JPPIPA 10(9) (2024)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Project-Based Learning in Smart Solar Panel System for Analysis 21st Century Skills

Ihtiari Prastyaningrum[1*], Pramudya Ardi[1], Endhah Purwandari[2], Wahyu Hidayat[3]

[1] Electronic Engineering Education, Faculty of Education, Universitas PGRI Madiun Madiun Indonesia
[2] Physics Department, Faculty of Mathematics and Natural Science, Universitas Jember, Jember, Indonesia.
[3] National Kaohsiung University of Science and Technology, Kaohsiung, ROC

Received: May 13, 2024
Revised: July 21, 2024
Accepted: September 25, 2024
Published: September 30, 2024

Corresponding Author:
Ihtiari Prastyaningrum
ihtiari.prastya@unipma.ac.id

DOI: 10.29303/jppipa.v10i9.7639

Abstract: Collaboration and communication are two types of 21st-century skills that are very important for students to have. By having good communication and collaboration skills, students can build a wider network in the future, which is useful to support their lives. Students' communication and collaboration skills can be known through various activities, one of which is the involvement of students in project-based learning. The purpose of this study is to determine the effect of a modified project-based learning model on students' collaboration and communication skills. The project-based learning that we did focused on the project of making a smart solar system. This research is a type of development research, with a mixed method research method. We developed a modified project-based learning model. The data collection process was carried out by conducting in-depth interviews, and in-depth observations, supported by literature studies. In addition, we also used a measurement questionnaire to provide a numerical assessment of students' collaboration and communication skills. Based on the research conducted, we found that the modified project-based learning model can be used to determine the extent of students' communication and collaboration skills. Where the measurement results show good criteria in some indicators and sufficient on several other indicators.

Keywords: project-based learning; communication; collaboration; smart solar system

Introduction

Education makes a significant contribution to the context of social life. The quality of human resources cannot be separated from the role of education (Wirawan et al., 2023). Quality education is expected to make a positive contribution to developing science and technology (Dewi & Arifin, 2024). Education is not only centered on knowledge but also on developing skills. Both are the main goals of education in changing the social context (Albar, 2021). Along the way, education increasingly developed. Not only developing in terms of knowledge but also skills. To compensate for this, the learning model used, apart from being able to increase knowledge, must also be able to improve skills. One of the skills that is currently being talked about a lot is 21st-century skills or what is usually called 21st-century skills. As we know, the 21st-century skills include four components, namely critical thinking skills, collaboration, creativity, and communication (Laar et al., 2020; Redhana, 2019; Yokhebed, 2019).

21st-century skills are very important for students to have to prepare themselves for the world of work of the future (Prastyaningrum et al., 2023). Various studies have been conducted on the integration of 21st-century skills in learning activities (Roshid & Haider, 2024). This integration allows students to explore their knowledge related to collaboration and communication skills in all matters (Atasoy et al., 2023). The promotion of various skills to face the challenges of 21st-century developments

How to Cite:
Prastyaningrum, I., Ardi, P., Purwandari, E., & Hidayat, W. (2024). Project-Based Learning in Smart Solar Panel System for Analysis 21st Century Skills. *Jurnal Penelitian Pendidikan IPA*, *10*(9), 6756–6765. https://doi.org/10.29303/jppipa.v10i9.7639

continues to be developed. This is of course done to prepare the younger generation, in this case, students who are ready and reliable to face the future. Therefore, exploring the potential of 21st-century skills is very important. One model that is seen as able to accommodate both knowledge and skills is the project-based learning model.

Project-based learning can be defined as a structured pedagogical approach. This approach allows for active and open involvement in the form of teamwork (Barak, 2021). The project-based learning model is also able to teach the process of solving various problems (Chalsum et al., 2023; Puti et al., 2024). This learning model is considered to be very suitable to be developed and applied in analyzing 21st-century skills. Various studies on this subject have also been conducted (Azmi & Festiyed, 2023; Sarjani et al., 2023; N. Yanti et al., 2023). In the scope of learning in higher education environments, project-based learning models are recommended to be used as a teaching method to promote meaningful learning and deep understanding by connecting theory and knowledge with students' daily lives. (Barak & Usher, 2019; Wu & Wu, 2020). For example, project-based learning is used to increase students' understanding of the three-phase induction motor. Where through project-based learning students can learn directly through practicums, not only through theory presented by lecturers (Prastyaningrum & Pratama, 2019). In addition, the project-based learning model can also be used to learn about science (Masaguni et al., 2023; N. L. I. M. Yanti et al., 2023). For example, biology learning strategies through project-based activities. Where this activity is able to increase learning motivation for students (Susanti et al., 2022).

