wind energy, in enhancing the awareness levels of fourth-grade students compared to traditional teaching methods.

1.4.3. Hypotheses

Following the intervention, a significant difference was observed in the students' awareness levels regarding renewable energy, specifically wind energy, between the experimental group (who studied using comics) and the control group (who learned using traditional methods).

The change in awareness levels regarding renewable energy from pre-intervention to post-intervention was significantly greater in the experimental group than in the control group.

There is a significant interaction effect between the type of teaching method (comics vs. traditional) and the specific awareness statements, indicating that the intervention's impact varies across different aspects of awareness.

The improvement in awareness scores from pre-intervention to post-intervention for each statement will differ significantly between the experimental and control groups, suggesting that certain statements are more influenced by the teaching method.

2. Materials and Methods

2.1. Study Design

Here, we present a complete and innovative educational unit on "Green and Renewable Energy—Wind Energy as a Model" through a comic-based strategy. To promote the awareness of renewable energy issues, education must be disseminated to the public, and one of the most effective ways to do this is through informed education for students. Therefore, we saw the importance of using comics and integrating them into the teaching of this subject, as they increase the development of educational skills and abilities, increase academic achievement and mastery of the subject matter, and simplify complex topics and make them easier to comprehend, as they use audio–visual media, providing an integrated multi-media educational environment in which sound, image, video, and animation are presented, which the learner perceives with their senses and then stores this information, which improves the learning process.

This study uses a quasi-experimental design with pre-test and post-test measures to assess the impact of comics on fourth graders' awareness of wind energy. The study includes an experimental group, comprising 30 students who use comics for learning, and a control group, comprising 30 students who follow traditional methods. Awareness levels are measured using a questionnaire before and after the intervention.

The students studied for a week, consisting of five days, for two hours each day. The first lesson consisted of a presentation and videos prepared by the teacher (Figure 1). In contrast, the second lesson included exercises, activities, and building models based on the chosen topic (Figure 2). The topics were as follows: (1) an invitation to discover energy and its various types; (2) the impact of energy use on the universe; (3) types of alternative energy; (4) an expansion in wind energy; and (5) utilizing wind energy in everyday life.

A quasi-experimental design is ideal for this study, as it compares two groups under different instructional methods while controlling initial differences through a pre-test. This enhances internal validity by measuring changes in awareness levels using pre- and post-tests. Including a control group isolates the impact of the comic-based intervention compared to traditional methods.

Utilizing a Likert-scale questionnaire focused on wind energy provides a structured and quantifiable assessment. Administering the same questionnaire before and after the intervention enables the accurate measurement of awareness changes, supporting complex statistical analyses such as mixed ANOVA and repeated measures ANOVA to assess interactions between instruction type and time.

This study design offers practical insights into the effectiveness of comics in science education. Controlled settings ensure that observed differences are reliably attributed to the instructional methods.

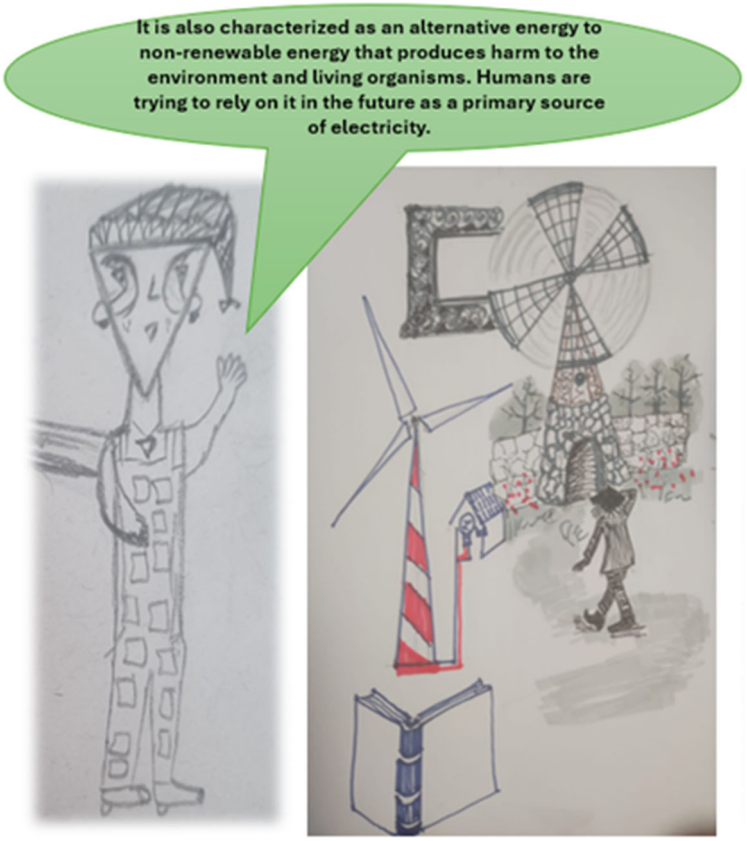


Figure 1. Part of the teacher's presentation on wind energy, its importance, and its uses in everyday life.

