Renewable Energy Learning Project in Physics Classroom: Achieving Education for Sustainable Development

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Abstract **– Increased energy demand, acceleration of renewable energy, and response to climate change are global challenges that are being faced today. To overcome this, education for sustainable development (ESD) is a concept that can be implemented through the renewable energy learning project (RELP) in physics lessons. This study analyzes the project-based learning on the RELP concept and its influence on project design, communication, and critical thinking skills. By using a one-shot case study method on 37 high school students divided into five groups, two types of renewable energy works were created: solar and wind. The results found that the students had the above three skills in the high category. Additionally, project design and communication skills significantly influenced critical thinking. This research implies providing a project-based physics learning concept relevant to 21st-century skills while achieving ESD.**

Keywords **– RELP, ESD, project design, communication, critical thinking.**

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1. Introduction

While discussions about renewable energy are no longer a new phenomenon, its widespread implementation, particularly in developing countries, has yet to be fully achieved [1]. Efforts to realize it are aimed at overcoming climate change, environmental degradation, the global energy crisis, and the price of fossil fuels, which continues to increase along with the increase in population [2], [3]. As a primary need, electrical energy is an essential part of living life in the digital era and increasingly rapid technological developments. This includes technology in realizing sustainable procurement of electrical energy originating from renewable energy to minimize carbon emissions from dependence on fossil fuels [4]. The electrical energy that comes from renewable energy comes from solar energy, biomass, wind, water gravity, geothermal heat, sea waves, and others [5], [6].

As a developing country, Indonesia is transitioning to using renewable energy for electricity generation. Indonesia seeks to target renewable energy use of 23% in 2025 and 31% in 2050, based on the National Energy Policy (NEP) [4]. Renewable energy is a form of realizing two of the Sustainable Development Goals (SDGs), number 7 (affordable and clean energy) and 13 (climate action), which are the basis for ensuring clean, reliable, affordable, and sustainable energy for present and future generations in order to decrease climate change effect on the Earth [7].

Integrated into the SDGs, Education of Sustainable Development (ESD) has an important role in taking action to realize renewable energy for Indonesia. The strategy for building sustainable energy requires resources from various elements comprehensively [8]. One is quality human resources created in the educational environment to form skills for a sustainable future [9].

Many topics and approaches to learning methods related to affordable, green, and clean energy have been suggested, including experimenting with renewable energy technology and forming projects in physics classrooms. Due to being included in the national education curriculum, teachers need to consider project-based physics learning through collaborative and interdisciplinary authentic problem-solving.

In project-based learning activities in groups, many skills can be formed based on references to 21st-century skills: critical thinking, collaboration, creativity, and communication [10], [11]. Creativity skills will grow when designing projects, and good communication skills can also be developed when working together [10], [12]. The Renewable Energy Learning Project (RELP) is carried out in learning that carries out projects related to renewable energy. RELP contains components that integrate ESD. Students introduced to ESD in RELP can develop one or several industry 4.0 skills. Therefore, this study aims to describe the RELP program and analyze the influence of RELP on students' project design, communication, and critical thinking skills. The following are the research questions:

1. What is the description, characteristics, and process of RELP in physics classrooms to achieve SDGs?
2. What are students' project design, communication, and critical thinking skills profiles after experiencing RELP?
3. What is the relationship between students' project design, communication, and critical thinking skills in the context of RELP?

2. Methodology

The study employed a one-shot case study design involving 37 high school students from East Java province [13]. The study's primary objectives were to elucidate the students' project activities and evaluate their project design and communication skills. Data were gathered during four physics subject sessions, aligning with the school's curriculum. The learning process unfolded across these four sessions, as depicted in Figure 1.

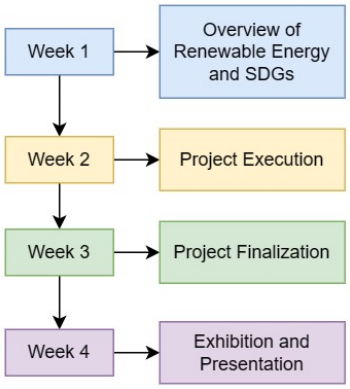

Figure 1. The sequence of RELP

The learning process commences with an introduction to renewable energy, its various types, and its significance. It also imparts knowledge about the sustainable development goals (SDGs) that are a global imperative while explaining the pivotal role of students in contributing to achieving these SDGs. Following this, students engage in group activities where they conceptualize the type of renewable energy project they intend to design, with guidance from the teacher. This process undoubtedly fosters their critical thinking skills and creativity.