So far, the advantages of project-based learning have been widely conveyed in several literature (Kuo et al., 2019; Sasson et al., 2018). Higher education today strives to train students with strong innovation capabilities. Various activities to improve students' innovative thinking have been carried out. Not only through theory-based learning, but also in practicum learning. It is intended that students are able to combine theoretical knowledge and practical knowledge.

The concept of project-based learning implies collaboration in terms of planning, implementation, and evaluation stages (Almulla, 2020). In its implementation, some prioritize certain effective practices and characteristics, where there is the involvement of educators in designing and determining learning objectives (Schutz et al., 2019; Von Esch & Kavanagh, 2017). Through project-based learning, students can gain knowledge through the realization of a project that they work on alone or with other people (Amamou, 2018). Besides that, it also allows students to develop their creativity.

Project-based learning is learning that can be done individually or in teamwork. However, teamwork is seen as more effective. Teamwork, when mediated with technology, has proven to be an effective form of collaborative activity in creating interesting and independent learning experiences (Lawlor, 2018). Using project-based learning methods that involve teamwork will of course also be able to practice communication and collaboration skills. These two skills are two of the four types of 21st-century skills.

In this regard, we designed a form of research that wanted to reveal students' communication and collaboration skills through modified project-based learning models. Solar power plants as a means of public street lighting were chosen to complement the realm of project-based learning mediation with technology

Knowledge related to solar power plants is very important for students to have. As we all know, current environmental conditions are increasingly worrying. The occurrence of an energy crisis, environmental pollution, climate change, and fuel scarcity are challenges that highlight the importance of using renewable alternative energy sources. (Chen, 2018). Among the many alternative energies, solar energy is considered to be one of the most potential because of its cleanliness and availability.

Solar power plants utilize photovoltaics as their main component. This solar photovoltaic energy technology was first used in space. Photovoltaic technology is an environmentally friendly technology and is widely used as a solar power generator. It is said to be environmentally friendly because the carbon emissions produced are low compared to the fossil fuels that contribute 400g and 1000g CO_2 eq/kWh (Chowdhury et al., 2020). The use of solar panels is also a climate change mitigation strategy (Cordero, 2020).

It has been stated previously that our research focuses on project-based learning activities with the topic of solar power plants as an energy source for street lighting. In this case, it is also connected to the analysis of communication and collaboration skills in students. This research is important to do, because although there are many similar studies, we feel that there is still a need for modifications in the learning model, especially in the syntax of the project-based learning model. With this research, it is hoped that it can contribute new knowledge so that in the future it can be developed further. Our aim in carrying out this research is to analyze students' communication and collaboration skills. These two abilities will greatly benefit students, both during college and when they are working.

Based on the results of bibliometric analysis using Vos Viewer software, it is known that not many studies have examined project-based learning about the ability to communicate and collaborate. The network and

visualization of these conditions are shown in Figure 1 and Figure 2. Through Figure 1 and Figure 2, it can be seen that project-based learning research related to communication and collaboration skills still really needs to be researched. This is also a gap in this research.

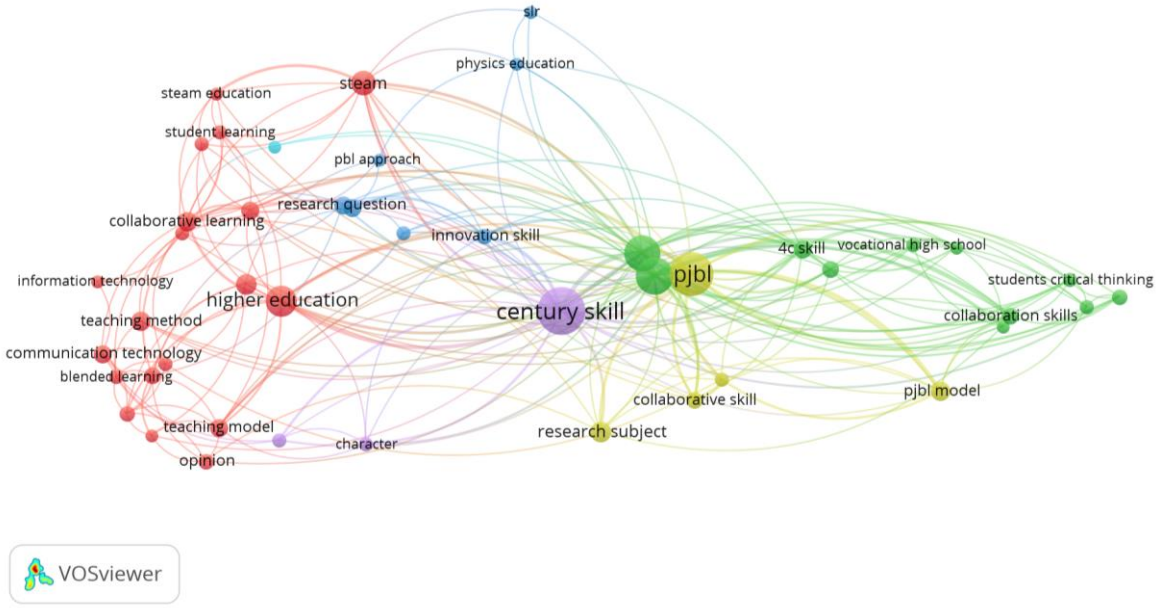

Figure 1. Network Visualization of PJBL research trends with communication and collaboration capabilities