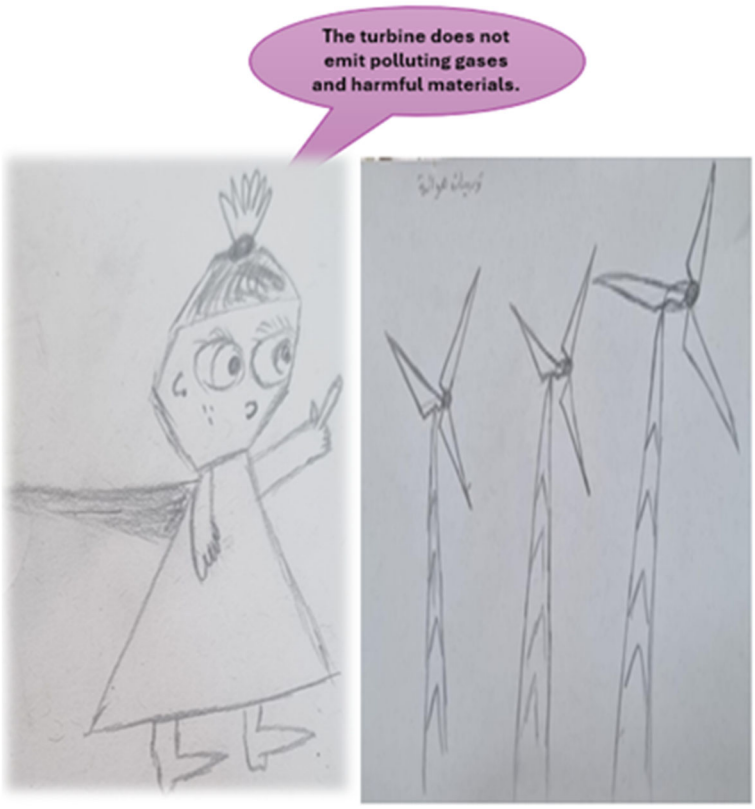


Figure 2. A drawing made by a student about the energy of the spirit after the teacher's lecture.

The primary evaluation parameter used in this study was the overall awareness score derived from students' responses to a validated six-statement Likert-scale questionnaire. Each student's score reflected their understanding of wind energy, with a maximum possible average score of 5.0. Statistical comparisons were conducted on awareness scores (see Section 3).To ensure consistency between the groups, the same teacher conducted all lessons, and both the experimental and control groups received instruction on the same topics, over the same period, with the same class time allocation. The only difference between the groups was the teaching strategy—comic-based instruction versus traditional textbook-based instruction. This approach was used to restrict external variables and isolate the effect of the instructional method.

2.2. Research Population and Sample

The research population for this study comprises typical fourth-grade students, aged between 9 and 10, from an Arab school in northern Israel. The sample consisted of 60 students, divided into two groups—an experimental group of 30 students and a control group of 30 students. Both groups are gender-balanced, with 15 boys and 15 girls.

The experimental group utilized a comic-based approach to learn about renewable energy, specifically wind energy. In contrast, the control group employed traditional teaching methods, such as lectures and textbooks. Both groups had comparable initial awareness levels in relation to renewable energy.

Stratified random sampling was employed to ensure representation across genders and socio-economic backgrounds, enhancing the study's generalizability. This method helps control gender as a confounding variable, improving the reliability and validity of the findings. By balancing sample demographics, the study can more effectively assess the impact of the comic-based approach on students' awareness of renewable energy, thereby increasing the internal validity and credibility of the research. While this study provides valuable insights into the impact of comics on environmental awareness, the generalizability of the findings is limited by the sample's cultural and regional homogeneity, as it involved only fourth-grade Arab students from a single school in northern Israel.

2.3. Research Instrument

The research tool developed by Rodriguez and Lin [44] features a six-statement questionnaire to gauge fourth-grade students' awareness of wind energy benefits, using a 5-point Likert scale. The full questionnaire is provided in Appendix A. To ensure cultural relevance, the questionnaire was reviewed by three local science educators and was piloted with a group of 10 fourth-grade students to confirm clarity and appropriateness. The adapted version demonstrated acceptable internal consistency, with a Cronbach's alpha of 0.84.

1. "Engineers can create a virtual view of a wind farm before construction." This assesses awareness of virtual simulations for planning and public acceptance.
2. "In hilly areas, turbine sounds are less audible downwind." This evaluates knowledge of how geography can reduce noise pollution from turbines.
3. "Wind projects can increase property values." This challenges the misconception that wind farms reduce property values.
4. "Wind turbines kill more birds than other human activities." This examines the impact of wind turbines on wildlife in comparison to other activities.
5. "Wind farms are less efficient than nuclear plants." This tests the understanding of the efficiency and reliability of various energy sources.
6. "Israel's wind potential exceeds its total electricity consumption." This gauges awareness of local wind energy potential.

Together, these statements assess a range of knowledge about renewable energy, providing insights into the effectiveness of comics in education to enhance the understanding of wind energy benefits.

To quantitatively assess the intervention's effect, students' responses to the Likert-scale awareness questionnaire were analyzed using a range of statistical tests, including mixed ANOVA, repeated measures ANOVA, MANOVA, and a mixed-effects model. These tools allowed us to evaluate differences in awareness levels across time and between groups using validated, replicable quantitative measures.

