Does Web-Based STEM Education Enhance Students' Research Activities and Knowledge of Solar Panels? An Evaluation of a Web Platform's Effectiveness

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***Abstract*—In line with the Sustainable Development Goals, integrating educational materials focused on energy efficiency and environmental protection into education has become a pressing priority. The purpose of this study is to determine the impact of Science, Technology, Engineering, and Mathematics (STEM) education on students' research activities in the field of solar energy through a web platform. A pedagogical experiment was organized in the teaching of the "Alternative Energy Sources" course within the physics education program. The web portal of the Growatt server was used as a remote monitoring platform for solar energy systems in the educational process. The pedagogical experiment involved 120 students (control and experimental groups) who implemented STEM projects on the topic of the effect of the angle of incidence on the output power of solar panels. Mathematical and statistical analyses were carried out, and hypotheses were tested using the G*Power software. The results of the study showed that during the course, students became familiar with the main types of solar panels and gained a deeper understanding of their operating principles. Project-based work grounded in STEM education was found to enhance students' research activities. Integrating research results into education enables students to work with real-time data and better understand solar energy systems through practical projects.**

***Keywords*—Science, Technology, Engineering, and Mathematics (STEM) education, STEM project learning, energy teaching, Growatt server, research activity**

I. Introduction

Web platforms enhance students' independence and make the learning process more flexible. They allow access to educational materials anytime and anywhere. Particularly in Science, Technology, Engineering, and Mathematics (STEM) education, web portals facilitate the use of visual tools such as graphs, diagrams, virtual laboratories, and 3D modeling, making it easier to understand complex topics. Our initial research and analysis of scientific literature have shown that topics such as "Solar Energy," "Wind Energy," and "Renewable Energy Sources" in STEM education attract significant interest from students [1–3].

Alternative energy sources are among the most important scientific and engineering challenges in the modern world. Research activities enable the application of the STEM methodology, directing students to solve real-world problems. Integrating new teaching methods into the educational process is crucial and relevant for shaping knowledgeable and conscious individuals capable of addressing energy challenges in modern society. Through research projects, students can propose innovative ideas about alternative energy sources, suggest efficient ways to use solar panels, and develop creative solutions.

Several web platforms support such needs. For instance, web platforms developed by various companies allow real-time monitoring of solar energy systems via the internet, continuous efficiency tracking, early detection of malfunctions, prompt troubleshooting, and overall optimization of energy production anytime and anywhere. Scientific and methodological works also indicate that web platforms are widely used in the educational process within engineering and technical fields [4]. Moreover, scientific research often includes analyzing solar panel performance using web platforms and mobile applications to account for various parameters.

According to Pourasl *et al.* [5], solar energy has become one of the fastest-growing sources of electricity worldwide (Table 1). By the end of 2022, the global installed solar Photovoltaic (PV) capacity exceeded 1,000 GW, accounting for more than 6% of global electricity generation. Countries such as China, the United States, and India are leading this transformation, significantly increasing investments in solar technology. These figures highlight that solar energy is no longer a niche area but a global trend with strategic importance, requiring new generations of specialists to understand its principles and optimize its applications through STEM-based approaches [6].

However, the rapid growth of the solar energy sector poses challenges to education systems. Preparing future professionals demands more than theoretical instruction—it requires practice-oriented, technology-integrated learning models that mirror real-world conditions. In this context, STEM education offers a holistic framework that enables students to connect scientific theory with engineering practice, particularly when supported by digital monitoring tools and real-time data.

Therefore, there is an urgent need to explore how educational institutions can bridge the gap between abstract knowledge and hands-on experience in solar energy through the integration of STEM pedagogy and web-based platforms.

However, there is limited research on the impact of using web-based platforms for solar energy education and their influence on student learning outcomes. Although several e-learning environments exist, few combine real-time data, virtual reality, or modelling tools specifically for renewable energy learning.

Table 1. Global installed solar capacity from 2013 to 2022 (IRENA, 2023)

Region	Solar energy capacity (MW)									
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
World	140,514	180,712	228,920	301,082	395,947	489,306	592,245	720,429	861,537	1053,115
Africa	716	1,709	2,242	3,455	5,200	8,150	9,493	10,819	11,628	12,641
Asia	36,225	60,691	90,581	140,489	211,853	276,406	332,854	410,326	485,413	597,573
Europe	84,189	91,095	99,604	106,173	112,299	121,603	142,272	162,795	190,143	227,799
N. America	13,645	20,129	27,043	38,731	47,828	57,664	69,656	86,493	107,192	126,443
S. America	198	465	921	1,589	3,672	5,512	8,562	13,164	20,795	32,773
Oceania	4,610	5,358	6,079	6,860	7,576	8,881	13,293	18,357	23,342	27,400

For example, Hatzilygeroudis *et al.* [7] introduced a hybrid educational platform that merges Moodle with a 3D virtual world dedicated to solar energy teaching, enabling interactive tutor-led and student-driven solar experiments. These platforms highlight the gap in empirical research on pedagogical effectiveness of digital solar energy tools in education—an area our study directly addresses. Furthermore, the following gaps in the scientific field have been identified:

- A lack of studies scientifically analyzing the experience of teaching solar panels through web platforms within STEM education.
- Insufficiently defined learning objectives when integrating STEM approaches and web platforms.
- Undefined methodologies for using real data collection tools to study parameters like angle, power, voltage, and current of solar panels in the learning process.

Our research aims to develop effective strategies to overcome these challenges and provide a deeper understanding of the impact of web platforms on education quality. Given that solar energy is a globally relevant trend [8], pre-paring future specialists in this field through education has become increasingly essential. Moreover, addressing the outlined research challenges will help determine the impact of STEM education on students' research activities in the field of solar energy using web platforms. Solar panels are often used in STEM research because they are related to various physical parameters such as light intensity, angle of incidence, and temperature. Investigating these factors provides students with an opportunity not only to understand energy production technologies but also to master the basic methods of scientific research. Developing an assessment system for the knowledge and skills acquired through web platforms is a scientific and pedagogical issue. Conducting research in this area aims to generate new scientific results in innovative directions. Our pedagogical study focused on the topic of the effect of the angle of incidence on the output power of solar panels. We used the Growatt company's server platform and the ShinePhone mobile application developed by Growatt during the learning process. STEM projects were implemented around this topic to enhance students' research activities

II. Literature Review

Let us delve into the scientific and methodological works dedicated to the development and application of web platforms, which form the basis of our current research, and discuss modern trends in education. Web-based technologies have emerged as essential components of modern STEM education, yet their pedagogical integration often lacks critical evaluation. Wu *et al.* [9] proposed a web-based assessment platform that ensured anonymity and reliability in evaluating STEM education. While the platform's design addresses institutional needs for standardised evaluation, its direct influence on students' conceptual understanding or engagement remains unexplored. Similarly, Purnama *et al.* [10] conducted a systematic literature review on e-learning, arguing for regular content updates to maintain pedagogical relevance. However, their work primarily examined general education and did not delve into domain-specific challenges such as physics or solar energy.