The central activity in the second and third meetings involves executing the project outside the school premises. However, during classroom sessions, the teacher closely supervises the project's progress, ensuring it aligns with the predefined learning objectives and the chosen SDGs theme. The teacher also guides students encountering difficulties or obstacles throughout this process. Upon project completion, students are tasked with producing a written report detailing their project and delivering a presentation on their designed renewable energy product.

Students' project design and communication skills were assessed during this process. In terms of the former, the assessment rubric used includes design complexity, originality of ideas, problem-solving contribution, conformity to the SDGs theme, and product quality. Meanwhile, the assessment rubric for the latter is the ability to write a written report, oral delivery, quality of presentation media, group readiness, and question and answer.

At the end of the lesson, a critical thinking skills narrative test is conducted, which has indicators: evaluating, analyzing, synthesizing, and forming arguments (structure and validity) [14]. There are three questions, each requiring students to work on each indicator. The final score is adjusted to the criteria according to Hendratno *et al.* [15]: N = 55-69 (middle); 70-75 (high); >75 (very high).

The research data were analyzed descriptively to describe the results of the RELP program and the products produced. What's more, data on project design, communication, and critical thinking skills were analyzed descriptively based on the final results obtained. Each variable is also analyzed for its relationship using the Spearman correlation and F-test, determining its interaction pattern. Finally, the findings of this research are analyzed for their relationship with the achievement of SDGs and conclusions drawn.

3. Results and Discussion

This section clarifies the description of the RELP project designed by the researcher and undertaken by the students.

3.1. RELP Overview

RELP exhibits several key characteristics: 1) It focuses on the creation of renewable energy projects to address the issue of electrical energy requirements; 2) It is oriented towards ESD, emphasizing the importance of sustainability and environmental consciousness; 3) It aims to train students' project design skills and communication abilities. Following a brainstorming session on renewable energy project ideas, each group selected a project theme based on the analysis of their respective regions (Table 1).

Many groups opted for the wind energy theme, particularly those situated in coastal areas with high wind energy potential. A sample of student's work is presented in Figure 2. This potential is harnessed to generate electrical energy. Some groups demonstrated exceptional creativity, like Groups II and IV, who repurposed used materials. The utilization of wind energy offers several advantages compared to other energy sources because of its modern technology, dependable infrastructure, and cheap cost [16]. Wind power is one of the most influential alternative renewable energy sources, offering the significant advantage of zero emissions of greenhouse gases [17].

Table 1. RELP project theme

Group	Theme	Project
I	Wind Energy (WE)	Creating a WE prototype using a fan propeller
II	Wind Energy	Creating WE prototypes using reused materials: bottle caps and CD cassettes
III	Wind Energy	Create a miniature house equipped with lights and WE power plant
IV	Wind Energy	Making WE prototypes using former cans and bottles
V	Solar Energy	Making a miniature garden out of ice cream sticks equipped with solar cells and lights

Intriguingly, only one group designed a solar energy prototype built on a miniature garden (Figure 2). It is possible that students have a residence that does not have wind potential, but sunlight. Indonesia is a country located on the equator so it has a very high potential for solar energy. The conversion of this energy into electrical energy is an excellent opportunity to overcome the increase in electrical energy and reduce the use of fossil-based electrical energy. Solar energy has advantages such as the use of solar PV modules to generate electricity, improving energy security by achieving a higher level of diversification, and generating electricity at a reasonable cost [18]. Solar installations can also be easily scaled to meet specific energy needs, from small residential to large utility-scale power plants [19]. Therefore, using solar energy is very beneficial for remote areas far from access to city electricity.

