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Learning Challenge: Farm Tractor Prototype with Solar Cell Technology in PjBL- STEM Learning using 4D Frame to Enhance the 21st Century Skills

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Abstract. The 21st century brings many new challenges and opportunities, mainly driven by technological advancements, globalization, and a rapidly changing workforce landscape. The main goal of education is no longer academic success but also equipping students with skills called 21st century skills. The 21st century skills needed to solve complex 21st century problems such as net zero challenges. Net zero aims to achieve carbon neutrality by balancing greenhouse gas emissions and removal from the atmosphere. The research aims to develop, implement, and analyze the effects of project based learning (PjBL)-science, technology, enggineering, and mathemathics (STEM) learning on students' 21st century skills to address the net zero challenge. The research also examined how students respond to renewable energy learning using the PjBL-STEM model through a solar-powered tractor project supported by the 4D frame. This study used a conversion mixed methods approach to transform qualitative data into quantitative data using established rubrics. The results showed that PjBL-STEM learning associated with environmental issues enhances students' 21st century skills and significantly affects the teaching of students' critical thinking. Meanwhile, students showed good performance in communication, collaboration, and creativity skills through discussion activities, teamwork, presentations, and engineering desain process.
Keywords: 21st Century skills, 4d frame, net zero, PJBL-STEM, renewable energy

Introduction

The 21st century world of work is undergoing dramatic changes (Schien, 2007) and altering the current generation's expectations about their career futures (Mann et al., 2020). The younger generation has a shift in perception from the established careers expected by previous generations (Ngoc, 2022). This shift must be responded to by schools as educational institutions that prepare students to be able to realize their career dreams.

Students who complete their education will join society and must acclimate to their surroundings. Additionally to being able to adapt to their surroundings, pupils also need to be able to meet their basic needs. In the rapidly evolving landscape of education, there is a growing recognition that traditional classroom instruction alone is insufficient in preparing students for the demands of the 21st century. The skills and competencies required for success continually shift as we enter the digital age. To meet these evolving needs, educational approaches must adapt accordingly.

The 21st century brings many new challenges and opportunities, mainly driven by technological advancements, globalization, and a rapidly changing workforce landscape (Grassini, 2023). Students must graduate with a strong foundation in core academic subjects and diverse skills that enable them to thrive in this dynamic environment. The disconnect between classroom content and job-related skills is the education system's current challenge. Educational institutions started changing how education is organized in response to the changes. The main goal of education is no longer academic success but also equipping students with skills called 21st century skills.

According to (partnership for 21st century skills, 2009) 21st century skills (4C) include critical thinking, creativity, collaboration, and communication. 21st century skills need to be possessed by students to solve complex problems in a globalized world and be able to adapt to change. Activities should be student-centered when designing a 21st century learning environment so students can explore, express, and discover their ideas. To develop collaboration and teamwork skills, learning instructions should also encourage teamwork. The goal is that when students face real-life problems, they can become problem solvers who can find creative solutions. To realize this learning atmosphere, there must be support from educators and supporting infrastructure in the environment.

To develop 21st century learning, teachers have taken various steps, including models and techniques that reorient education to better prepare students for and adapt to life in the twenty-first century. One of these instructional models is science, technology, engineering, and mathemathics (STEM) and project-based learning (PjBL). PjBL is student-centered learning and aids learners in developing innovative solutions to issues about their social lives through projects (Guo et al., 2020). The study of STEM subjects motivates pupils to engage in active learning (Bayanova et al., 2023). STEM education strives to equip students with the vital skills required in the workplace. Students actively participate in learning activities, problem-solving, and integrating varied knowledge to develop useful student abilities through STEM learning.

As we navigate the complexities of this era, it becomes evident that STEM learning plays a pivotal role in shaping not only individual careers but also the trajectory of nations and the global community (Waite & McDonald, 2019). STEM fields are at the forefront of technological advancements, addressing pressing societal issues and driving economic growth (Bacovic et al., 2022). To harness the full potential of STEM, it is essential to understand how STEM learning has evolved, adapted, and continues to evolve in response to the demands of our time. One of the notable trends in STEM education is the shift from siloed, discipline-specific teaching to a more interdisciplinary approach. Researchers have recognized that real-world challenges rarely fit neatly into the confines of a single STEM field. Educators and scholars emphasize the importance of integrated STEM learning to prepare students for the complex problems they will encounter in their careers and civic life (Bybee, 2013). Interdisciplinary STEM education promotes linkages across science, technology, engineering, and mathematics, developing students' global perspectives and problem-solving skills (PSS) (National Academy of Engineering and National Research Council, 2014). This approach mirrors the interconnected nature of contemporary STEM professions and cultivates essential skills such as critical thinking, collaboration, and creativity (Huang et al., 2022).