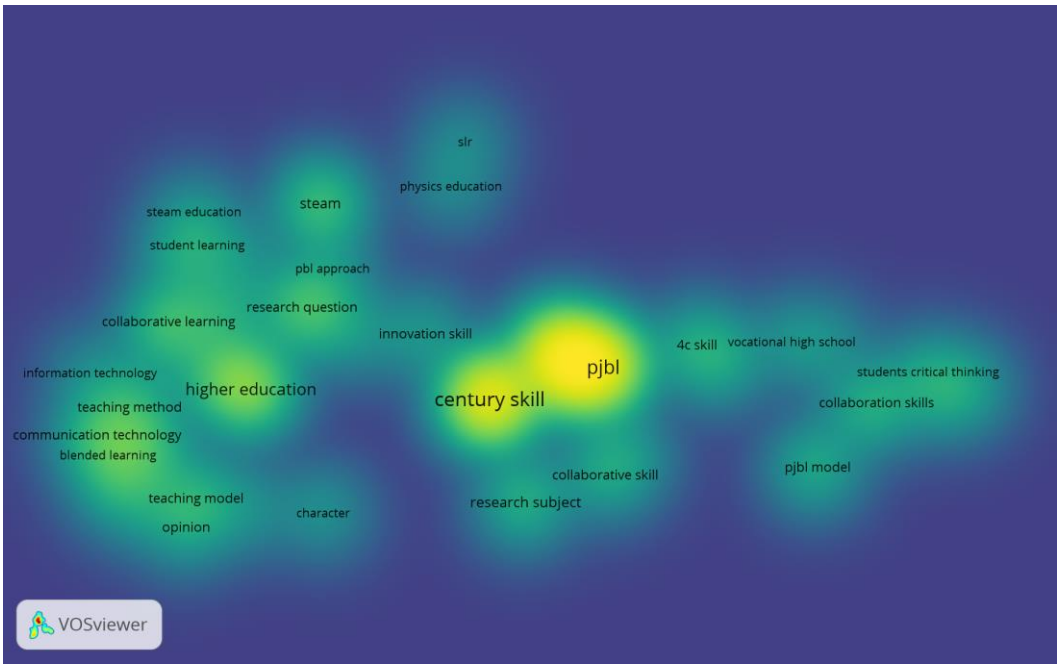

Figure 2. Density Visualization of PJBL research trends with communication and collaboration capabilities

Method

The type of research used is development research, with the ADDIE research model. We developed a modified project-based learning model to determine students' communication and collaboration skills. Project Based Learning has a general syntax that starts with fundamental questions as observation material. Based on the observation results, the project design is then carried out. In order for the project planning to run optimally, a schedule is prepared. In the syntax monitoring the activeness and development of the student project is monitored and supervised when doing the project. After the project is completed, it is continued by assessing the results that have been done, if it is considered to have met the standards, then proceed to the evaluation stage of the learning experience, where students are asked to present the projects that have been made (Suradika et al., 2023).

The ADDIE model that we use in this research is shown in Figure 3. Where the process begins with analyzing the learning activities that have taken place so far. Where the focus of activity analysis is only on learning activities that use project-based learning models. At this stage, several things were found that were deemed necessary to be given a little modification.

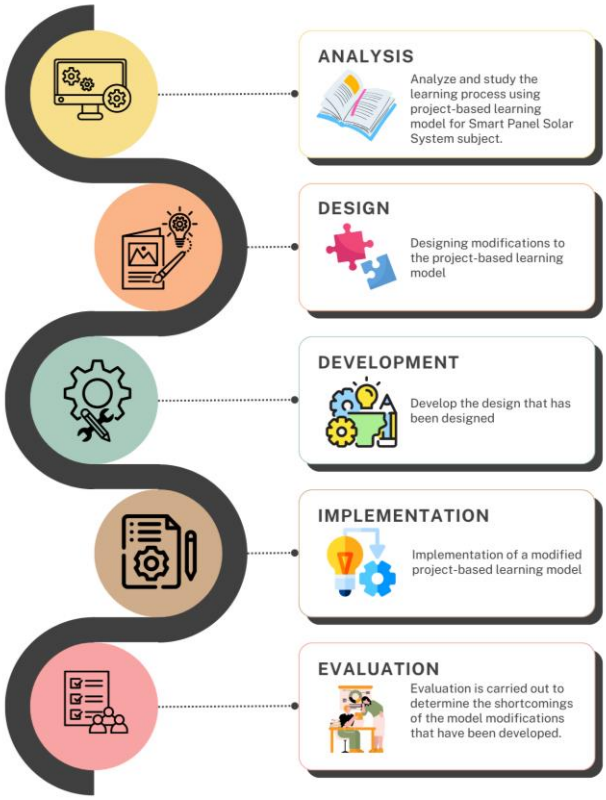

Figure 3. ADDIE Model

The next stage is design, where the design is based on the syntax of project-based learning. Broadly speaking, the syntax of project-based learning is stated in Table 1 (Kemdikbud, 2014).