Birney and McNamara [11] demonstrated that students' self-confidence in technological skills improved through interdisciplinary STEM and computer science curricula. Their study confirms the motivational impact of authentic, community-based programs, though its findings remain limited to affective outcomes rather than cognitive or research skills development. In contrast, our study integrates digital tools to cultivate both motivation and inquiry-based competencies in the context of solar energy.

The introduction of immersive technologies in engineering education, as explored by Mouttalib *et al.* [12], showcases the capacity of WebXR-based platforms to simulate industrial conditions. However, their pedagogical effectiveness remains under-assessed due to the absence of data on student performance or concept mastery. Abichandani *et al.* [13] addressed this by designing a virtual reality system for teaching solar energy fundamentals. While their system facilitates visual learning, it lacks structured integration with student-led experimentation or real-time data analysis, limiting its value in developing research competencies.

Eickenberg *et al.* [14] presented a website that serves as an educational and outreach tool on solar energy. Despite its accessibility, the study does not evaluate the platform's impact on learning outcomes or critical thinking. These gaps are particularly relevant as digital systems become more central to technical education.

Amalu *et al.* [15] conducted a comprehensive analysis of the critical skills required for STEM graduates, particularly in the solar energy industry, highlighting the need for problem-solving, entrepreneurship, and interdisciplinary competencies to meet labor market demands. Similarly, Shahbazloo and Mirzaie [16] investigated the application of a 5E-based STEM education model in the context of solar energy, demonstrating that such an approach significantly enhances students' creativity and academic achievement. These findings suggest that integrating STEM approaches into solar energy education not only supports knowledge acquisition but also develops essential 21st-century skills.

Several studies focus on the technological side of solar monitoring but do not connect it to instructional design. Gaevskii *et al.* [17] analysed photovoltaic inverter performance using web-based systems, identifying efficiency determinants, while Hermansyah *et al.* [18] implemented a weather-station control platform capable of energy source switching. These platforms support real-time data interaction, yet neither study considers their educational implementation. Furthermore, Damarwan *et al.* [19] demonstrated how environmental variables such as humidity and light intensity affect panel output, but stopped short of evaluating how students might engage with such dynamic variables to form hypotheses or test engineering designs.

Abisoye *et al.* [20] introduced an Long Short-Term Memory (LSTM)-based machine learning model to forecast solar radiation. Their approach significantly improved prediction accuracy over traditional models, suggesting clear benefits for system planning. However, the study was not situated within an educational framework. Its results, although technically robust, do not explore how students might use or interpret such forecasts in a learning environment—limiting their pedagogical transferability.

Beyond theoretical research, several digital platforms have been employed for practical management of solar energy. For instance, commercial tools like SMA Sunny [21], SolarEdge Monitoring Platform [22], and PVSyst [23] have proven effective for technical diagnosis and forecasting. Yet their utility in educational settings is rarely addressed. These platforms offer rich real-time data environments, but without curriculum integration or scaffolding, their potential to support inquiry-based STEM learning remains untapped.

Dosymov *et al.* [24] and Giang *et al.* [25] explored digital technologies in STEM learning, such as computer modelling and augmented reality. While these studies documented increased student engagement, they did not provide deep insight into how these tools influence conceptual development or research skill acquisition. Moreover, they focus on general STEM topics rather than specific domains like renewable energy, thereby missing the opportunity to link digital innovation with pressing environmental challenges.

Üzmuş *et al.* [26] developed a Digital Signal Processor (DSP)-based hybrid control system for photovoltaic applications. While technically advanced, such engineering solutions are rarely adapted into learning platforms that support student experimentation or understanding. The complexity of the system architecture, unless simplified and pedagogically framed, poses a barrier for its direct integration into classroom practice.

Finally, Onime *et al.* [27] created an augmented virtuality tool—a solar energy calculator—for engineering education. Unlike earlier systems, this tool was explicitly designed for students and offered a simplified interface to experiment with energy production variables. However, the study did not assess long-term learning gains or its impact on students' independent research abilities.

The reviewed literature affirms the growing presence of web-based and digital tools in STEM education. However, several critical gaps persist. Many studies focus on platform development or technological innovation without addressing pedagogical integration. There is limited empirical evidence evaluating how real-time data use in solar energy education affects students' conceptual understanding or research competencies. Moreover, most platforms lack scaffolding that supports inquiry-based learning aligned with curriculum objectives.

Our study addresses these gaps by integrating web-based solar monitoring into a structured STEM learning model. It extends prior research by emphasising not only the motivational appeal of digital tools but also their cognitive and investigative affordances (Fig. 1).

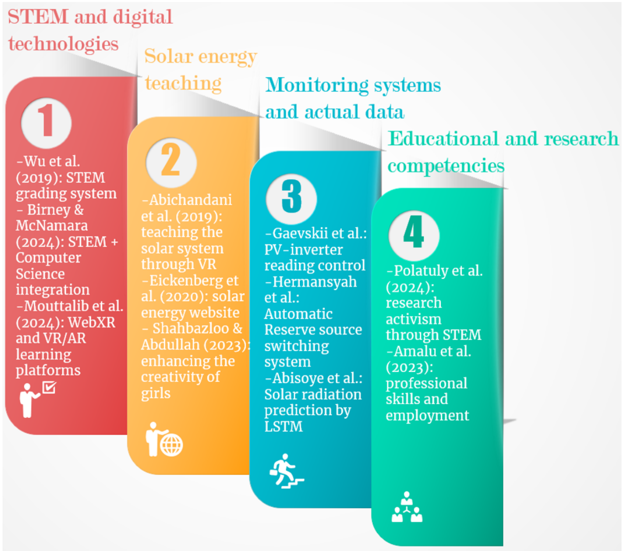

Fig. 1. Classification of literature for the use of STEM-based web platforms in the field of solar energy.

Therefore, exploring the long-term prospects of studying the relationship between solar energy and STEM education using reliable monitoring programs remains relevant. Fully utilizing or correctly integrating the capabilities of existing web platforms into the educational process represents a new scientific direction for fostering students' research activities.