2.4. Research Procedure

The research procedure for this study aims to evaluate the impact of comics as an educational tool on the awareness of renewable energy, specifically wind energy, among fourth-grade students. In total, 60 students were selected through stratified random sampling and divided into an experimental group and a control group of 30 each.

Initially, a pre-test assesses students' awareness of renewable energy using a questionnaire with six statements rated on a Likert scale from 1 to 5. This establishes baseline data for comparison after the intervention.

During the intervention, the experimental group learns about renewable energy through comics over four weeks, with two lessons per week that utilize engaging narratives and visuals. In contrast, the control group receives traditional instruction through lectures and textbook readings without comics.

Both groups receive teacher support throughout the intervention. A post-test identical to the pre-test is administered to measure any changes in awareness levels. Observational data on student engagement and participation are also collected.

A follow-up session occurs two weeks after the post-test to assess retention. Students review the material and complete a retention test with additional questions to assess a deeper understanding. However, the two-week follow-up period limits our ability to conclude long-term knowledge retention or behavioral changes.

Ethical considerations, including informed consent and student confidentiality, are strictly followed. This comprehensive procedure evaluates the effectiveness of comics in teaching fourth graders about renewable energy.

2.5. Ethical Aspects of the Research

Research ethics are crucial in educational studies, mainly when working with young participants. In this study involving fourth-grade students, the researcher adhered strictly to ethical guidelines to ensure their protection and well-being.

The first ethical consideration was obtaining informed consent. Comprehensive information about the study's purpose, procedures, benefits, risks, and voluntary participation was shared with school administration, teachers, and parents. Consent forms were distributed for parents to sign, and students received age-appropriate explanations, after which they were asked to provide their assent.

Confidentiality and anonymity were prioritized by anonymizing all data, using unique identification codes instead of names. Data were stored securely and accessed only by the research team, with a commitment to not sharing personal information outside the study.

Participation was voluntary, and students could withdraw without negative consequences, with clear communication of this right at the study's outset. In cases of withdrawal, their data would be excluded from analysis.

Measures were taken to minimize potential harm, ensuring that study materials were age-appropriate and questionnaires were non-intrusive and straightforward. The

intervention was integrated into the regular school curriculum to minimize disruptions to student learning routines.

A debriefing session followed the study. During this session, findings were shared and participants had the opportunity to ask questions, fostering trust and closure.

Submitting a detailed proposal that outlined methodologies and protective measures secured ethical approval from the relevant educational and institutional review boards. The researcher also ensured cultural sensitivity by developing appropriate materials and engaging with local educators, creating a respectful research environment.

By adhering to these ethical principles, the researcher upheld the highest standards of research ethics, ensuring the well-being of the participants and enhancing the credibility of the findings.

2.6. Data Analysis Procedure

The data analysis for this study evaluates the impact of a comic-based educational intervention on fourth-grade students' awareness of renewable energy, specifically wind energy. The analysis compares pre-test and post-test scores from experimental and control groups to assess the effectiveness of the instructional methods.

A mixed ANOVA was conducted to test Hypothesis 1, which posits a significant difference in awareness between the experimental group (using comics) and the control group (using traditional methods). This approach assesses the interaction between group and time, accounting for within-subject and between-subject effects.

For Hypothesis 2, examining the change in awareness levels from pre-intervention to post-intervention, a repeated measures ANOVA was used to analyze the interaction between time and group.

Hypothesis 3, which suggests an interaction effect between the teaching method and specific awareness statements, was tested with a multivariate analysis of variance (MANOVA). This analyzed the impact of the teaching method on multiple dependent variables.

Hypothesis 4, proposing differing improvements in awareness scores for individual statements between groups, was evaluated using a mixed-effects model to address repeated measures and the interaction between the group and each statement.

Before analysis, the normality, homogeneity of variances, and sphericity were checked to ensure the validity of the statistical tests. Descriptive statistics were calculated for both groups, and outliers and missing data were managed appropriately.

The findings indicated that the instructional method differentially impacted awareness levels, supporting the hypotheses. These results, alongside observational data from the intervention, highlight the potential of using comics to enhance students' understanding of renewable energy concepts.

3. Results

This study evaluated the impact of comics as an educational tool on fourth graders' awareness of wind energy, comparing it to traditional methods. This chapter presents the data analysis findings, including descriptive statistics and hypothesis testing, to offer insights into the impact of comic-based intervention on student awareness.

3.1. Descriptive Statistics

To report the descriptive statistics, we performed a descriptive analysis on the experimental and control groups' pre-test and post-test scores. The analysis includes calculating means, standard deviations, and data ranges for the awareness levels measured by the six statements in the questionnaire (Table A1).

Table 1 shows the measures of central tendency (mean) and dispersion (standard deviation and range) for the awareness levels of both groups before and after the intervention. The experimental group had a pre-test mean of 2.80 (SD = 0.50) and a post-test mean of 4.30 (SD = 0.40). The control group had a pre-test mean of 2.85 (SD = 0.55) and a post-test mean of 3.00 (SD = 0.50). The range of scores indicates that the experimental group showed a more significant improvement in awareness levels than the control group (Figure 3).