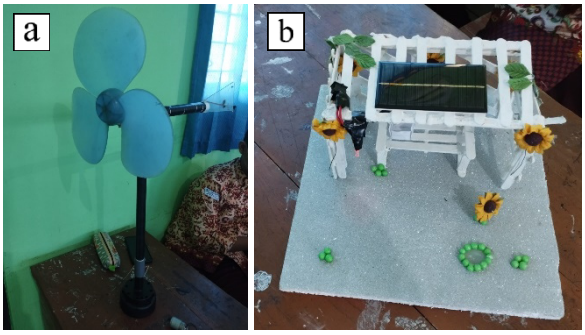

Figure 2. Sample of students' work (a) group I and (b) group V

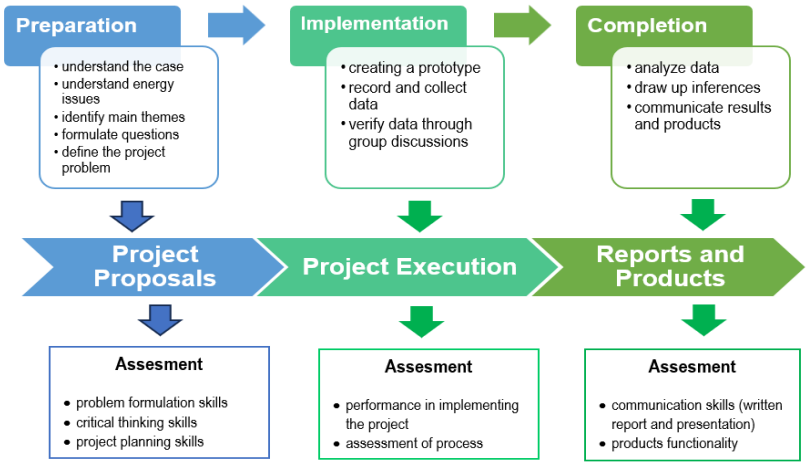

Figure 3. The process of RELP

Once students have determined the theme of their project, the next stage is project implementation (Figure 3). This is done by executing the project collaboratively through teacher supervision. During this process, there is a process assessment of their project design skills as well as their performance in creating the project. Theoretically, according to Bloom's taxonomy, this activity reaches level 6, involving the highest order of thinking skills, where individuals synthesize and evaluate information and generate new ideas, solutions, or projects [20]. Students are expected to design and plan renewable energy projects from scratch at this level. They need to consider the technical, economic, and environmental aspects of the project, related to ESD.

The RELP project creation process aligns with Vygotsky's socio-constructivist theory, which posits that an individual's learning process is influenced by both their social environment and themselves. Three key points are used to explain further this: 1) intellectual development happens when students come across new concepts and struggle to connect them to what they already know; 2) social interaction enhances intellectual development; and 3) the teacher's role is to facilitate and mediate students' learning [21]. Colleague assistance and teacher facilitation during group projects can support students' cognitive development.

After the project is completed, the final stage of RELP is project evaluation, analyzing the findings, making conclusions, and presenting the results in front of the class. The teacher assesses students' written reports, product functionality, and presentation skills.

3.2. Students' Project Design, Communication, and Critical Thinking Skills

This section explains the results of the RELP implementation on students' project design, communication, and critical thinking skills. Figure 4 depicts those skills scores in each group. The average score for project design is 83.4, and communication skills is 90. The high average scores in the project design and communication skills categories indicate that the RELP program has successfully provided quality education to learners. The ability to communicate well is vital in outlining ideas and projects related to renewable energy to the parties involved [22]. A high score in the project design category indicates that students can design projects related to renewable energy. This is important in developing sustainable solutions and innovation in the field of renewable energy. Meanwhile, the results of critical thinking skills have varying criteria, where group 4 has middle criteria, groups 1, 3, and 5 have high criteria, and group 2 has very high criteria.

This shows that students are able to develop critical thinking skills in designing and implementing renewable energy projects.

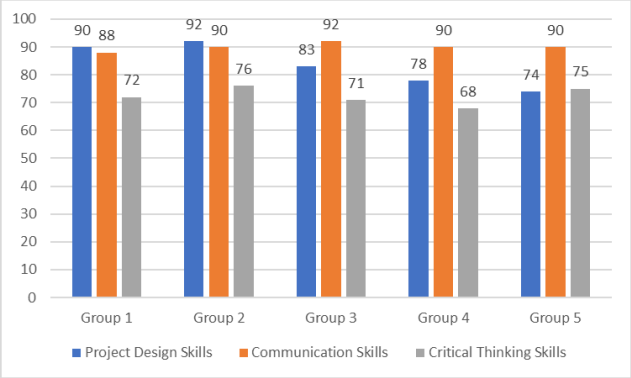

Figure 4. The results of students' project design, communication, and critical thinking skills

An interesting finding is that groups with high or very high criteria maximized the potential in their surroundings, including used materials. Although Group 4 utilized former materials, they made a power plant that did not work. As a result, they could not explain how their project solved the problem. However, the average score of students' critical thinking skills as a whole is 75, indicating high criteria. Consequently, the RELP program is generally successful in teaching students to design and implement renewable energy projects, with a selection of project themes including wind and solar energy. Learners have good project design skills and strong communication skills, which are essential in sharing project ideas and results with others. In addition, students' critical thinking skills were also evident in the evaluation results, demonstrating their ability to address the technical and environmental aspects of renewable energy projects. Overall, the RELP program successfully developed students' ability to design, implement, and communicate about renewable energy projects.

Box plot visualization results (Figure 5) on communication results obtained a median value of 90, and the design project box plot shows that the distribution of design project values tends to range between 78 and 90. Quartile 3 value is 90. Quartile 3 is the middle value between the median (Q2) and the maximum value [23]. This means that 25% of the data that is higher than the median is above 90. The median (83) is the data's midpoint when sorted from smallest to largest. This shows that 50% of the data is above 83 and 50% is below 83. Quartile 1 (78) is the middle value between the minimum and median [23]. This means that 25% of the data that is lower than the median is below 78. Based on this information, it can be concluded that an upward trend characterizes the data distribution because Q3 is higher than the median.