III. Materials and Methods

A. Research Design

The study was based on a quasi-experimental approach. Control and experimental groups were formed from fourth-year students enrolled in the Physics Teacher Education programme at Khoja Akhmet Yassawi International Kazakh-Turkish University. Each group consisted of 60 students (a total of 120 students). Of the participants, 43 were male and 77 were female. All participants had completed core physics courses and were enrolled in the "Alternative Energy Sources" course, making them a suitable cohort for evaluating the effectiveness of STEM-based instruction using web platforms in the context of renewable energy education. The control group was taught using traditional methods, while the experimental group was introduced to the STEM education approach. During the research, the Growatt server web platform for solar energy systems was utilized. This course aimed to teach students the fundamental principles of solar energy, including the operational principles of solar panels. The following scientific hypotheses were developed prior to the research:

- H0: The use of STEM education methods based on web platforms does not significantly affect students' research activities and their knowledge of solar panels.
- H1: The use of STEM education methods based on web platforms improves students' research activities and their knowledge of solar panels.

B. *Research Instruments*

The following tools were employed during the research:

The Growatt server web platform and ShinePhone mobile application were used to monitor real-time data and study the performance of solar panels. Solar panels and inverters were connected to the Growatt server, and inverter parameters were synchronized with the server at this stage. An instructor created an account to input panel-related information, granting students access to the platform. Through the web platform, both the instructor and students monitored the real-time power generation of the panels. Students collected performance data at various angles of sunlight, compared the results, and utilized the platform's and application's analytical capabilities.

Autodesk Inventor software was used as a critical tool in STEM education to develop students' engineering design and modeling skills. Students created 3D models (e.g., a goniometer to measure the angle of sunlight incidence) and developed prototypes for real engineering projects. A 3D printer was employed to produce the developed models.

G*Power software was used to test hypotheses and perform mathematical and statistical analyses.

A customized survey was developed to assess students' research skills and their understanding of the topic.

C. *Sample and Data Collection*

Data collection was conducted in two stages:

- Pre-experiment phase: A survey was administered to assess the initial levels of research activity in both the control and experimental groups before the course on "Alternative Energy Sources," specifically in teaching the operational principles of solar panels.
- Post-experiment phase: The effectiveness of the educational experiment in terms of students' knowledge, research activities, and participation in STEM projects was evaluated. The collected quantitative data underwent statistical processing. Using the G*Power software, the statistical significance of the differences between the results of the control and experimental groups was analyzed.

To assess the impact of the intervention on students' research competencies, a customised survey instrument was developed and administered to both experimental and control groups.

The main objective of the survey was to evaluate students' self-reported competencies in conducting research activities within a STEM-based solar energy context. Specifically, it aimed to capture students' confidence, skill application, data interpretation, and engagement in inquiry-based tasks.

The survey consisted of 12 items divided into four categories:

- Research planning skills (e.g., identifying research questions)
- Data analysis and interpretation (e.g., using solar panel output data)
- Application of STEM knowledge in real contexts
- Self-efficacy and motivation for independent research

Responses were rated using a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree), allowing for a quantitative comparison of perceived research skill levels before and after the intervention.

Each category was assigned equal weight in the analysis. Composite scores were calculated for each participant, and group means were compared using paired samples t-tests and Analysis of Covariance (ANCOVA) to determine statistically significant differences in research competency development. The survey underwent content validation by three subject-matter experts in STEM pedagogy and solar energy education. The experts assessed the alignment of survey items with research competencies targeted by the instructional model. In order to ensure validity, the content of the questionnaire was checked with the participation of three experts in the field of STEM and physics pedagogy. Minor adjustments to item phrasing and ordering were made based on expert feedback to ensure clarity and content relevance.

IV. Result and Discussion

A. *Implementation of STEM Projects*

In accordance with the content of the "Alternative Energy Sources" course, the Growatt platform was used as a key tool during the pedagogical experiment to monitor the operation of solar energy systems in real-time. The platform provided students with the opportunity to analyze solar panel performance, solve engineering problems, and make decisions based on real data. This approach ensured the integration of key STEM elements: Science, Technology, Engineering, and Mathematics.

During the pedagogical experiment, the STEM education methodology was implemented in the following five stages:

1) *Problem identification and analysis*

Students were tasked with exploring the effects of various parameters, including the angle of incidence, on the performance of solar panels. At this stage, they gained an understanding of the energy conversion process and the overall operating principles of solar energy systems.

2) *Development of engineering projects*

Students focused on constructing models to optimize solar panel performance by adjusting the angle of incidence. At this stage, the Growatt platform enabled the collection of real-time data. By monitoring output data, the platform facilitated the observation of power generation levels, efficiency, and overall solar panel performance.

3) *Mathematical calculations and modeling*

Students collected data on the relationship between the angle of incidence and power generation, creating mathematical models. Based on the collected data, they constructed graphs and performed calculations.

4) *Analysis using real data*

Real-time data collected through the Growatt platform were integrated with the ShinePhone application, allowing students to evaluate the efficiency of the tools, identify errors, and propose their own engineering solutions.

5) Development of research skills

The integration of the Growatt platform and STEM projects fostered the development of students' research and practical skills. They learned to collect and analyze data, compare their findings with laboratory conditions, and propose their own solutions (Fig. 2).

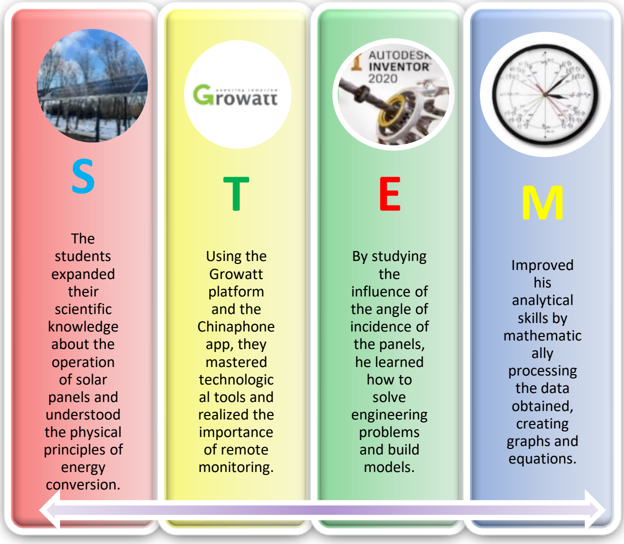

Fig. 2. Implementation of STEM project integration in teaching the topic of solar energy.

Students selected the most favorable day for conducting the research based on the local weather forecast. This decision was crucial since, according to the instructor's assignment, the output power of the solar panels needed to be studied under the influence of only one factor (angle). Choosing the optimal day based on weather conditions ensured the quality of the research results. This allowed students to effectively study the key factors affecting solar panel performance and obtain accurate data.

The research was conducted on December 28, 2024, as the weather was clear, cloudless, and without precipitation. Additionally, the sunrise (7:58) and sunset (17:09) times were considered, and calculations were conducted with a 2-hour interval around solar noon (12:35) (Fig. 3).