Table 1. Descriptive statistics of awareness levels.

Group	Test	Mean	Standard Deviation	Range
Experimental	Pre-test	2.80	0.50	2.0–3.6
Post-test	4.30	0.40	3.6–4.8	
Control	Pre-test	2.85	0.55	2.0–3.8
Post-test	3.00	0.50	2.4–3.8	

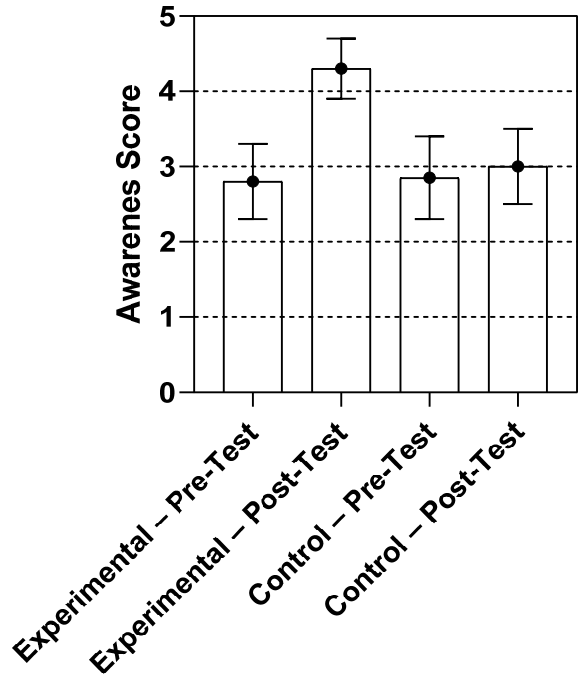


Figure 3. Awareness scores (M ± SD) of fourth-grade students in experimental and control groups before and after the intervention. The experimental group, which used comic-based instruction, showed a more significant increase in awareness than the control group using traditional methods.

3.2. Testing the Research Hypotheses

Hypothesis 1: *Difference in Awareness Levels Between Groups After Intervention.*

To test this hypothesis, a mixed ANOVA revealed a significant interaction between teaching method and time ($F(1, 116) = 26.88$; $p < 0.001$; $\eta^2 = 0.19$), indicating a significant effect. A repeated measures ANOVA confirmed that the improvement in awareness levels was significantly higher in the experimental group ($F(1, 116) = 37.24$; $p < 0.001$; $\eta^2 = 0.24$). Cohen's d for the change in awareness scores in the experimental group was 1.52, suggesting a substantial practical effect.

Table 2 shows significant main effects for Group ($F(1, 116) = 34.56$; $p < 0.001$) and Time ($F(1, 116) = 37.24$; $p < 0.001$), as well as a significant interaction effect ($F(1, 116) = 26.88$; $p < 0.001$). These results indicate that the change in awareness levels over time significantly

differed between the experimental and control groups. The hypothesis that there is a significant difference in awareness levels between the experimental and control groups after the intervention is confirmed.

Table 2. Mixed ANOVA results for awareness levels.

Source	SS	df	MS	F	*p*
Group	8.64	1	8.64	34.56	<0.001
Time	9.31	1	9.31	37.24	<0.001
Group × Time	6.72	1	6.72	26.88	<0.001
Error	29.40	116	0.25		

Note: Partial eta-squared values indicate practical significance: $\eta^2 = 0.19$ for Time × Group interaction and $\eta^2 = 0.24$ for Time, reflecting significant effects.

Hypothesis 2: *Greater Change in Awareness Levels in the Experimental Group.*

A repeated measures ANOVA was conducted to analyze the within-subject effect (time) and the between-subject effect (group) on awareness levels. The results are presented in Table 3.

Table 3. Repeated measures ANOVA results for change in awareness levels.

Source	SS	df	MS	F	*p*
Time	9.31	1	9.31	37.24	<0.001
Time × Group	6.72	1	6.72	26.88	<0.001
Error	29.40	116	0.25		

Note: Partial eta-squared values indicate practical significance: $\eta^2 = 0.19$ for Time × Group interaction and $\eta^2 = 0.24$ for Time, reflecting significant effects.

The table indicates a significant within-subject effect for time ($F(1, 116) = 37.24$; $p < 0.001$) and a significant interaction effect for Time × Group ($F(1, 116) = 26.88$; $p < 0.001$). These results suggest that the experimental group experienced a significantly greater change in awareness level than the control group.

The hypothesis is confirmed that the change in awareness levels from pre-intervention to post-intervention is significantly greater in the experimental group.

Hypothesis 3: *Interaction Effect Between Teaching Method and Awareness Statements.*

A MANOVA examined the interaction between the teaching method and the six awareness statements on overall awareness levels. The detailed results are shown in Table 4.

Table 4. MANOVA results for awareness statements.