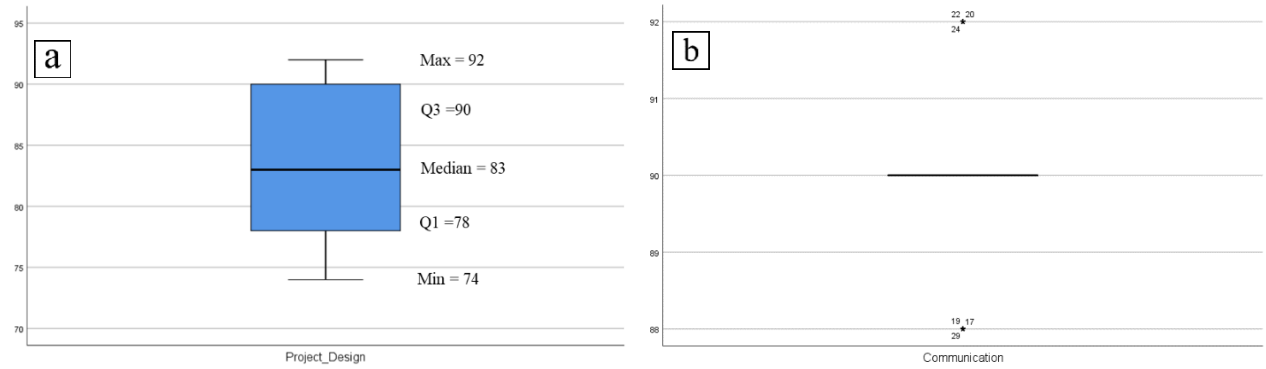

Figure 5. Box plot interpretation of (a) project design and (b) communication skills

In RELP, this data can represent the project design outcome or ability of a group of learners involved in the program. The high median (83) indicates that the average design project of learners is at a fairly good level. Q1 (78) and Q3 (90) show the spread of scores between participants, with most learners having design capabilities above 78 and some learners having excellent design capabilities above 90. This suggests that the RELP program may improve learners' project design capabilities and communication skills.

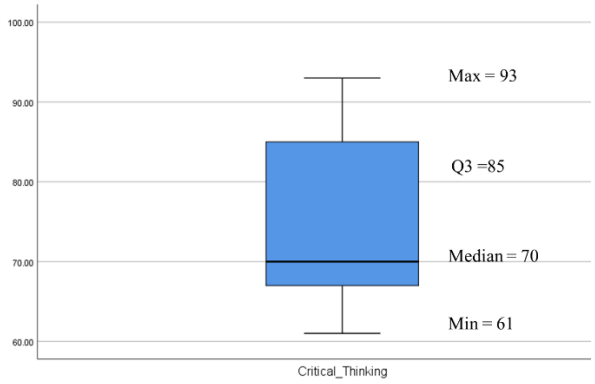

Figure 6. Box plot interpretation of critical thinking skills

The box plot results on critical thinking skills (Figure 6) found that the range between the minimum (61) and maximum (93) values showed significant variation in the level of critical thinking skills. This could reflect the significant differences between individuals in critical thinking skills. The thickness of the box (the distance between Q1 and Q3) gives an idea of the distribution of most of the data. The thicker box on the upper side (Q3) indicates that most individuals have higher levels of critical thinking skills.

After the implementation of RELP learning, it shows that most of the learners have excellent communication and project design skills. The development of design skills and communication skills in renewable energy learning is a beneficial outcome of RELP. The projects related to renewable energy in RELP allow learners to apply theoretical knowledge in real situations. This allows learners to develop design skills that can be applied in the development of renewable energy solutions. In addition, project-based activities often involve teamwork which helps learners improve their communication skills [24], [25], including the ability to collaborate, share ideas, and coordinate with team members [26]. Projects in RELP end with a presentation or report. Learners have to communicate the results of their project to an audience, which develops their communication skills [27]. By participating in renewable energy projects, learners will gain very meaningful real-life experiences [28], which can improve their understanding of the concepts and their ability to design innovative solutions [29].