Table 1. Syntax of Project-Based Learning

Step	Activity
1	Start with an essential question
2	Design a plan for the project
3	Create the schedule
4	Monitor the students and project progress
5	Asses the outcome
6	Evaluate the experience

Modifications are given to the syntax for the project-based learning learning model. Communication skills are emphasized more in the first and sixth syntax, namely starting with essential questions and evaluating the experience. Where there are additional evaluation activities for students' communication skills during the observation process. Meanwhile, collaboration skills between students are emphasized in the syntax of monitoring the students and project progress.

Assessment of communication and collaboration skills is based on 4C skill achievement indicators. The data collection process is carried out by direct assessment. Some of the communication indicators used include listening attitude, self-confidence, honesty and responsibility for the ideas expressed, ability to use spoken and written language well, and logical and structured thinking. Meanwhile, assessments related to the ability to collaborate are based on several achievement indicators which include the ability to work together, being able to adapt, having a sense of empathy and mutual respect, being able to compromise between group members, and being able to cooperate between group members. (Redhana, 2019).

The initial data collection process follows the syntax of the project-based learning model. At the "start with essential question" stage, students made observations on several sources to find out their opinions about the need for solar power plants. At this stage, an assessment is also carried out regarding student communication skills. The second stage based on syntax is the "Design a plan for the project" stage where students design a model of an intelligent solar power plant using an IoT system. The design that has been created is submitted to the supervisor for assessment and validation process. Next is the schedule preparation stage "Create the schedule". Students prepare a project implementation schedule. The schedule is prepared in detail, complete with achievements for each activity according to the established schedule.

The supervising lecturer carries out monitoring at the "Monitor the students and project progress" stage. At this stage, monitoring is carried out to find out how far the project is progressing and the obstacles experienced. By carrying out monitoring activities in an orderly and

regular manner, the handling of the obstacles faced will also be faster. In this way, project implementation will be maximally successful. At this stage, students' collaboration skills are also assessed. Assessment activities not only focus on communication and collaboration skills but also on the results of the projects carried out. The assessment includes the function of the tool, tool safety, usefulness, ease of maintenance, and accuracy of results. Assessment of these results is included in the syntax "Assess the outcome".

The final stage is the "Evaluate the experience" stage. At this stage, an evaluation process is carried out on the results achieved. The assessment is carried out through presentation activities. At this stage, an assessment of communication skills is also carried out. The assessment includes the ability to present project results, answer questions, and provide input to other groups presenting.

Result and Discussion

The purpose of this research is to develop a modified project-based learning model to determine students' collaboration and communication skills. The project set in this study is the manufacture of a smart panel solar system. The research began with an observation process through interviews with several resource persons, both students and lecturers, related to project-based learning that had been carried out so far. In addition, we also conducted interviews with several sources who understand solar-based public street lighting.

The first observation shows that project-based learning activities still need to be further developed, especially in relation to 21st century skills. As we know, 21st century skills are very important in preparation for life in the future (Ahmed Alismail, 2023). The second observation shows that solar power plants really need to be developed, considering that currently the availability of fossil energy as one of the supplies for electricity generation is running low. In addition, solar power includes renewable energy that is clean and free of pollutants (Massoud et al., 2023). But so far there are several obstacles related to the use of solar power plants. One of them is the maintenance process which requires high costs.

Students' communication skills can be assessed through observation activities. Communication is defined as the art of conveying information and meaningful interactions to exchange thoughts and attitudes with each other (Kalia et al., 2022). This communication skill is very important because it can make it easier to understand each other (Groene et al., 2022). Based on the measurements taken, the results are shown in Table 2.