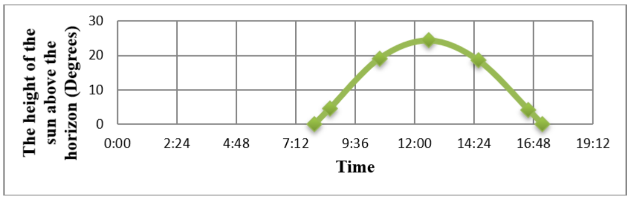

Fig. 3. Graph of the dependence of the height of the sun above the horizon (degrees) and time.

On December 28, students used the StarWalk2 mobile application to calculate the azimuth and altitude of the Sun above the horizon for the local times of 8:35, 10:35, 12:35, 14:35, and 16:35. These enabled students to determine the angle of incidence of sunlight on the surface of the solar panels using Eq. (1) for θ.

$$cos\theta = sinh_s \cdot cos\beta + cosh_s \cdot sin\beta \cdot cos(\gamma_s - \gamma_p) \quad (1)$$

where

β—The tilt angle of the panel (β—the angle between the panel and the horizon). In our case, $\beta = 28°$

γ_p—The azimuth of the panel is the angle between the direction of the panel and the south direction. In our case, $\gamma_p = 0°$, Because the panels are oriented towards the south.

γ_s: Azimuth of the sun—The angle between the Sun's position at a specific time of day and the south direction (varies depending on the time of day).

h_s: The Sun's altitude is the angle between the Sun and the horizontal plane.

For calculation convenience, the data were converted from degrees and minutes to radians according to Eq. (2).

$$radians = degrees \cdot \frac{\pi}{180} \quad (2)$$

1) The tilt angle of the panel (β).

$$\beta = 28^0$$

$$\beta(in\, radians) = 28 \cdot \frac{\pi}{180} = 0.4887\, rad$$

2) Panel azimuth (γ_p)

$$\gamma_p = 0^0$$

$$\gamma_p(in\, radians) = 0$$

3) Azimuth of the sun (γ_s)

$$a.\ \gamma_s = 54^0$$

$$\gamma_s(in\, radians) = 54 \cdot \frac{\pi}{180} = 0.9425\, rad$$

$$b.\ \gamma_s = 29^0$$

$$\gamma_s(in\, radians) = 29 \cdot \frac{\pi}{180} = 0.5061\, rad$$

$$c.\ \gamma_s = 0^0$$

$$\gamma_s(in\, radians) = 0$$

$$d.\ \gamma_s = -29^0$$

$$\gamma_s(in\, radians) = -29 \cdot \frac{\pi}{180} = -0.5061\, rad$$

$$e.\ \gamma_s = -54^0$$

$$\gamma_s(in\, radians) = -54 \cdot \frac{\pi}{180} = -0.9425\, rad$$

4) Height of the sun (h_s)

$$h_s = 4^0 + \frac{53}{60} = 4.883^0$$

$$h_s(in\, radians) = 4.883^0 \cdot \frac{\pi}{180} = 0.0852\, rad$$

The data obtained through the StarWalk2 mobile application can be effectively utilized in physics and STEM-related courses to enhance students' understanding of solar energy concepts. By calculating the azimuth and altitude of the Sun, students can explore how solar panel orientation affects energy efficiency. This hands-on approach enables them to apply theoretical knowledge to real-world scenarios, fostering critical thinking and analytical skills.

B. Methodology for Implementation in STEM Education

The implementation of this methodology follows structured STEM education phases:

1) Phase 1: Concept introduction and theoretical background

Students are introduced to the fundamental concepts of solar energy, solar panel orientation, and the role of azimuth and altitude in energy absorption. Eq. (1) is presented to demonstrate how the angle of incidence of sunlight on solar panels can be determined mathematically.

2) Phase 2: Data collection using technology

On December 28, students used the StarWalk2 mobile application to measure the azimuth and altitude of the Sun for five specific local times: 8:35, 10:35, 12:35, 14:35, and 16:35. The collected data is recorded for further analysis.

3) Phase 3: Mathematical analysis and application

Students use Eq. (1) to calculate the angle of incidence of sunlight on the solar panel surface. Given that the tilt angle of the panel is $\beta = 28°$ and its azimuth (γ_p) is 0° (oriented south), students substitute measured values for the azimuth of the Sun (γ_s) and the altitude of the Sun (h_s) into Eq. (1) to compute cosθ.

For calculation convenience, data is converted from degrees to radians using Eq. (2): radians = degrees × π/180

4) Phase 4: Data interpretation and visualization

The results are plotted on graphs to illustrate how the angle of incidence changes throughout the day. Students compare theoretical and measured values to assess potential discrepancies and analyze the factors influencing solar panel efficiency.

5) Phase 5: Practical implementation and STEM-based experimentation

Students engage in hands-on experiments by adjusting panel angles and comparing energy output at different times of the day. Discussions are held on the importance of optimal panel orientation and how it affects the efficiency of solar power systems.

The application of the methodology for calculating the Sun's astronomical parameters and the angle of incidence of sunlight on the panel is crucial for the efficient use of solar energy. This methodology ensures maximum power generation from the panels and enhances the effectiveness of students' research in the fields of energy efficiency and the use of alternative energy sources. By substituting the calculated angular values into Eq. (1), students performed the calculations and obtained the results presented in Table 2.

Table 2. Results of calculating the angle of incidence of sunlight

No	Time	8:35	10:35	12:35	14:35	16:35
1.	**Azimuth (γ_s)**	54°	29°	0°	−29°	−54°
2.	**Height (h_s)**	4°53′	19°15′	24°40′	18°56′	4°25′
3.	**The angle of incidence of the radiation (θ)**	69.5°	47.3°	37.3°	47.6°	69.9°

A specially designed 3D goniometer model provides students with the opportunity to measure the angle of sunlight incidence on a panel, explore the panel's positioning, study the direction of sunlight, and analyze angular changes. Printing the goniometer using a 3D printer represents an innovative approach to teaching by incorporating STEM education methods. Utilizing the 3D-printed goniometer model elevates STEM education to a practical, technological, and innovative level. This method significantly deepens students' understanding of solar energy systems while enhancing their engineering skills, research activities, and mathematical literacy. Students gained hands-on experience in working with 3D modeling software (such as Autodesk Inventor, Tinkercad, or SolidWorks) and mastered the process of turning a digital model into a tangible product (see Fig. 4).

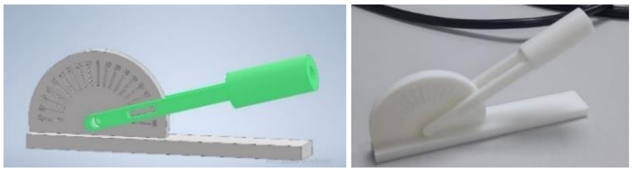

Fig. 4. The goniometer model developed in Autodesk inventor and its product printed using a 3D printer.