In addition, RELP learning has a close relationship with the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach. In RELP, learners can utilize STEAM elements to understand, design, and implement renewable energy solutions [30], [31]. They gain a scientific understanding of the science fundamentals that underpin renewable energy technologies. Technology is key in RELP, with learners learning the latest technologies used in renewable energy [32]. Engineering aspects are also reflected in the process of designing and building renewable energy projects, with learners planning solar panel installations, building wind turbines, and developing energy storage systems. Art also has a role in expressing creativity in project design, such as aesthetically pleasing solar panel layouts. Math also plays a role in technical planning, requiring learners to perform complex calculations related to power, efficiency, investment [33],[34], and energy savings. In RELP, STEAM elements are combined and interdisciplinary, creating a holistic understanding of renewable energy and preparing learners for careers in various relevant STEAM fields. This enables learners to contribute to achieving the SDGs with a deep knowledge of renewable energy solutions and the positive impact they make in building a more sustainable world [35], [36].

Overall, this RELP has excellent potential to create students' having communication and project design skills. As learners are involved in designing and developing renewable energy solutions. This process requires strong creative thinking, analysis, and planning [37]. Learners learn to design renewable energy projects from scratch, which includes technical calculations, component selection, and technology integration [38]. This helps them develop strong project design skills. In RELP, learners gain practical experience in designing and developing renewable energy solutions. Learners to plan, measure, and implement these projects, which helps them understand the technical aspects of design [27]. RELP projects allow learners to think creatively and find innovative solutions to renewable energy challenges. This hones their ability to design efficient and sustainable projects. As RELP projects often involve teamwork, learners learn to communicate with team members, divide tasks, and coordinate within the team [27], [39]. This trains interpersonal communication skills [40], [41]. It can be concluded that RELP learning activities provide opportunities for learners to develop renewable energy-oriented project design skills and effective communication skills. Thus, RELP learning supports learners in contributing to innovative renewable energy solutions and communicating about sustainable issues more effectively in society.

3.3. Relationship Between Project Design and Communication with Critical Thinking Skills

This section explains the interrelationship between the three skills because the interaction pattern of these variables can provide an understanding of the multiplier effect on RELP as project-based learning. Table 2 shows Spearman's coefficient correlation (C.C.) and significance between critical thinking with project design and communication skills. First, critical thinking has a significant relationship with project design and communication because the significance value is <0.05. Second, the strength of the correlation between project design and critical thinking skills has a very strong relationship. Third, the strength of the correlation between communication and critical thinking skills has a sufficient relationship.

Table 2. Correlation test between project design and communication with critical thinking skills

Spearman's Rho		Project Design	Communi-cation
Critical Thinking	C.C.	0.796	0.341
	Sig.	0.00*	0.04*
	N	37	37

Furthermore, the F test results show that project design and communication simultaneously significantly affect critical thinking skills (Table 3). Through the R^2 value, it can be implied that the influence of the two variables on critical thinking skills is 76.40%.

Table 3. F test result

R	R^2	F-value	Sig.
0.874	0.764	55.176	0.00*

Definitely, project design skills have a significant relationship with critical thinking skills because when students design a project, they must first have an authentic problem that must be addressed and the potential used to solve the problem. In the case of RELP, students must identify a problem related to energy and analyze the potential in their surrounding environment that can be utilized to solve the problem. This involves analyzing and breaking down complex issues into manageable components, a fundamental aspect of critical thinking [42]. Moreover, critical thinking involves the evaluation and analysis of information and evidence. In project design, students need to gather, analyze, and interpret data to inform their decision-making and design choices. Strong critical thinking skills are essential for making sense of complex data and drawing meaningful conclusions [43]. Several studies confirm the significant relationship between project design and critical thinking skills [44], [45].

In addition to project design skills, critical thinking also significantly influences communication. Students are required to present their renewable energy projects to an audience, such as their peers and teachers. Strong communication skills are necessary for these presentations to be engaging and informative. Critical thinking skills underpin the ability to anticipate questions, objections, and counterarguments, helping students deliver compelling pitches [46]. Not only that, these skills help students organize their thoughts and convey them logically, ensuring that their messages are well-structured and easily understood by others. Forming arguments is included in one critical thinking skills assessment rubric [14]. Empirical evidence also shows that communication has a considerable relationship with critical thinking skills [47], [48].

3.4. RELP and Sustainable Development Goals

This section describes the implications of RELP in the physics classroom with the achievement of SDGs, where the project is very relevant to the goals, a series of global goals launched by the United Nations to achieve a more sustainable world [49].

RELP is directly related to SDG 7, which aims to ensure everyone's access to affordable, reliable, sustainable, and modern energy. Learners involved in RELP learn about renewable energy and how to utilize it to meet global energy needs. Renewable energy is important to sustainable urban and residential development [50]. Learners studying at RELP can contribute to efforts to create more sustainable and environmentally friendly cities and settlements. RELP supports SDG 13 by helping learners understand the importance of climate change mitigation through renewable energy. Learners can play a role in reducing greenhouse gas emissions and accelerating the utilization of renewable energy.