Table 2. Communication Skills Measurement Results

Indicator	Result	Interpretation
Have an attitude of being able to listen and respect other people's opinions	4.0	Good
Have a confident attitude in communicating and expressing your ideas	3.6	Good
Have an honest attitude and be responsible for the ideas or ideas that have been put forward	3.8	Good
Able to express ideas or suggestions in public	3.8	Good
Able to use spoken and written content that matches the content of the person you are talking to or communicating with	3.9	Good
Able to use a logical and structured train of thought in communicating	3.9	Good
Able to communicate using other than Indonesian	3.3	Good Enough

Table 2 shows the measurement results of the communication skills indicators. Knowing the extent of students' communication skills, especially verbally is important, communicating verbally will reduce the risk of misinterpretation of the message conveyed (Abed et al., 2023). This study uses three assessment categories, namely good, sufficient and insufficient. Where these three categories we compiled based on the Likert scale, where the Likert scale is very powerful to measure related attitudes, opinions and perceptions of a person (Batterton & Hale, 2017). The average measurement results show a good interpretation except for the ability to communicate using languages other than Indonesian. In this case, it is English. The low ability of students in foreign languages is due to students not being accustomed to speaking in foreign languages, especially during lectures. This needs attention, considering the development of globalization requires the younger generation to be able to communicate in English, especially in the field of engineering (Rajprasit et al., 2015).

After the observation process, students continued with project planning. Since the observation results showed that currently the maintenance process is one of the things that needs more attention, the project focused on making an intelligent solar power generation system that focuses on ease of maintenance. The design of this

intelligent solar power generation system is equipped with an IoT system. This IoT system itself is relatively commonly used in the installation of solar power generation systems (Prasanna Rani et al., 2023; Ramu et al., 2021). The existence of IoT here is intended to make the maintenance process easier.

The design that has been made is validated by a team of experts. Validation is done to determine the validity of the design that has been made. The validation results were then analyzed with Aiken's V index. The results of the analysis are shown in Table 3.

Table 3. Validation Result

Indicator	V	Interpretation
Design View	0.6	Valid
Suitability of media and material	0.75	Valid
Ease of operation	0.6	Valid
Cost efficiency	0.7	Valid
Effectiveness	0.6	Valid
Layout settings	0.65	Valid
Average	0.65	Valid

Table 3 shows that the design made is declared valid. Based on the validity level, it is stated that the design can be continued at the realization stage. However, there is a minor revision to the design, namely the use of the IoT system. The design is designed using IoT integration, where the system will provide notification via telegram if no voltage is generated, and this will result in the street lighting not turning on. The absence of voltage in the system is due to the loose bolts attached to the battery. The minor revision given is the addition of information on each component in the system design. This is intended to make it easier during manufacturing.

Once the design is approved, the next stage is the schedule design stage. The schedule is designed by considering the personal schedule of each student. In the schedule planning, it is also equipped with a PIC for each activity, as well as the progress that must be achieved. This is intended to make it easier to control and overcome obstacles that occur during the project process.

Next is the implementation stage, where this stage is the core of the entire project. At this stage students start working on the project based on the schedule and division of tasks that have been prepared. Project implementation begins with the tool assembly process (Figure 3). In the tool assembly process, students are asked to assemble the tool according to the design that has been agreed upon and validated.

Figure 3. Tool assembly process

After the device was assembled and tested, the next step was the installation process (Figure 4). At both stages (assembly and installation), collaboration skills were assessed. The ability to collaborate is considered an important core in the learning process (Aini et al., 2020). The learning process can run well if students can interact with each other and exchange ideas to share information. Therefore, improving collaboration skills is essential for effective learning (Khalil & Ebner, 2017). In addition, collaboration skills must also be developed, because later they will often be required to work together in groups as part of their preparation for the 21st-century globalization era.

Figure 4. Installation Process

The results of measuring student collaboration skills are shown in Table 3. Through the table, you can find out what indicators were used, what the values were after processing, and the interpretation of these values.

Table 4. Collaboration Ability Measurement Results

Indicator	Result	Interpretation
Able to have the ability to collaborate or coordinating group members	3.4	Good Enough
Able to adapt to various roles and responsibilities as well work productively with others.	4.0	Good
Able to have a sense of empathy and respect other people's different perspectives when working in groups.	3.9	Good
Able to compromise with other members of the group to achieve predetermined goals.	3.9	Good
Able to apply the principles of cooperation in group activities	4.0	Good
Able to collaborate between group	3.8	Good
Able to analyze the ability of cooperation within himself to become a leader in the group.	3.2	Good Enough

Table 4 shows the results of measuring student collaboration skills. Based on Table 4, it appears that the average student's collaboration skills are good, but the indicators of the ability to coordinate groups and analyze the ability to cooperate still show lower scores than others. After analyzing through discussion forums with students, there are several causes. The reason students have not been able to coordinate a group is because students do not have an interest in organization. This really needs attention, considering that students not only need abilities and skills, but also personal psychological quality (Politsinsky & Demenkova, 2014), and this can be obtained through organizational activities.

Based on the assessment, it appears that students have not been able to analyze their own ability to work together. This is because students lack experience in conducting self-assessment. This is triggered by their feelings that sometimes consider self-assessment less necessary. This assumption must be corrected immediately, considering that self-assessment is a very important component in learning, where through self-assessment students can reflect on their learning (Sharma et al., 2016).