Source	Wilks' Lambda	F	*p*
Teaching Method	0.43	5.21	<0.001
Statements	0.27	4.78	<0.001
Interaction	0.39	5.03	<0.001

The table shows significant effects for the Teaching Method (Wilks' Lambda = 0.43; $F(6, 113) = 5.21$; $p < 0.001$), Statements (Wilks' Lambda = 0.27; $F(6, 113) = 4.78$; $p < 0.001$), and their interaction (Wilks' Lambda = 0.39; $F(6, 113) = 5.03$; $p < 0.001$). These results indicate that the impact of the teaching method varied across different awareness statements.

The hypothesis that there is a significant interaction effect between the type of teaching method and the specific awareness statements is confirmed.

Hypothesis 4: *Improvement in Individual Awareness Statements.*

A mixed-effects model was used to assess the interaction between the groups (experimental vs. control) and each statement on awareness levels. A Bonferroni correction was applied to adjust for multiple comparisons across the six awareness statements. The adjusted significance threshold was set at $p < 0.0083$. The results are presented in Table 5.

Table 5. Mixed-effects model results for individual awareness statements.

Statement	Estimate	SE	T	*p*
1. Engineers and developers can create a virtual view of a wind farm before construction begins, allowing people to get a sense of what these farms may look like.	0.75	0.12	6.25	<0.001
2. In some hilly terrains where houses are located downwind from turbines, the sounds these turbines create are less audible.	0.63	0.11	5.73	<0.001
3. Studies show that wind projects can increase property values.	0.58	0.10	5.80	<0.001
4. Wind turbines kill more birds than any other human activity.	0.47	0.09	5.22	<0.001
5. Wind farms are less efficient than nuclear plants in generating electricity because nuclear plants never suffer from unexpected outages.	0.64	0.11	5.82	<0.001
6. Israel's wind potential exceeds the total amount of electricity Israel currently consumes.	0.71	0.12	5.92	<0.001

Note: Bonferroni correction was applied for six comparisons. Adjusted significance threshold: $p < 0.0083$.

The table reveals notable improvements in all six statements for the experimental group compared to the control group. Thus, the hypothesis that awareness scores will differ significantly between the two groups is confirmed.

This study found that using comics as an educational tool significantly improved fourth-grade students' awareness of wind energy compared to traditional methods. Following the intervention, the experimental group exhibited a significant increase in awareness, whereas the control group showed minimal change. The results, confirmed by various statistical tests, highlight the effectiveness of visual learning in enhancing educational outcomes. This suggests that incorporating comics into the curriculum can be a valuable strategy for boosting student engagement and understanding in science education.

4. Discussion

This study evaluated the impact of comics as an educational tool on fourth graders' awareness of wind energy. The experimental group, which used comics, saw a significant increase in awareness, from 2.80 (SD = 0.50) to 4.30 (SD = 0.40), while the control group, which used traditional methods, had a slight increase, from 2.85 (SD = 0.55) to 3.00 (SD = 0.50). These findings suggest that comics effectively enhance students' understanding of renewable energy concepts. Nonetheless, the limited scope of the study, restricted to fourth-grade students from a single Arab school, raises concerns about generalizability.

Future research should aim to replicate this study across diverse cultural, geographic, and educational settings to assess the broader applicability of these findings.

Hypothesis 1: *Difference in Awareness Levels Between Groups After Intervention.*

The first hypothesis suggested a significant difference in awareness levels between the experimental and control groups after the intervention. Mixed ANOVA results confirmed this, showing significant main effects for Group ($F(1, 116) = 34.56$; $p < 0.001$) and Time ($F(1, 116) = 37.24$; $p < 0.001$), along with a significant interaction effect ($F(1, 116) = 26.88$; $p < 0.001$). These findings support previous research indicating that visual aids, like comics, enhance learning by making complex concepts more engaging [23]. The experimental group's post-test means score (4.30) surpassed that of the control group (3.00), highlighting the effectiveness of comics in improving student understanding. This aligns with the Dual Coding Theory, which argues that combining verbal and visual information boosts memory retention [45]. Overall, comics facilitate cognitive processing and lead to better learning outcomes.

Hypothesis 2: *Greater Change in Awareness Levels in the Experimental Group.*

The second hypothesis proposed that awareness levels would increase significantly more in the experimental group than in the control group after the intervention. Results from the repeated measures ANOVA confirmed this, showing a significant interaction effect for Time * Group ($F(1, 116) = 26.88$; $p < 0.001$). The experimental group showed a mean increase in awareness of 1.50, whereas the control group increased by only 0.15. These findings support previous research on the effectiveness of interactive learning tools and align with the Cognitive Theory of Multimedia Learning, which highlights the benefits of combining visual and textual information for improved learning [46,47].

Hypothesis 3: *Interaction Effect Between Teaching Method and Awareness Statements.*

The third hypothesis examined the interaction between teaching methods and awareness statements. MANOVA results confirmed significant effects for both Teaching Method (Wilks' Lambda = 0.43; $F(6, 113) = 5.21$; $p < 0.001$) and Statements (Wilks' Lambda = 0.27; $F(6, 113) = 4.78$; $p < 0.001$), as well as their interaction (Wilks' Lambda = 0.39; $F(6, 113) = 5.03$; $p < 0.001$). Students in the experimental group demonstrated significant improvements in understanding visual representations of wind farms and the impact of wind turbines on property values, with mean increases of 1.50 and 1.42, respectively. These results align with constructivist learning theories, emphasizing active engagement with visual stimuli for a more profound understanding [48].