4. Conclusion

RELP is an effective project-based physics learning method that provides project design, communication, and critical thinking skills for students. This research shows that RELP is a potential learning approach solution to increase awareness about affordable and clean energy and the ability to design renewable energy-related technologies. Moreover, both students' project design and communication skills significantly affect critical thinking. The results of this study provide positive implications that RELP can be implemented successfully in secondary schools as a response to the problem of fossil energy reserves and the challenges of future renewable energy sources. The project aligns with SDGs 7 (affordable and clean energy) and 13 (climate action), thus actualizing ESD. Finally, RELP can be a relevant and innovative learning tool to prepare future generations to face increasingly pressing global energy and climate issues.

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References:

[1]. Effendi, Y., & Resosudarmo, B. P. (2022). Development of renewable electricity in ASEAN countries: socio-economic and environmental impacts. *Asia-Pacific Journal of Regional Science*, *6*(1), 247–266. Doi: 10.1007/s41685-021-00206-7

[2]. Cioncolini, A., Nabawy, M. R., Silva-Leon, J., O'connor, J., & Revell, A. (2019). An experimental and computational study on inverted flag dynamics for simultaneous wind–solar energy harvesting. *Fluids*, *4*(2), 87.

[3]. Ling, F., & Hornbuckle, K. C. (2022). Environmental Engineers Addressing the Grand Challenges of the 21st Century. *ACS Environmental Au*, *2*(3), 176–177. Doi: 10.1021/acsenvironau.2c00025

[4]. Syafii, S., Anugrah, P., Laksono, H. D., & Yamashika, H. (2021). Economic Feasibility Study on PV/Wind Hybrid Microgrids for Indonesia Remote Island Application. *TEM Journal*, *10*(4), 2001–2006. Doi: 10.18421/TEM104-66

[5]. Ghadi, Y., & Elamsy, T. (2021). Analyzing the Application of Fuzzy Logic in Renewable Energy Systems. *2021 8th International Conference on Internet of Things: Systems, Management and Security, IOTSMS 2021*, *10*(4), 1610–1615. Doi: 10.1109/IOTSMS53705.2021.9704995

[6]. Adeosun, T. A., Amosu, C. O., Omitogun, O. A., Amusa, O. M., & Morenikeji, B. A. (2023). Renewable Energy for Sustainable Development in Developing Countries: Benefits to the Environment. *Journal of Energy Research and Reviews*, *13*(3), 1–25. Doi: 10.9734/jenrr/2023/v13i3262

[7]. Islami, M. S., Urmee, T., & Kumara, I. N. S. (2021). Developing a framework to increase solar photovoltaic microgrid penetration in the tropical region: A case study in Indonesia. *Sustainable Energy Technologies and Assessments*, *47*, 101311. Doi: 10.1016/j.seta.2021.101311

[8]. Lee, C. W., & Zhong, J. (2014). Top down strategy for renewable energy investment: Conceptual framework and implementation. *Renewable Energy*, *68*, 761-773.

[9]. Kozak-Holland, M., & Procter, C. (2020). The challenge of digital transformation. *Managing Transformation Projects: Tracing Lessons from the Industrial to the Digital Revolution*, 1-11.

[10]. Gomez-del Rio, T., & Rodriguez, J. (2022). Design and assessment of a project-based learning in a laboratory for integrating knowledge and improving engineering design skills. *Education for Chemical Engineers*, *40*, 17–28. Doi: 10.1016/j.ece.2022.04.002

[11]. Weng, X., Cui, Z., Ng, O.-L., Jong, M. S. Y., & Chiu, T. K. F. (2022). Characterizing Students' 4C Skills Development During Problem-based Digital Making. *Journal of Science Education and Technology*, *31*(3), 372–385. Doi: 10.1007/s10956-022-09961-4

[12]. Sumarni, W., & Kadarwati, S. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11–21. Doi: 10.15294/jpii.v9i1.21754

[13]. Yin, R. K. (2017). *Case Study Research and Applications Design and Methods*. SAGE Publications, Inc.