Self-assessment is a descriptive and evaluative act that a person performs on themselves. This assessment refers to the ability to pay attention to our actions, the curiosity to examine the impact of these actions, and the willingness to use these observations to improve future behavior and thinking (Andrade, 2019). By conducting self-assessment, students will be able to analyze their strengths and weaknesses which can later be used as one of the considerations for determining their next life decisions.

The next stage after working on the project is the result assessment stage. The results of the project were presented by the students. Students presented one by one according to their respective job disc. Through presentation activities, two values will be obtained, namely assessments related to communication skills and academic abilities related to the tools they make. The questions asked during the presentation included questions about the basic theory of solar panels, the power plant they made, and the IoT system they used. The assessment is determined based on the answers they use. Based on the assessment results, the percentage of student understanding related to these three things is shown in Figure 5.

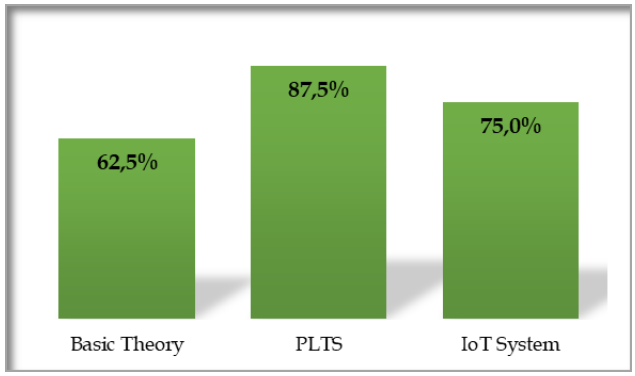

Figure 5. Percentage of theoretical ability

Based on Figure 5, it appears that understanding the basic theory of solar panels has the lowest percentage compared to others. Some questions related to basic theory include how the energy change system in solar panels, what is meant by energy gap and how the photon process can be converted into electrical energy. This happens because students have weaknesses in literacy, especially those related to theory.

In the process of assessing the outcome, communication skills were also reassessed. If previously communication was assessed based on how they made observations, but at this stage it was assessing how they made presentations.

Based on Table 5, it appears that during the presentation, students mastered the content of the presentation. They can communicate well, and interact with the audience. This is because students have mastered the presentation material, have prepared the material and also practiced. It is very important to prepare for a presentation. Because a presentation must be structured in content, and able to convey what is the

purpose and purpose of a presentation. Besides that, appearance is also a thing that determines the quality of a presentation, including the ability to answer questions, the audience, high confidence and body language, and feedback will be discussed (Stonehouse, 2018).

Table 5. Measurement of Communication Skills Through the Presentation Stage

Indicator	Result	Interpretation
Speak with an enthusiastic spirit and transmit enthusiasm and enthusiasm to the participants	3.9	Good
Deliver presentations clearly and with correct intonation	4.0	Good
Deliver a presentation without looking at notes	3.8	Good
Able to interact and use two-way communication with listeners	4.0	Good
Use eye contact with participants	4.0	Good

After going through all the processes, the last stage in project-based learning is the evaluation stage. At this stage students reflect on the work that has been done. Students are given the opportunity to express their feelings and experiences while completing the project. The evaluation stage allows students to pursue their own abilities to become better (Venable et al., 2016).

Conclusion

The conclusion obtained in this study is that, in the project-based learning model, modifications can be made to measure the extent of students' communication and collaboration skills. The results of measuring communication and collaboration skills in students on average have a good interpretation. The weakness of this research is in terms of limitations in the number of respondents, so that only two groups were involved in the implementation of the project. In addition, this research also requires considerable costs, because it requires some equipment that is quite expensive. Suggestions for future research are to add the number of respondents so that the data obtained regarding the effectiveness of this modified project-based learning model can be more accurate. In addition, other modifications can also be made, for example related to the elements of creativity and critical thinking.

Acknowledgments
We would like to express our thanks to the Ministry of Education, Culture, Research, and Technology, the entire Matching Fund Grant funding team, and students of the Electrical Engineering Education Study Program at PGRI Madiun University.

Author Contributions
Conceptualization, IP and PA; methodology, IP; software, PA; validation, IP and PA; format analysis, IP dan EP; investigation, PA; data curation, WH and EP; writing—original draft preparation, IP; writing—review and editing, IP and EP; visualization, PA and WH; supervision, IP and PA; project administration, PA; All authors have read and agreed to the published version of the manuscript.

Funding
This research was funded by Matching Fund Part 5 grant, Ministry of Education, Culture, Research, and Technology with number SK 0493/E/TU.00.01/2021.

Conflicts of Interest
No conflict of interest.