The goniometer model developed in Autodesk Inventor and 3D printed is designed for precise angle measurements in physics, engineering, and STEM education. It is used to determine the tilt of solar panels, analyze geometric properties, and conduct experiments requiring accurate angular assessment. The model is first designed digitally, then printed using durable materials for stability. After calibration, it is placed on or adjacent to the object of interest, and measurements are recorded. This tool enhances hands-on learning by integrating digital modeling and 3D printing, making theoretical concepts more tangible and applicable in real-world scenarios.

This tool is placed on the surface of the panel and aligned directly towards the Sun. When sunlight passes through the cylindrical opening, the angle of incidence is determined. Using this data, students obtain the output power of the solar panels at specific times to study their dependence on the angle of sunlight incidence through monitoring on the Growatt server. The Growatt server updates information every 5 minutes, allowing for precise determination of power at the selected times (see Fig. 5).

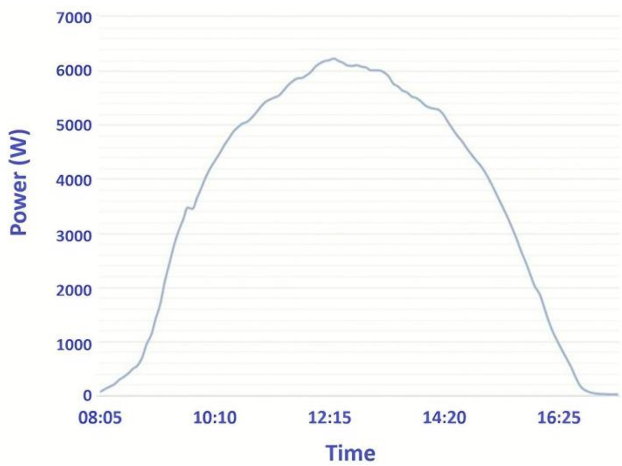

Fig. 5. Output power of panels at specified times determined on the Growatt server (December 28, 2024).

Thus, the Growatt server collects real-time data on the output power generated by solar panels. Plotting the data on the dependence of sunlight's angle of incidence on the panel at specific times is highly significant at multiple levels in the STEM education process (see Table 3).

Based on this dependence, students explore how energy is generated by solar panels and how it is influenced by natural factors. Through this process, they gain a deeper understanding of the principles of energy conversion. Using the graph, students can identify the most efficient angle for positioning solar panels and provide specific recommendations for improving engineering projects. By determining linear or trigonometric dependencies, students can develop a mathematical characterization of the graph.

Table 3. The dependence of the output power on the angle of incidence of sunlight on the panel

The angle of incidence of the radiation *(θ)*	Output power (W)
69.50	405.1
47.30	4956.6
37.30	6095.9
47.60	4797.8
69.90	664.6

C. Results of the Pedagogical Experiment Based on STEM Education

Within the framework of this study, the "Solar Energy Sector" was taught using two different methods: the control group was taught using the traditional teaching method, while the experimental group was taught based on the STEM education approach and the integration of a web platform.

The teaching process for the control group was organized according to the traditional method. In this group, the educational process was mainly limited to lectures, PowerPoint presentations, and textbooks. The working principles of solar panels and theoretical content were delivered through the instructor's explanations, while practical skills were limited to methodological guidelines without real-time data. Web platforms, actual modeling tools, and research-based tasks were not used. As a result, students' interest in the subject and their engagement in practical activities remained limited.

The teaching process for the experimental group was based on the principles of STEM education and was combined with modern digital technologies. During the learning process, students monitored the operation of solar panels in real time via the Growatt server's web platform and the ShinePhone mobile application, collecting practical data. Additionally, a 3D goniometer model was developed using Autodesk Inventor and actual models were created using a 3D printer. Through these models, students determined the angle at which sunlight hit the panel and studied its effect on performance (Table 4).

Table 4. General comparative analysis

Criterion	Control group	Experiment group
Type of training	Traditional	STEM + web platform
Platform	absent	Growatt, ShinePhone
Source	Theoretical	Real-time data
Practice	absent	present (actual date, corner task, schedule)
Modeling	absent	3D modeling (goniometer)
Research skills	low	High

During the learning process, on December 28, 2024, a specific day was selected for the study, and the Sun's azimuth and altitude were calculated using the StarWalk2 application. Based on the obtained angle values, students calculated the angle of incidence (θ) of sunlight on the panel using a formula and compared it with the power data from the Growatt platform. Graphs were plotted based on the collected data, and the optimal operating angle for solar panels was determined.

In the experimental group, students conducted independent research and engaged in activities aimed at solving real engineering problems. This significantly contributed to the development of their research competencies, engineering thinking, as well as analytical and creative abilities.

D. Processing and Analysis of Statistical Data

Mathematical and statistical analyses were carried out on the quantitative data obtained during the study. Preliminary checks (normality and homogeneity of variance) were conducted to ensure the reliability of the data. All statistical calculations and analyses were performed using the Jamovi 2.4 software platform.

Jamovi was chosen due to its user-friendly visual interface, a range of parametric and non-parametric tests, and support for complex analysis methods such as ANCOVA. Using this platform, the pretest and posttest results of the experimental and control groups were compared, and the effectiveness of the pedagogical experiment was evaluated based on the obtained data.

E. Evaluation of the Effectiveness of STEM Education

The results of descriptive statistics showed that the average pretest score of the students participating in the study was 5.49, which increased to 6.47 in the posttest stage. This indicates a positive change in students' knowledge levels after the teaching process. Additionally, the standard deviation in the posttest stage (SD = 1.363) was higher than in the pretest stage (SD = 0.418), indicating a wider variation in the results and differences in the level of knowledge acquired. Overall, this data reflects the effectiveness of the teaching method and provides a basis for further statistical analysis (Table 5).

Table 5. Results of descriptive statistics

Control Stages	N	average	median	SD	SE
PreTest	120	5.49	5.52	0.418	0.0382
PostTest	120	6.47	6.37	1.363	0.1245

To determine the difference between students' pretest and posttest results, a paired samples t-test was used. This method allows for comparing the knowledge levels of participants in the same group before and after the learning process.

As a result of the analysis, Student's t-statistic was found to be = −7.77, with degrees of freedom (*df*) = 119, and a *p*-value < 0.001. This result is considered statistically highly significant since $p < 0.05$.

Accordingly, the null hypothesis was rejected, confirming that there is a significant difference between the pre-instruction and post-instruction results of the experimental group. In other words, the applied teaching method contributes to the improvement of learning outcomes.