[14]. Reynders, G., Lantz, J., Ruder, S. M., Stanford, C. L., & Cole, R. S. (2020). Rubrics to assess critical thinking and information processing in undergraduate STEM courses. *International Journal of STEM Education*, *7*(9), 1–15. Doi: 10.1186/s40594-020-00208-5

[15]. Hendratno, Yasin, F. N., Istiq'faroh, N., & Suprayitno. (2023). Development of Textbook Based on Character Using Multimedia to Improve Critical Thinking Skills for Elementary School Students. *Studies in Learning and Teaching*, *4*(1), 52–67. Doi: 10.46627/silet.v4i1.193

[16]. Olabi, A. G., Obaideen, K., Abdelkareem, M. A., AlMallahi, M. N., Shehata, N., Alami, A. H., Mdallal, A., Hassan, A. A., & Sayed, E. T. (2023). Wind Energy Contribution to the Sustainable Development Goals: Case Study on London Array. *Sustainability*, *15*(5), 4641. Doi: 10.3390/su15054641

[17]. Florescu, A., Barabas, S., & Dobrescu, T. (2019). Research on Increasing the Performance of Wind Power Plants for Sustainable Development. *Sustainability*, *11*(5), 1266. Doi: 10.3390/su11051266

[18]. Madvar, M. D., Nazari, M. A., Arjmand, J. T., Aslani, A., Ghasempour, R., & Ahmadi, M. H. (2018). Analysis of stakeholder roles and the challenges of solar energy utilization in Iran. *International Journal of Low-Carbon Technologies*, *13*(4), 438–451. Doi: 10.1093/ijlct/cty044

[19]. Mousavi, S. A., Mehrpooya, M., & Delpisheh, M. (2022). Development and life cycle assessment of a novel solar-based cogeneration configuration comprised of diffusion-absorption refrigeration and organic Rankine cycle in remote areas. *Process Safety and Environmental Protection*, *159*, 1019–1038. Doi: 10.1016/j.psep.2022.01.067

[20]. Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing:A revision of Bloom's taxonomy of educational Objectives*. Longman.

[21]. Arends, R. I. (2011). *Learning to Teach* (Ninth). McGraw-Hill Education.

[22]. Vlachopoulos, D., & Makri, A. (2019). Online communication and interaction in distance higher education: A framework study of good practice. *International Review of Education*, *65*(4), 605–632. Doi: 10.1007/s11159-019-09792-3

[23]. Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive statistics and normality tests for statistical data. *Annals of Cardiac Anaesthesia*, *22*(1), 67. Doi: 10.4103/aca.ACA_157_18

[24]. Vogler, J. S., Thompson, P., Davis, D. W., Mayfield, B. E., Finley, P. M., & Yasseri, D. (2018). The hard work of soft skills: augmenting the project-based learning experience with interdisciplinary teamwork. *Instructional Science*, *46*, 457–488. Doi: 10.1007/s11251-017-9438-9

[25]. Baird, M. (2019). Project based learning to develop 21st century competencies. In *Technology and the Curriculum: Summer 2019*. Power Learning Solutions.

[26]. Safarini, T. L. S. D. (2019). Developing students' collaboration skills through project-based learning in statistics. *Journal of Physics: Conference Series*, *1265*(1), 12011.

[27]. Stehle, S. M., & Peters-Burton, E. E. (2019). Developing student 21st Century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM Education*, *6*(1), 1–15. Doi: 10.1186/s40594-019-0192-1

[28]. Morley, D. A., & Jamil, M. G. (2021). Introduction: Real World Learning—Recalibrating the Higher Education Response Towards Application to Lifelong Learning and Diverse Career Paths. In *Applied Pedagogies for Higher Education: Real World Learning and Innovation across the Curriculum*, 1–17. Springer International Publishing. Doi: 10.1007/978-3-030-46951-1_1

[29]. Molderez, I., & Fonseca, E. (2018). The efficacy of real-world experiences and service learning for fostering competences for sustainable development in higher education. *Journal of Cleaner Production*, *172*, 4397–4410. Doi: 10.1016/j.jclepro.2017.04.062

[30]. Adriyawati, Utomo, E., Rahmawati, Y., & Mardiah, A. (2020). Steam-project-based learning integration to improve elementary school students' scientific literacy on alternative energy learning. *Universal Journal of Educational Research*, *8*(5), 1863–1873. Doi: 10.13189/ujer.2020.080523

[31]. Rahmawati, Y., Taylor, E., Taylor, P. C., Ridwan, A., & Mardiah, A. (2022). Students' engagement in education as sustainability: implementing an ethical dilemma-STEAM teaching model in chemistry learning. *Sustainability*, *14*(6), 3554. Doi: 10.3390/su14063554

[32]. Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., & De Cock, M. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 2. Doi: 10.20897/ejsteme/85525

[33]. Timms, M. J., Moyle, K., Weldon, P. R., & Mitchell, P. (2018). *Challenges in STEM learning in Australian schools: Literature and policy review*. Australian Council for Educational Research (ACER).