References

Abed, L. G., Abed, M. G., & Shackelford, T. K. (2023). An Exploratory Study of Verbal and Non-Verbal Communication in Saudi Arabian Families. *Behavioral Sciences*, *13*(2), 175. https://doi.org/10.3390/bs13020175

Ahmed Alismail, H. (2023). Teachers' Perspectives of Utilizing Distance Learning to Support 21st Century Skill Attainment for K-3 Elementary Students During the COVID-19 Pandemic Era. *Heliyon*, *9*(9), e19275. https://doi.org/10.1016/j.heliyon.2023.e19275

Aini, M., Narulita, E., & Indrawati. (2020). Enhancing Creative Thinking and Collaboration Skills through ILC3 Learning Model: A Case Study. *Journal of Southwest Jiaotong University*, *55*(4), 59. https://doi.org/10.35741/issn.0258-2724.55.4.59

Albar, S. B. (2021). Problem and Project-Based Learning Through an Investigation Lesson: Significant Gains in Creative Thinking Behaviour Within the Australian Foundation (Preparatory) Classroom. *Thinking Skills and Creativity*, *41*(3). https://doi.org/10.1016/j.tsc.2021.100853

Almulla, M. A. (2020). The Effectiveness of the Project-Based Learning (PBL) Approach as a Way to Engage Students in Learning. *SAGE Open*, *10*(3). https://doi.org/10.1177/2158244020938702

Amamou, S. (2018). Tutoring in Project-Based Learning. *Procedia Computer Science*, *126*, 176–185. https://doi.org/10.1016/j.procS.2018.07.221

Andrade, H. L. (2019). A Critical Review of Research on Student Self-Assessment. *Frontiers in Education*, *4*, 87. https://doi.org/10.3389/feduc.2019.00087

Atasoy, I., Özdemir, S. Ç., & Evli, M. (2023). Relationship Between Individual Innovativeness and 21st Century Skills of Nursing and Midwifery Students: A cross Sectional Study. *Nurse Education Today*, *126*, 105830. https://doi.org/10.1016/j.nedt.2023.105830

Azmi, N., & Festiyed, F. (2023). Meta Analysis: The Influence of Instrument Assessment on Project-Based Learning Models to Improve 4C Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 2184–2190. https://doi.org/10.29303/jppipa.v9i4.2606

Barak, M. (2021). A Cultural Perspective to Project-Based Learning and The Cultivation of Innovative Thinking. *Thinking Skills and Creativity*, *39*(Query date: 2024-05-04 05:21:29). https://doi.org/10.1016/j.tsc.2020.100766

Barak, M., & Usher, M. (2019). The Innovation Profile of Nanotechnology Team Projects of Face-to-Face and Online Learners. *Computers & Education*, *137*, 1–11. https://doi.org/10.1016/j.compedu.2019.03.012

Batterton, K. A., & Hale, K. N. (2017). The Likert Scale What It Is and How To Use It. *Phalanx*, *50*(2).

Chalsum, U., Arsyad, M., & Helmi, H. (2023). Development of Student Worksheets (LKPD) to Measure Student Creativity. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 1861–1867. https://doi.org/10.29303/jppipa.v9i4.2674

Chen, X. (2018). Teaching–learning–based artificial bee colony for solar photovoltaic parameter estimation. *Applied Energy*, *212*, 1578–1588. https://doi.org/10.1016/j.apenergy.2017.12.115

Chowdhury, Md. S., Rahman, K. S., Chowdhury, T., Nuthammachot, N., Techato, K., Akhtaruzzaman, Md., Tiong, S. K., Sopian, K., & Amin, N. (2020). An overview of solar photovoltaic panels' end-of-life material recycling. *Energy Strategy Reviews*, *27*, 100431. https://doi.org/10.1016/j.esr.2019.100431

Cordero, E. C. (2020). The role of climate change education on individual lifetime carbon emissions. *PLoS ONE*, *15*(2). https://doi.org/10.1371/journal.pone.0206266

Dewi, M. R., & Arifin, Z. (2024). Analysis of 21st Century Skills in the Implementation of Project Based Learning in Biology Learning Merdeka Curriculum. *Jurnal Penelitian Pendidikan IPA*, *10*(4), 2118–2128. https://doi.org/10.29303/jppipa.v10i4.5941

Groene, O. R., Ehrhardt, M., & Bergelt, C. (2022). Attitude and Communication Skills of German Medical Students. *BMC Research Notes*, *15*(1), 11. https://doi.org/10.1186/s13104-021-05901-4

Kalia, M., Rohilla, R., Virk, A., & Goel, N. (2022). Introducing Communication Skills Training Among Interns Using Attitude, Ethics, and Communication Module. *Indian Journal of Community Medicine*, *47*(3), 352. https://doi.org/10.4103/ijcm.ijcm_953_21

Kemdikbud. (2014). *Materi Pelatihan Guru Implementasi Kurikulum 2013 Tahun Ajaran 2014/2015: Mata Pelajaran IPA SMP/MTs*. Kementrian Pendidikan dan Kebudayaan.