F. ANCOVA Test

To evaluate the effectiveness of different teaching methods during the study, factors influencing students' posttest results were analyzed. For this purpose, the Analysis of Covariance (ANCOVA) method was applied. This method allows not only for comparing the final outcome indicators (posttest) of each group (experimental and control), but also for determining the pure effect of the method by considering their initial preparation level (pretest) as a covariate.

The advantage of the ANCOVA method is that it assesses the effect of the independent variable (teaching method) on the dependent variable (posttest), while accounting for prior differences (pretest). Thus, even if the initial level of each group differs, the method helps accurately determine the actual change in final outcomes.

The result obtained through this approach provides a statistical basis for confirming that the difference in academic outcomes between the groups was due to the impact of the teaching method.

Table 6. Results of the ANCOVA test

Indicators	sum of squares	df	arithmetic mean value of the square	F	P
PreTest	0.307	1	0.307	0.200	0.655
Group	40.512	1	40.512	26.438	< 0.001
Waste	179.281	117	1.532		

Table 6 presents the ANCOVA results, showing the analysis of the difference between the posttest scores of the experimental and control groups, taking the pretest results as a covariate. The analysis yielded a value of $F (1,117) = 26.438$, $p < 0.001$ for the Group variable. This indicates a statistically highly significant difference between the groups. Thus, the applied teaching method (the STEM approach and the model based on web platform integration) had a substantial impact on students' academic achievement.

For the PreTest variable, the result was $F = 0.200$, $p = 0.655$, meaning that this covariate did not have a statistically significant effect on the posttest result. This, in turn, indicates that the initial preparation level did not significantly influence the students' final performance.

Therefore, this result obtained through the ANCOVA method confirms the effectiveness of the innovative method used in the teaching process and proves the relevance of its implementation in educational practice.

Tested using G*Power software to reject the null hypothesis in a reliable, factual way.

And the value $F = 0.200$ in PreTest is only for covariate. It is not related to the assessment of the effect of an independent variable (group), so there is no need to compare it with F crit (Fig. 6).

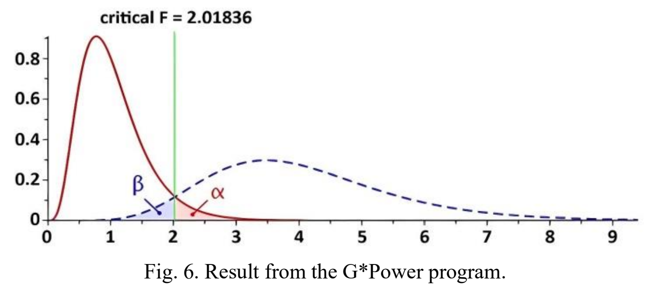

Fig. 6. Result from the G*Power program.

In analyzing the research results, the ANCOVA method was applied to assess the effectiveness of teaching methods while considering the pretest as a covariate. In this analysis, the F value corresponding to the Group variable was calculated as $F = 26.438$. To evaluate the statistical reliability of the study, the critical F value (Fcrit) was determined as 2.018 using the G*Power program.

As a result of the comparison:

$26.438 > 2.018$, meaning the calculated F value is significantly higher than the critical value. This indicates a statistically significant difference between the groups under study. Thus, the applied teaching method (STEM approach and web-platform-based model) had a clear and reliable impact on students' academic achievement.

This conclusion confirms the research hypothesis: the innovative methods used in the teaching process were effective in improving educational outcomes. Furthermore, the effect size calculated in the ANCOVA analysis (Partial $\eta^2 = 0.184$) proves that the difference is not only statistically significant but also practically meaningful.

The parametric tests used in the study (t-test and ANCOVA) require that the data meet certain statistical assumptions. Therefore, the normality of the data and the homogeneity of variances were tested.

The Shapiro–Wilk test was employed to assess normality. For all groups, the p-values were greater than 0.05, indicating that the data were normally distributed. This result validates the appropriateness of using parametric tests.

Additionally, Levene's test was used to examine the homogeneity of variances. The obtained p-values were also above 0.05, indicating that the variances of the control and experimental groups were homogeneous. These findings confirm the reliability of the t-test and ANCOVA results used for group comparisons (Table 7).

Table 7. Results of checking preliminary forecasts

Group	Shapiro-Wilk p	Levene p
Control	0.147	0.318
Experiment	0.092	0.318

The results of the preliminary assumption checks confirmed the appropriateness of applying parametric methods (Shapiro–Wilk $p > 0.05$, Levene $p > 0.05$). The t-test results demonstrated a statistically significant difference between the experimental and control groups ($p < 0.01$).

These findings indicate that the web-based STEM learning platform is an effective tool for enhancing students' research skills and expanding their knowledge of renewable energy sources.

V. Discussion

The results of this study demonstrate that the integration of STEM-based methods with web platforms significantly enhances students' research engagement and cognitive understanding in the field of solar energy. Students in the experimental group were able to interact with real-time data, apply mathematical models, and conduct engineering-based investigations, all of which contributed to higher academic performance. The statistical outcomes, analyzed using G*Power and Jamovi, confirmed the effectiveness of the approach, rejecting the null hypothesis (H_0) and supporting the alternative (H_1): STEM-based instruction using web platforms positively impacts student outcomes.

These findings align with prior studies emphasizing the effectiveness of hands-on, project-based STEM instruction in improving research competencies and critical thinking. Inquiry-based instruction is a critical component of STEM education that enhances scientific understanding and engagement among students. When students engage in real-world tasks, such as optimizing solar panel output using calculated angles of sunlight incidence, they not only grasp theoretical principles but also internalize the practical relevance of their learning.

Onime *et al.* [27] found that students who interacted directly with solar panel installations through participatory learning models showed greater enthusiasm and deeper understanding of solar technologies. Similarly, in this study, the use of the Growatt web platform and the ShinePhone mobile app allowed students to gather real-time power data from photovoltaic systems, which they then analyzed using self-developed mathematical models. The 3D-printed goniometer added another practical dimension, allowing students to measure and adjust panel angles physically—further anchoring learning in direct experience.

This work also confirms that STEM education fosters vital problem-solving and research skills. As noted by Polatuly *et al.* [28], the application of theoretical knowledge to practical challenges—such as determining the optimal angle of incidence for solar panels—is crucial in STEM fields. Web-based modules that encourage such inquiry enhance not only scientific literacy but also students' readiness for engineering tasks.

The interdisciplinary nature of STEM was particularly evident in the fusion of scientific, technological, engineering, and mathematical components throughout the project stages. As Kaleci *et al.* [29] and Nugroho *et al.* [30] have argued, project-based and inquiry-driven curricula are highly effective in promoting integrated learning, which prepares students to address real-world problems using a blend of domain knowledge.