One of the defining features of STEM in the 21st century is its interdisciplinary nature (Daugherty & Carter, 2017). The boundaries between STEM are becoming increasingly porous, reflecting the real-world challenges that require holistic solutions. (Partnership for 21st century skills, 2009) observed that STEM disciplines are interconnected, and successful STEM education should foster collaboration and problem-solving across these domains. This calls for pedagogical approaches that transcend traditional subject-specific silos.

The idea of a "net zero" future has come to the top of conversations and policy agendas as we negotiate the intricacies of the twenty-first century and face the pressing global issues posed by climate change and environmental sustainability (Hao et al., 2023). The goal of "net zero" is to achieve carbon neutrality by achieving a balance between greenhouse gas emissions and removal from the atmosphere(Zhao, 2022). An extensive transformation of businesses, energy systems, and human behaviors is required to complete this enormous undertaking. The quest of a "net zero" world and STEM education are intrinsically linked, and this connection lies at the core of this enormous project. With environmental science, policy, and sustainability studies, STEM fields lay the groundwork for comprehending, reducing, and adapting to climate change's effects. In this context, this research embarks on a journey to develop, implement, and investigate the effects of PjBL-STEM learning on students' 21st century skills. This research examines how students can respond to renewable energy learning using a STEM learning model through a solar-powered tractor project supported by the 4D frame.

Methods

This study aims to assess the effectiveness of integrating a farm tractor prototype with solar cell technology into PjBL-STEM using the 4D frame instructional approach. Our goal is to enhance the 21st century skills of 10th grade students through hands-on, multidisciplinary STEM learning experiences.

This study used a conversion mixed methods technique, whereby predefined rubrics were used to convert qualitative data into quantitative data. Observation sheets were used for examples of evidence in student work outputs related to the specified 21st century competencies. With this conversion strategy, the 21st century ability qualitatively displayed in student activity was graded using the rubrics, combining qualitative and quantitative methodologies in the analysis (Figure. 1).

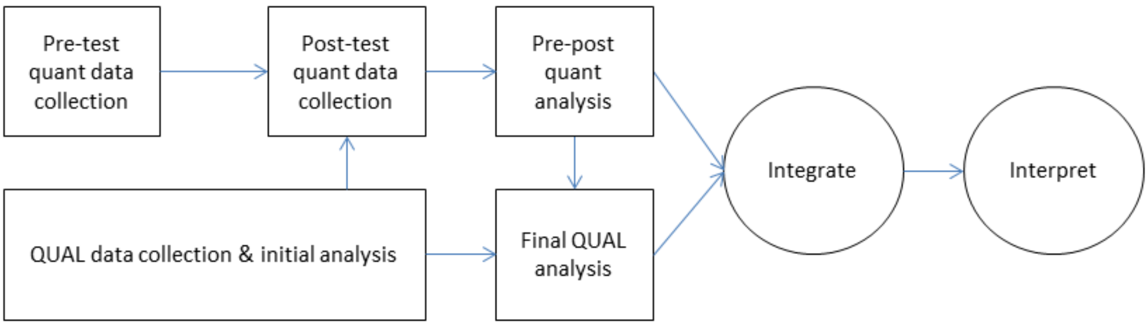

Figure 1. Diagram of mixed methods research design

Our study will involve twenty 10th grade students from a local high school, selected through purposive sampling. These students will be divided into small groups to engage in the PjBL-STEM activities. Before implementing the farm tractor prototype with solar cell technology in the PjBL-STEM learning using 4D frame, we will administer a pre-test to all participating students. This pre-test will consist of assessments to measure their baseline knowledge, skills, and attitudes related to critical thinking skills (CTS).

The intervention will involve the integration of the farm tractor prototype with solar cell technology into the PjBL-STEM curriculum, incorporating the 4D frame instructional approach. Students will work collaboratively on projects that involve designing, building, and testing a functional prototype of a solar-powered farm tractor. The activities will emphasize problem-solving, critical thinking, teamwork, and creativity.

Upon completing the PjBL-STEM program, we will administer a post-test to the same group of students. Like the pre-test, the post-test will include assessments to measure changes in their knowledge, skills, and attitudes related to CTS. By comparing post-test results to the pre-test baseline, we aim to determine the impact of the intervention.

In this study, we employed a paired t-test to analyze the data collected from the pre-test and post-test assessments of CTS to assess the impact of the farm tractor prototype with solar cell technology in PjBL-STEM learning using 4D frame on the 10th grade participants. Using the developed rubrics, we also measured creativity, communication, and collaboration skills. Qualitative data gathered through interviews and observation will be analyzed thematically to gain deeper insights into students' experiences and perceptions of PjBL-STEM learning.