[34]. Acosta-Gonzaga, E., & Walet, N. R. (2018). The role of attitudinal factors in mathematical on-line assessments: a study of undergraduate STEM students. *Assessment & Evaluation in Higher Education*, *43*(5), 710–726. Doi: 10.1080/02602938.2017.1401976

[35]. Hoque, F., Yasin, R. M., & Sopian, K. (2022). Revisiting education for sustainable development: Methods to inspire secondary school students toward renewable energy. *Sustainability*, *14*(14), 8296.

[36]. Vasconcelos, C., Silva, J., Calheiros, C. S. C., Mikusiński, G., Iwińska, K., Skaltsa, I. G., & Krakowska, K. (2022). Teaching sustainable development goals to university students: a cross-country case-based study. *Sustainability*, *14*(3), 1593. Doi: 10.3390/su14031593

[37]. Isabekov, A., & Sadyrova, G. (2018). Project-Based Learning to Develop Creative Abilities in Students. In J. Drummer, G. Hakimov, M. Joldoshov, T. Köhler, & S. Udartseva (Eds.), *Vocational Teacher Education in Central Asia: Developing Skills and Facilitating Success*, 43–49. Springer International Publishing. Doi: 10.1007/978-3-319-73093-6_4

[38]. Xie, C., Schimpf, C., Chao, J., Nourian, S., & Massicotte, J. (2018). Learning and teaching engineering design through modeling and simulation on a CAD platform. *Computer Applications in Engineering Education*, *26*(4), 824–840.

[39]. Cook, K. L., & Bush, S. B. (2018). Design thinking in integrated STEAM learning: Surveying the landscape and exploring exemplars in elementary grades. *School Science and Mathematics*, *118*(3–4), 93–103. Doi: 10.1111/ssm.12268

[40]. Jaiswal, A., Karabiyik, T., Thomas, P., & Magana, A. J. (2021). Characterizing team orientations and academic performance in cooperative project-based learning environments. *Education Sciences*, *11*(9), 520. Doi: 10.3390/educsci11090520

[41]. Jones, C., Volet, S., Pasternak, D. P., & Heinimäki, O.-P. (2022). Interpersonal affect in groupwork: A comparative case study of two small groups with contrasting group dynamics outcomes. *Frontline Learning Research*, *10*(1), 46–75. Doi: 10.14786/flr.v10i1.851

[42]. Ericson, J. D. (2022). Mapping the Relationship Between Critical Thinking and Design Thinking. *Journal of the Knowledge Economy*, *13*(1), 406–429. Doi: 10.1007/s13132-021-00733-w

[43]. Mutakinati, L., Anwari, I., & Yoshisuke, K. (2018). Analysis of students' critical thinking skill of middle school through stem education project-based learning. *Jurnal Pendidikan IPA Indonesia*, *7*(1), 54–65. Doi: 10.15294/jpii.v7i1.10495

[44]. Handhika, J., Cari, C., Sunarno, W., Suparmi, A., & Kurniadi, E. (2018). The influence of project-based learning on the student conception about kinematics and critical thinking skills. *Journal of Physics: Conference Series*, *1013*(1), 12028. Doi: 10.1088/1742-6596/1013/1/012028

[45]. Issa, H. B., & Khataibeh, A. (2021). The Effect of Using Project Based Learning on Improving the Critical Thinking among Upper Basic Students from Teachers' Perspectives. *Pegem Journal of Education and Instruction*, *11*(2), 52–57.

[46]. Castaño, J. P., Arnal-Pastor, M., Pagán-Castaño, E., & Guijarro-García, M. (2023). Bibliometric analysis of the literature on critical thinking: an increasingly important competence for higher education students. *Economic Research-Ekonomska Istraživanja*, *36*(2), 2125888. Doi: 10.1080/1331677X.2022.2125888

[47]. Carlgren, T. (2013). Communication, Critical Thinking, Problem Solving: A Suggested Course for All High School Students in the 21st Century. *Interchange*, *44*(1), 63–81. Doi: 10.1007/s10780-013-9197-8

[48]. Wanah, H. N., Jamaluddin, A. Bin, Zahra, F., Zubaidah, S., & Arsih, F. (2023). Critical thinking, communication skills and biology learning outcomes: Are they correlated? *AIP Conference Proceedings*, *2569*(1), 20018. Doi: 10.1063/5.0112421

[49]. Hassani, H., Huang, X., MacFeely, S., & Entezarian, M. R. (2021). Big data and the united nations sustainable development goals (UN SDGs) at a glance. *Big Data and Cognitive Computing*, *5*(3), 28. Doi: 10.3390/bdcc5030028

[50]. Østergaard, P. A., Duic, N., Noorollahi, Y., Mikulcic, H., & Kalogirou, S. (2020). Sustainable development using renewable energy technology. *Renewable Energy*, *146*, 2430–2437. Doi: 10.1016/j.renene.2019.08.094