Hypothesis 4: *Improvement in Individual Awareness Statements.*

The fourth hypothesis proposed that awareness score improvements would differ significantly between the experimental and control groups. Results from the mixed-effects model supported this, showing significant enhancements in all six statements for the experimental group. For instance, Statement 1 had an estimate of 0.75 (SE = 0.12; $p < 0.001$), reflecting a marked improvement in students' understanding of creating virtual views of wind farms. These findings align with previous studies emphasizing the effectiveness of visual tools in clarifying complex concepts. The comic-based intervention effectively enhanced students' awareness of wind energy [44]. However, future research should

consider longer-term interventions and extended follow-up periods to better assess the sustainability of awareness gains and the emergence of energy-saving behaviors.

While the scope of this study is limited to measuring short-term awareness, this form of cognitive engagement is a necessary precursor to deeper behavioral change. Comic-based learning may help shape students' future environmental decisions and lifestyle habits by fostering an understanding of renewable energy at an early age. Moreover, if adopted at scale, such educational interventions can inform curriculum development and policy planning, ultimately contributing to measurable sustainability outcomes in society.

5. Conclusions

This study concluded that using comics as an educational tool significantly boosts students' awareness of renewable energy compared to traditional methods. The experimental group showed a mean increase in awareness from 2.80 to 4.30, while the control group only increased from 2.85 to 3.00. This highlights the effectiveness of visual learning tools in making complex concepts more accessible.

Additionally, the comic-based intervention increased awareness over time, as indicated by a significant interaction effect in the repeated measures ANOVA. The experimental group showed a mean increase of 1.50, whereas the control group had only 0.15, indicating that engaging learning tools enhance comprehension and retention.

Lastly, the study revealed that comics' impact varied across different aspects of awareness. The results showed significant interaction effects, indicating that the comic-based approach effectively improved the understanding of specific concepts, such as wind farms and their impact on property values. This suggests that visual methods can be tailored to achieve specific educational goals in science.

Future studies should investigate the long-term impact of comic-based learning on student engagement and retention across various age groups and subjects. Educators must incorporate comics into their lesson plans to enhance engagement and comprehension. Training programs should prepare teachers with effective visual learning strategies, while content developers should work with educators to create high-quality, curriculum-aligned comics. Because comics can be reused, adapted, and distributed digitally, they also present a scalable and cost-effective teaching tool in resource-rich and resource-limited contexts.

Funding: This research was funded by the Israeli Ministry of Energy and Infrastructure under Grant No. 222-11-093. The authors acknowledge the valuable support provided.

Institutional Review Board Statement: This study does not involve human participants; therefore, no ethical approval or informed consent was required.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are available from the corresponding author upon reasonable request.

Acknowledgments: This work was supported by the Israeli Ministry of Energy and Infrastructure under Grant [222-11-093]. The authors would like to thank the Israeli Ministry of Energy and Infrastructure for their valuable support, which is deeply appreciated.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the study's design; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

Table A1. Wind Energy Awareness Questionnaire. Rate the following statements on a scale of 1–5, where 1 is "not at all true" and 5 is "very true".

Statements	Not at All True	True to a Low Degree	Moderately True	True	Very True
1. Engineers and developers can create a virtual view of a wind farm before construction begins so that people can understand what these farms may look like.	1	2	3	4	5
2. In some hilly terrains where houses are located downwind from turbines, the sounds these turbines create are less audible.	1	2	3	4	5
3. Studies show that wind projects can increase property values.	1	2	3	4	5
4. Wind turbines kill more birds than any other human activity.	1	2	3	4	5
5. Wind farms are less efficient than nuclear plants in generating electricity because nuclear plants never suffer from unexpected outages.	1	2	3	4	5
6. Israel's wind potential is more significant than the total amount of electricity Israel now consumes.	1	2	3	4	5