Results and Discussion

The integration of science, technology, engineering, and mathematics is related to the implementation of PjBL-STEM. In this study, students will make the farm tractor prototype with solar cell technology based on the STEM field. The integration of STEM in making farm tractor prototype with solar cell technology activities can be presented in Table 1.

Table 1. STEM activities in farm tractor prototype with solar cell technology

Science (S)	Technology (T)	Engineering (E)	Mathematics (M)
Renewable Energy and its Applications	Using solar cells, Arduino, the internet, and handphones as a technology to simplify human activities	Designing Drawing	Measuring Calculating

The study's science field addresses the idea of renewable energy. Before students create a farm tractor prototype with solar cell technology project, students must first know the concept of renewable energy. After understanding the concept, students are challenged to apply the idea of renewable energy in solving an environmental problem. In this concept, students are expected to be able to analyze the type of renewable energy that is appropriately used in making products so that they are appropriate. This study's technology field can be shown in the preparation stage when students use the internet to find relevant sources of information, know the working principle of Arduino as a microcontroller, apply the function of solar cells in life, and use the 4D frame mechatronic application to set the direction of motion of the developed product.

The engineering stage, which can be observed at the stage of students making design drawings, selecting tools and materials that are by design, assembling, and testing the design through trial and error, and developing the design into a prototype that functions by the development objectives. Mathematics in this study refers to the measurements and calculations made by students, especially during EDP activities. This research shows that the pjbl-stem model helps support students' CTS, especially at the edp stage. this is found along the problem-solving steps through problem identification, analyzing the purpose of solving problems, and analyzing potential obstacles faced when carrying out projects. CTS are also trained when students work in groups and discuss ideas and designs from their thoughts, exchange ideas, and test them to decide which method to develop so that they can strengthen the arguments they make. these results align with the researchers of (Mutakinati et al., 2018; Yu et al., 2020; Rennie, 2021; Yaki, 2022) which stated that stem/edp plays an essential role in developing CTS. farmer (Farmer & Wilkinson, 2018) also noted that group interaction can increase students' CTS through communication. therefore, students argued using reasoning from various sources, including discussion activities requiring CTS (Yazici et al., 2020). This was likely accomplished due to the student's active participation in the learning process through, among other things, teamwork, hands-on and mind-on activities, and the solution of open-ended problems (Yaki, 2022).

The production of a unique and suitable reaction, product, or solution to an unrestricted task is called creativity (Ambabile, 2013). Based on (Besemer & Treffinger, 1981), two criteria have been chosen for each of the three dimensions of creativity. The resolution dimension has been selected based on practical and valuable parameters. Useful criteria refer to how the product is evident and meets the practical application, as opposed to valuable criteria, which refer to how the product is considered worthy by others because it satisfies the product's financial, physical, social, and psychological requirements. Then, the elaboration dimension's well-crafted and expressive criteria were chosen. Expressive criteria are described as how the product should be presented communicatively and understandably.

In contrast, well-crafted criteria refer to how the product appears and has been produced or redone with the care that the concept develops. The novelty component was chosen last, including the germinal and original criteria. Germinal criteria relate to how the product will likely suggest an addition for future creative development. Original criteria refers to how the product is distinctive and challenging to locate with the same product concept in a similar experience. The outcome is determined using the criteria for each creativity dimension. The creativity rubric is presented in Table 3, and the result of students' creativity is presented in Table 4.

Table 2. The creativity rubric

Creativity Dimension	Creativity Indicators	Group 1			Group 2		
		1	2	3	1	2	3
Novelty	Germinal			✓		✓	
	Original		✓			✓	
Resolution	Valuable			✓			✓
	Useful		✓				✓
Elaboration	Well Crafted			✓			✓
	Expressive		✓			✓	

Table 3. Students' creativity result

Creativity Dimension (%)			Average	Category
Novelty	Resolution	Elaboration		
75	92	83	83.33	Good

According to the study's findings, students who study renewable energy through PjBL-STEM-based learning exhibit strong creativity. stem project-based learning teaches students how to design (Figure 2) and make items (Figure 3 and 4) to materialize their ideas. by using the 4d frame to construct aesthetically pleasing and functional things, students are allowed to develop their ideas. it might be said that pupils who study science utilizing pjbl-stem exhibit strong creativity. research states that STEM education improves students' creativity in lower education (Üret & Ceylan, 2021) and higher education (Gu et al., 2023; Karamustafaoğlu & Pektaş, 2023; Mutakinati et al., 2018; Puchongprawet & Chantraukrit, 2022; Rennie, 2021). The creative products' quality increased when the students studied in STEM education, emphasizing the engineering design process

(Puchongprawet & Chantraukrit, 2022). EDP effectively improves students' creativity and collaborative abilities.