Importantly, this study also aligns with the growing recognition of digital education's role in enhancing educational equity. As Joseph and Uzondu [31] assert, the flexibility of web-based STEM learning can help democratize access to quality education. In our study, students from diverse backgrounds were able to access sophisticated analytical tools and contribute equally to collaborative projects, regardless of prior experience. This supports the broader educational goal of cultivating a generation of well-informed, skilled learners who can actively contribute to global sustainability challenges, including the transition to renewable energy.

However, it is worth acknowledging that the study had certain limitations, such as being conducted within a single institution and relying on a specific solar monitoring platform (Growatt). Future research should explore the application of this model across different educational contexts and technologies. Furthermore, longitudinal studies are needed to assess the sustained impact of such educational interventions on student learning and career outcomes.

In conclusion, this study illustrates the powerful synergy between STEM education, web-based technologies, and practical solar energy applications. It offers a replicable model for developing research capacity, fostering inquiry-based learning, and preparing students for innovation-driven careers in the renewable energy sector.

VI. Conclusion

This study has demonstrated that integrating STEM-based instructional strategies with web platform technologies offers a highly effective approach to enhancing students' research competencies and conceptual understanding in the field of solar energy. By employing the Growatt monitoring platform, 3D modeling tools, and inquiry-based learning methods, students engaged in a real-world exploration of photovoltaic systems and their performance, particularly in relation to the angle of solar incidence.

The quasi-experimental design, supported by statistical analyses using tools such as G*Power and Jamovi, provided empirical evidence that the web-based STEM approach significantly improved students' academic performance and research activity compared to traditional instruction. The ANCOVA analysis confirmed that the teaching method itself—not students' prior preparation—was the key factor influencing the observed improvement in outcomes.

Moreover, this research has added value to the existing body of literature by offering a replicable framework for integrating real-time data collection, engineering modeling, and renewable energy studies within STEM education. It reinforces previous findings that inquiry-based, project-oriented learning increases student engagement and motivation, while also contributing to their scientific literacy and practical problem-solving abilities.

The findings are especially relevant in the context of global sustainability challenges, where educational institutions are tasked with preparing future specialists capable of understanding and optimizing renewable energy systems. By equipping students with analytical tools and applied knowledge through accessible web-based platforms, this pedagogical model promotes inclusive and forward-thinking learning environments.

While the study was limited to a single institution and a specific set of technologies, its implications are far-reaching. Future research should aim to expand the model across diverse educational settings, incorporate varied renewable technologies, and track long-term impacts on career development and innovation.

In summary, this study underscores the potential of web-based STEM education to transform how students engage with complex energy concepts, offering them both the tools and the mindset needed to contribute to a more sustainable and technologically advanced future.

For future researchers, further exploration of the long-term impact of web-based STEM education on student learning outcomes is recommended. Expanding the scope of research by including diverse educational levels and institutions could provide a more comprehensive understanding of the effectiveness of such platforms. Additionally, integrating artificial intelligence and machine learning tools into web-based learning environments may enhance adaptive learning experiences and personalized education. Incorporating real-time data analysis tools and interactive simulations in STEM courses can improve student engagement and comprehension. Educators should be encouraged to use digital monitoring platforms, such as the Growatt server, to provide students with practical exposure to renewable energy systems. Training sessions and workshops on the integration of web-based technologies in STEM education should be conducted to ensure effective implementation.

Ethics Statements

The studies involving humans were approved by Ethics Committee of Khoja Akhmet Yassawi International Kazakh-Turkish University (No. 40, 07.04.2025). All students who participated in the pedagogical experiment provided informed consent, and their anonymity and confidentiality were maintained throughout the study.

Generative AI Statement

No generative AI or AI-supported technologies were used.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

NZh, NG and ShR conducted the research; BK and MN analyzed the data; NZh and MA wrote the paper; all authors had approved the final version.

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References

[1] A. Pattayev, N. Gen, S. Ramankulov, S. Polatuly, M. Tuiyebayev, I. Usembayeva, and G. Rizakhojayeva, "Evaluation of the effectiveness of using STEAM projects in teaching physics: Student interest in the field of solar energy," *Qubahan Academic Journal*, vol. 4, no. 3, pp. 678–693, 2024. doi: 10.48161/qaj.v4n3a911

[2] C. M. Firetto, E. Starrett, and M. E. Jordan, "Embracing a culture of talk: STEM teachers' engagement in small-group discussions about photovoltaics," *International Journal of STEM Education*, vol. 10, no. 1, 42, 2023. doi: 10.1186/s40594-023-00442-7

[3] D. T. K. Oanh, "Integrated STEM education competence framework for university lecturers," *European Journal of Educational Research,* vol. 14, no. 1, pp. 135–150, 2025. doi: 10.12973/eu-jer.14.1.135

[4] C. Kefalis and A. Drigas, "Web based and online applications in STEM education," *International Journal of Engineering Pedagogy,* vol. 9, no. 4, pp. 76–85, 2019. doi: 10.3991/ijep.v9i4.10691

[5] H. H. Pourasl, R. V. Barenji, and V. M. Khojastehnezhad, "Solar energy status in the world: A comprehensive review," *Energy Reports,* vol. 10, pp. 3474–3493, 2023. doi: 10.1016/j.egyr.2023.10.022

[6] H. I. Purnama, I. Wilujeng, and C. S. A. Jabar, "Web-based e-learning in elementary school: A systematic literature review," *International Journal on Informatics Visualization*, vol. 7, no. 3, pp. 749–759, 2023. doi: 10.30630/joiv.7.3.1203

[7] I. Hatzilygeroudis, K. Kovas, F. Grivokostopoulou, and Z. Palkova, "A hybrid educational platform based on virtual world for teaching solar energy," in *Proc. EDULEARN14*, 2014, pp. 522–530.