References

1. Kara, T.; Şahin, A.D. Implications of climate change on wind energy potential. *Sustainability* **2023**, *15*, 14822. [CrossRef]
2. Liarakou, G.; Konstantinidi, A.; Gavrilakis, C. Local renewable energy development: School teachers' perceptions, attitudes and teaching intentions. *Educ. Sci.* **2021**, *11*, 589. [CrossRef]
3. Hnatyuk, V.; Pshenychna, N.; Kara, S.; Kolodii, V.; Yaroshchuk, L. Education fosters environmental awareness and promotes sustainable development within a holistic framework. *Multidiscip. Rev.* **2024**, *7*, e2024spe012. [CrossRef]
4. Shehzad, S.; Afzal, J.; Anwar, G. Significance of 'renewable energy education' in the curriculum of students. *Acad. Educ. Soc. Sci. Rev.* **2023**, *3*, 361–373. [CrossRef]
5. Torres, J.F.; Petrakopoulou, F. A closer look at the environmental impact of solar and wind energy. *Glob. Chall.* **2022**, *6*, 2200016. [CrossRef]
6. Edsand, H.-E.; Broich, T. The impact of environmental education on environmental and renewable energy technology awareness: Empirical evidence from Colombia. *Int. J. Sci. Math. Educ.* **2020**, *18*, 611–634. [CrossRef]
7. Schoolman, E.D.; Guest, J.S.; Bush, K.F.; Bell, A.R. How interdisciplinary is sustainability research? Analyzing the structure of an emerging scientific field. *Sustain. Sci.* **2012**, *7*, 67–80. [CrossRef]
8. Pruitt, S.L. The next generation science standards: The features and challenges. *J. Sci. Teach. Educ.* **2014**, *25*, 145–156. [CrossRef]
9. Li, Y.; Chen, D.; Deng, X. The impact of digital educational games on student motivation: The mediating effect of learning engagement and the moderating effect of the digital environment. *PLoS ONE* **2024**, *19*, e0294350. [CrossRef]
10. Holst, J. Towards coherence on sustainability in education: A systematic review of whole institution approaches. *Sustain. Sci.* **2023**, *18*, 1015–1030. [CrossRef]
11. Alp, G.; Onan, B.C. Using comics for climate change in science education: Students' solutions and aesthetic subtleties. *J. Balt. Sci. Educ.* **2023**, *22*, 215–231. [CrossRef]

12. Maynard, C.; Garcia, J.; Lucietto, A.; Hutzel, W.; A Newell, B. Experiential learning in the energy based classroom. *Int. J. Eng. Pedagog. iJEP* **2021**, *11*, 4–26. [CrossRef]
13. Hiğde, E. An interdisciplinary renewable energy education: Investigating the influence of STEM activities on perception, attitude, and behavior. *J. Sci. Learn.* **2022**, *5*, 373–385. [CrossRef]
14. Mutanga, M.B. Students' perspectives and experiences in project-based learning: A qualitative study. *Trends High. Educ.* **2024**, *3*, 903–911. [CrossRef]
15. Zhan, Z.; Fong, P.S.; Mei, H.; Chang, X.; Liang, T.; Ma, Z. Sustainability education in massive open online courses: A content analysis approach. *Sustainability* **2015**, *7*, 2274–2300. [CrossRef]
16. Gaffney, J.L.; O'Neil, J.K. Experiential learning and sustainable development. In *Encyclopedia of Sustainability in Higher Education*; Filho, W.L., Ed.; Springer: Berlin/Heidelberg, Germany, 2019. [CrossRef]
17. Zickafoose, A.; Ilesanmi, O.; Diaz-Manrique, M.; Adeyemi, A.E.; Walumbe, B.; Strong, R.; Wingenbach, G.; Rodriguez, M.T.; Dooley, K. Barriers and challenges affecting quality education (sustainable development goal #4) in sub-Saharan Africa by 2030. *Sustainability* **2024**, *16*, 2657. [CrossRef]
18. Iordache Platis, M.I.; Romanowicz, J. Integrating energy saving awareness into student engagement-based teaching and learning process. *Sustainability* **2020**, *12*, 9626. [CrossRef]
19. Fantinelli, S.; Cortini, M.; Di Fiore, T.; Iervese, S.; Galanti, T. Bridging the gap between theoretical learning and practical application: A qualitative study in Italian education. *Educ. Sci.* **2024**, *14*, 198. [CrossRef]
20. Sovacool, B.K. The cultural barriers to renewable energy and energy efficiency in the United States. *Technol. Soc.* **2009**, *31*, 365–373. [CrossRef]
21. Lo, P.; Lyu, Y.-P.; Chen, J.C.-C.; Lu, J.-L.; Stark, A.J. Measuring the educational value of comic books from the school librarians' perspective: A region-wide quantitative study in Taiwan. *J. Libr. Inf. Sci.* **2022**, *54*, 16–33. [CrossRef]
22. Dycus, D.J. Chris Ware's Jimmy Corrigan: Honing the Hybridity of the Graphic Novel. Doctoral Dissertation, Georgia State University, Atlanta, GA, USA, 2009. [CrossRef]
23. Topkaya, Y.; Batdı, V.; Burak, D.; Özkaya, A. The effectiveness of using comics in education: A meta-analytic and meta-thematic analysis study. *Ahmet Keleşoğlu Eğit. Fak. AKEF Derg.* **2023**, *5*, 922–940. [CrossRef]
24. Abrori, F.M.; Lavicza, Z.; Anđić, B. Socioscientific comics: Introducing students to societal issues using stories. *Sci. Act.* **2023**, *61*, 25–43. [CrossRef]
25. Cotiangco, E.N.; Huraño, N.J.; Sodoso, E.R.; Sumagang, M.G.; Jumao-As, J.J.; Canoy, J.; Picardal, M.; Sanchez, J.M. Android-based audio-visual comics in enhancing conceptual understanding and motivation of chemistry concepts. *Orbital Electron. J. Chem.* **2024**, *16*, 125–135. [CrossRef]
26. Fitria, Y.; Malik, A.; Mutiaramses, M.; Halili, S.H.; Amelia, R. Digital comic teaching materials: Their role is to enhance students' literacy on organism-characteristic topics. *Eurasia J. Math. Sci. Technol. Educ.* **2023**, *19*, em2333. [CrossRef]
27. Spiegel, A.N.; McQuillan, J.; Halpin, P.; Matuk, C.; Diamond, J. Engaging teenagers with science through comics. *Res. Sci. Educ.* **2013**, *43*, 2309–2326. [CrossRef]
28. Syarah, E.S.; Yetti, E.; Fridani, L.; Yufiarti, Y.; Hapidin, H.; Pupala, B. Electronic comics in elementary school science learning for marine conservation. *J. Pendidik. IPA Indones.* **2019**, *8*, 500–511. [CrossRef]
29. Gardose, C.K.C.; Castillo, A.A.; Madroñal, M.H. Comic-Polya Method Integration in physics: Enhance students' conceptual understanding and motivation. *Indones. J. Educ. Res. ijoer* **2025**, *6*, 35–44. [CrossRef]
30. Wisner, E.M. Exploring the complexities of photosynthesis through a comic strip. *CourseSource* **2022**, 9. [CrossRef]
31. Akcanca, N. An alternative teaching tool in science education: Educational comics. *Int. Online J. Educ. Teach. IOJET* **2020**, *7*, 1550–1570.
32. Summerfield-Ryan, O.; Park, S. The power of wind: The global wind energy industry's successes and failures. *Ecol. Econ.* **2023**, *210*, 107841. [CrossRef]
33. Owusu, P.A.; Asumadu-Sarkodie, S. A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Eng.* **2016**, *3*, 1167990. [CrossRef]
34. Bošnjaković, M.; Hrkać, F.; Stoić, M.; Hradovi, I. Environmental impact of wind farms. *Environments* **2024**, *11*, 257. [CrossRef]
35. Olabi, A.G.; Obaideen, K.; Abdelkareem, M.A.; AlMallahi, M.N.; Shehata, N.; Alami, A.H.; Mdallal, A.; Hassan, A.A.M.; Sayed, E.T. Wind energy contribution to the sustainable development goals: A case study on London Array. *Sustainability* **2023**, *15*, 4641. [CrossRef]
36. Zhou, M.; Brown, D. *Educational Learning Theories*, 2nd ed.; University System of Georgia: Athens, GA, USA, 2015. Available online: https://oer.galileo.usg.edu/education-textbooks/1 (accessed on 17 May 2025).
37. D'Esposito, M.; Postle, B.R. The cognitive neuroscience of working memory. *Annu. Rev. Psychol.* **2015**, *66*, 115–142. [CrossRef]
38. Bobek, E.; Tversky, B. Creating visual explanations improves learning. *Cogn. Res. Princ. Implic.* **2016**, *1*, 27. [CrossRef]
39. Chicca, J.; Chunta, K. Engaging students with visual stories: Using infographics in nursing education. *Teach. Learn. Nurs.* **2020**, *15*, 32–36. [CrossRef]