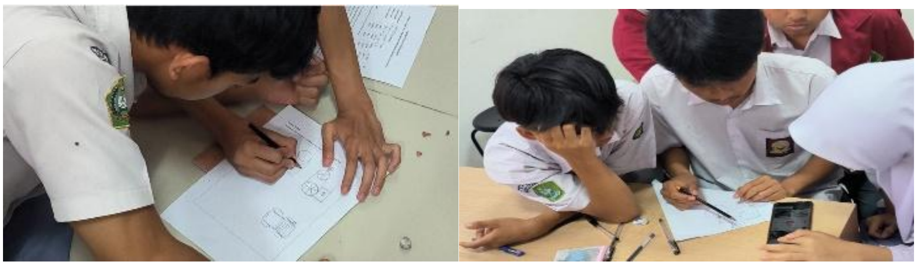

Figure 2. Drawing product design (EDP)

Figure 3. Assembling products (EDP)

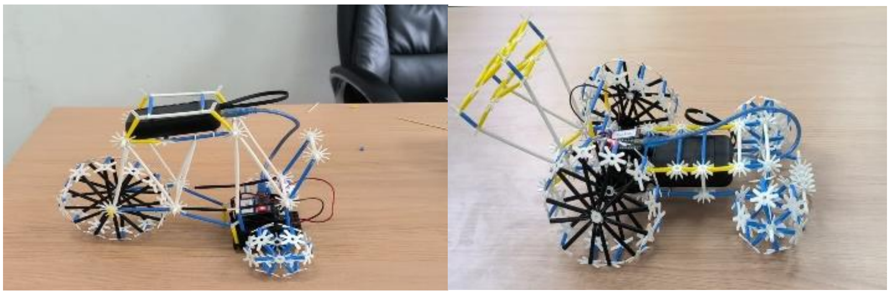

Figure 4. Product development result

The result is obtained based on the criterion of collaboration skill presented in Table 5 and the result of student creativity shown in Table 6.

Table 4. The collaboration rubric

Collaboration Dimension	Group 1				Group 2			
	1	2	3	4	1	2	3	4
Leadership			✓				✓	
Teamwork			✓					✓
Responsibility & productivity			✓				✓	

Table 5. Students' collaboration result

Collaboration Dimension (%)			Average	Category
Leadership	Teamwork	Responsibility & Productivity		
75	88	75	80	Good

The results show the excellent collaboration skills shown by students during the learning process. This is in line with research conducted by (Latip et al., 2020; Lertcharoenrit, 2020). Observations of the action and interaction aspects related to student activities and interactions when performing and discussing the project.

Activities for developing collaborative abilities include participation, perspective-taking, and social control. Collaboration skills are trained when students work in teams, so they must have a good leadership attitude, be able to work together in groups, and have responsibility for the tasks and success of the team. The result is obtained based on the criterion of communication dimension. The creativity rubric is presented in Table 7, and the effect of student creativity is shown in Table 8.

Table 6. The communication rubric

Communication Dimension	Group 1				Group 2			
	1	2	3	4	1	2	3	4
Presenting Ideas verbally			✓				✓	
Giving feedback				✓			✓	
Presentation			✓				✓	

Table 7. Students' communication result

Communication Dimension (%)			Average	Category
Presenting Ideas verbally	Giving feedback	Presentation		
75	88	75	80	Good

The results show the excellent communication skills shown by students during the learning process. This aligns with research conducted by (Mukaromah & Wusqo, 2020; Nurramadhani et al., 2023; Piyush et al., 2022; Wiyono et al., 2022), which states that learning with STEM can train and improve communication skills. Observers can observe that students are interested in learning in groups and discussions. Students provide arguments from different points of view while collaborating in groups. This makes them accustomed to communicating actively.

Product presentation activities (Figure 5) also support training students' communication skills. Students become more courageous in conveying the results of their findings and can provide feedback. In this activity, students share the product they made, the purpose of each part developed, and the product's functionality and test the product in front of the teacher and other groups. Students become more courageous in conveying the results of their findings and can provide feedback.

Conclusion

The PjBL-STEM learning model has been proven to train and improve 21st century skills. PjBL-STEM learning provides a good experience for students to be directly involved in solving complex problems through multi-disciplines, including the net zero challenge.

The students' acquisition of 21st century skills can be a provision for students to contribute and provide real action in the net zero challenge.

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