[8] R. Sankar, P. K. J. Althaf, and S. Sreevas, "A Study on low cost electrification using solar energy a field work," *International Journal of Computer Theory and Engineering*, vol. 4, no. 6, pp. 1015–1019, 2012. doi: 10.7763/ijcte.2012.v4.629

[9] C. C. Wu, C. Y. Yang, M. S. Hwang, and C. Y. Lee, "A trustworthy web-based system platform for teaching evaluation and STEM education," *International Journal of Electrical Engineering Education*, 2019. doi: 10.1177/0020720919853427

[10] H. I. Purnama, I. Wilujeng, and C. S. A. Jabar, "Web-based e-learning in elementary school: A systematic literature review," *International Journal on Informatics Visualization*, vol. 7, no. 3, pp. 749–759, 2023. doi:10.30630/joiv.7.3.1203

[11] L. Birney, and D. M. McNamara, "Students' self-efficacy and confidence in technological abilities resulting from participation in "The Curriculum and Community Environmental Restoration Science (STEM + Computer Science)," *Journal of Curriculum and Teaching,* vol. 13, no. 1, pp. 24–35, 2024. doi:10.5430/jct.v13n1p24

[12] H. Mouttalib, M. Tabaa, and M. Youssfi, "Towards a platform for higher education in virtual reality of engineering sciences," in *Proc. 2024 Communications in Computer and Information Science*, Springer, 2024, vol. 1728, pp. 107–119. doi:10.1007/978-3-031-47366-1_8

[13] P. Abichandani, W. McIntyre, W. Fligor, and D. Lobo, "Solar energy education through a cloud-based desktop virtual reality system," *IEEE Access*, vol. 7, pp. 147081–147093, 2019. doi: 10.1109/ACCESS.2019.2945700

[14] G. Eickenberg, A. Nevarez-Lira, Z. Altahat, and W. S. Vaz, "Educational and outreach website for solar energy," in *Proc. 2020 IEEE Int. Conf. Electro Inf. Technol.*, 2020, pp. 81–86. doi: 10.1109/EIT48999.2020.9208319

[15] E. H. Amalu, M. Short, P. L. Chong, D. J. Hughes, D. S. Adebayo, F. Tchuenbou-Magaia, P. Lahde, M. Kukka, O. Polyzou, T. I. Oikonomou, C. Karytsas, A. Gebremedhin, C. Ossian, and N. N. Ekere, "Critical skills needs and challenges for STEM/STEAM graduates increased employability and entrepreneurship in the solar energy sector," *Renewable and Sustainable Energy Reviews*, vol. 185, 113776, 2023. doi: 10.1016/j.rser.2023.113776

[16] F. Shahbazloo, and R. Abdullah Mirzaie, "Investigating the effect of 5E-based STEM education in solar energy context on creativity and academic achievement of female junior high school students," *Thinking Skills and Creativity*, vol. 49, 101336, 2023. doi: 10.1016/j.tsc.2023.101336

[17] A. Gaevskii, V. Bodnyak, and A. Gaevskaya, "Analysis of monitoring data on the operation of pv-inverters connected to distribution network," *Alternative Energy and Ecology (ISJAEE)*, vol. 31–36, pp. 12–22, 2019. doi: 10.15518/isjaee.2018.31-36.012-022

[18] H. Hermansyah, K. Kasim, and I. K. Yusri, "Solar panel remote monitoring and control system on miniature weather stations based on web server and ESP32," *International Journal of Recent Technology and Applied Science*, vol. 2, no. 1, pp. 1–24, 2020. doi: 10.36079/lamintang.ijortas-0201.56

[19] E. S. Damarwan, M. L. Hakim, A. S. J. Wardhana, and P. Budiastuti, "The effect of luminous intensity, humidity, and temperature on the output voltage of solar panels," *Jurnal Edukasi Elektro*, vol. 7, no. 1, pp. 26–35, 2023. doi: 10.21831/jee.v7i1.60179

[20] B. O. Abisoye, Y. Sun, and Z. Wang, "Machine learning forecasting model for solar energy radiation," *International Journal of Computer Theory and Engineering*, vol. 16, no. 2, pp. 66–75, 2024. doi: 10.7763/IJCTE.2024.V16.1355

[21] N. A. Doria, O. Shaikh, S. Y. Tao, and R. A. Frye, "S2405 post-infantile giant cell hepatitis," *American Journal of Gastroenterology,* vol. 115, no. 1, pp. S1276–S1277, 2020. doi: 10.14309/01.ajg.0000711668.07016.c8

[22] A. Burgio, D. Cimmino, A. Nappo, L. Smarrazzo, and G. Donatiello, "An IoT-based solution for monitoring and controlling battery energy storage systems at residential and commercial levels," *Energies,* vol. 16, no. 7, 3140, 2023. doi: 10.3390/en16073140

[23] D. Muhammad, A. Hiendro, and Y. Yandri, "Determination of tilt and azimuth angles of solar panels at tanjungpura university solar power plant using pvsyst 7.3 software simulation," *Telecommunications, Computers, and Electricals Engineering Journal,* vol. 1, no. 3, 218, 2024. doi: 10.26418/telectrical.v1i3.72983

[24] Y. Dosymov, I. Usembayeva, S. Polatuly, S. Ramankulov, B. Kurbanbekov, A. Mintassova, and N. Mussakhan, "Effectiveness of computer modeling in the study of electrical circuits: Application and evaluation," *International Journal of Engineering Pedagogy*, vol. 13, no. 4, pp. 93–112, 2023. doi: 10.3991/ijep.v13i4.34921

[25] N. T. Giang, N. V. Dinh, P. N. H. Ngu, D. B. Chau, N. P. Thao, and T. T. P. Thao, "Applying augmented reality technology in STEM education: A bibliometrics analysis in Scopus database," *European Journal of Educational Research*, vol. 14, no. 1, pp. 73–87, 2025. doi: 10.12973/eu-jer.14.1.73

[26] H. Üzmuş, N. Genç, and M. A. Çelik, "FV sistemler için DSP tabanlı hibrit kontrol yöntemi [DSP-based hybrid control method for PV systems]," *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, vol. 38, no. 4, pp. 2251–2260, 2023. doi: 10.17341/gazimmfd.1062711

[27] C. E. O. Onime, J. Uhomoibhi, and E. Pietrosemoli, "An augmented virtuality based solar energy power calculator in electrical engineering," *International Journal of Engineering Pedagogy*, vol. 5, no. 1, pp. 4–7, 2015. doi: 10.3991/ijep.v5i1.3841

[28] S. Polatuly, S. Ramankulov, I. Usembayeva, D. Kazakhbayeva, N. Shektibayev, B. Kurbanbekov, E. Dosymov, "Empowering future physicists: the role of case technology in research competency development," *Cogent Education*, vol. 11, no. 1, 2362547, 2023. doi: 10.1080/2331186X.2024.2362547

[29] D. Kaleci, and Ö. Korkmaz, "Stem education research: content

analysis," *Universal Journal of Educational Research*, vol. 6, no. 11, pp. 2404–2412, 2018. https://doi.org/10.13189/ujer.2018.061102

[30] O. F. Nugroho, A. Permanasari, H. Firman, and R. Riandi, "Stem learning for science education program: reference to indonesia," *Jurnal Inspirasi Pendidikan,* vol. 11, no. 2, pp. 90–100, 2021. doi: 10.21067/jip.v11i2.5908

[31] O. B. Joseph, and N. C. Uzondu, "Curriculums development for interdisciplinary stem education: a review of models and approaches," *International Journal of Applied Research in Social Sciences,* vol. 6, no. 8, pp. 1575–1592, 2024. doi: 10.51594/ijarss.v6i8.1371