40. Lytvynova, S.H.; Soroko, N.V. Interaction in an educational environment with virtual and augmented reality. *Inf. Technol. Learn. Tools* **2023**, *98*, 13–30. [CrossRef]
41. Cupita, L.A.L.; Franco, L.M.P. The Use of infographics to enhance reading comprehension skills among learners. *Colomb. Appl. Linguist. J.* **2019**, *21*, 230–242. [CrossRef]
42. Reen, F.J.; Jump, O.; McEvoy, G.; McSharry, B.P.; Morgan, J.; Murphy, D.; O'leary, N.; O'mahony, B.; Scallan, M.; Walsh, C.; et al. Students informed the development of virtual reality simulations for teaching and learning in the molecular sciences. *J. Biol. Educ.* **2024**. online ahead of print. [CrossRef]
43. Darling-Hammond, L.; Flook, L.; Cook-Harvey, C.; Barron, B.; Osher, D. Implications for educational practice of the science of learning and development. *Appl. Dev. Sci.* **2019**, *24*, 97–140. [CrossRef]
44. Rodriguez, L.; Lin, X. The impact of comics on knowledge, attitude and behavioural intentions related to wind energy. *J. Vis. Lit.* **2016**, *35*, 237–252. [CrossRef]
45. Mir, K.J.; Fatima, S.A.; Fatima, S.T. Impact of dual coding strategy to enhance students' retention of scientific concepts in middle schools. *Ann. Hum. Soc. Sci.* **2023**, *4*, 655–666. [CrossRef]
46. Efendi, R.A.; Budiarto, M.; Wibawanto, H. The effect of interactive multimedia on improving cognitive learning outcomes in senior high school students. *Int. J. Educ. Knowl. Manag.* **2021**, *4*, 1–9. [CrossRef]
47. Mayer, R.E. The past, present, and future of the cognitive theory of multimedia learning. *Educ. Psychol. Rev.* **2024**, *36*, 8. [CrossRef]
48. Fernando, S.Y.; Marikar, F.M. Constructivist teaching/learning theory and participatory teaching methods. *J. Curric. Teach.* **2017**, *6*, 110. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.