Khalil, H., & Ebner, M. (2017). Using Electronic Communication Tools in Online Group Activities to Develop Collaborative Learning Skills. *Universal Journal of Educational Research*, *5*(4), 529–536. https://doi.org/10.13189/ujer.2017.050401

Kuo, H.-C., Tseng, Y.-C., & Yang, Y.-T. C. (2019). Promoting college student's learning motivation and creativity through a STEM interdisciplinary PBL human-computer interaction system design and development course. *Thinking Skills and Creativity*, *31*, 1–10. https://doi.org/10.1016/j.tsc.2018.09.001

Laar, E. van, Deursen, A. J. A. M. van, Dick, J. A. G. M. van, & Haan, J. de. (2020). Determinants of 21st-Century Skills and 21st-Century Digital Skills for Workers: A Systematic Literature Review. *SAGE Open*, *10*(1). https://doi.org/10.1177/2158244019900176

Lawlor, J. (2018). Bridge21: Teamwork, technology and learning. A pragmatic model for effective twenty-first-century team-based learning. *Technology, Pedagogy and Education*, *27*(2), 211–232. https://doi.org/10.1080/1475939X.2017.1405066

Masaguni, A. N., Lamangantjo, C. J., Katili, N., Pikoli, M., Buhungo, T. J., & Payu, C. S. (2023). Development of Science Learning Modules Based on Project Based Leraning on Additives and Addictive Substances (A Research in Class VIII SMP Negeri 7 Telaga Biru). *Jurnal Penelitian Pendidikan IPA*, *9*(12), 10758–10767. https://doi.org/10.29303/jppipa.v9i12.5731

Massoud, M., Vega, G., Subburaj, A., & Partheepan, J. (2023). Review on Recycling Energy Resources and Sustainability. *Heliyon*, *9*(4), e15107. https://doi.org/10.1016/j.heliyon.2023.e15107

Politsinsky, E. V., & Demenkova, L. G. (2014). The Organization of the Training of Technical College Students Using Practice-Oriented Tasks. *Asian Social Science*, *11*(1), 187. https://doi.org/10.5539/ass.v11n1p187

Prasanna Rani, D. D., Suresh, D., Rao Kapula, P., Mohammad Akram, C. H., Hemalatha, N., & Kumar Soni, P. (2023). IoT Based Smart Solar Energy Monitoring Systems. *Materials Today: Proceedings*, *80*, 3540–3545. https://doi.org/10.1016/j.matpr.2021.07.293

Prastyaningrum, I., Imansari, N., & Kholifah, U. (2023). Analysis of Critical Thinking Skills and Collaboration of Electronic Engineering Education Students in Electrical Machinery Course. *IJIET (International Journal of Indonesian Education and Teaching)*, *7*(1), 114–120. https://doi.org/10.24071/ijiet.v7i1.5091

Prastyaningrum, I., & Pratama, H. (2019). The Application of Project Based Learning Method in

Learning Micro-Hydro Electrical Power. *Journal of Physics: Conference Series*, *1171*, 012031. https://doi.org/10.1088/1742-6596/1171/1/012031

Puti, T. N., Karyanto, P., & Fatmawati, U. (2024). Application of Project-Based Learning and Discovery Learning in Virtual Media on Analytical Thinking Skills for Animal Classification. *Jurnal Penelitian Pendidikan IPA*, *10*(6), 3083–3091. https://doi.org/10.29303/jppipa.v10i6.4635

Rajprasit, K., Pratoomrat, P., & Wang, T. (2015). Perceptions and Problems of English Language and Communication Abilities: A Final Check on Thai Engineering Undergraduates. *English Language Teaching*, *8*(3), 111. https://doi.org/10.5539/elt.v8n3p111

Ramu, S. K., Irudayaraj, G. C. R., & Elango, R. (2021). An IoT-Based Smart Monitoring Scheme for Solar PV Applications. *Electrical and Electronic Devices, Circuits, and Materials*, 211–233. https://doi.org/10.1002/9781119755104.ch12

Redhana, I. W. (2019). Mengembangkan Keterampilan Abad Ke-21 dalam Pembelajaran Kimia. *Jurnal Inovasi Pendidikan Kimia*, *13*(1). https://doi.org/10.15294/jipk.v13i1.17824

Roshid, M. M., & Haider, Md. Z. (2024). Teaching 21st-Century Skills in Rural Secondary Schools: From Theory to Practice. *Heliyon*, *10*(9), e30769. https://doi.org/10.1016/j.heliyon.2024.e30769

Sarjani, L. P. W., Suastra, I. W., & Subagia, I. W. (2023). The Influence of Project-Based Learning Models on Collaboration Skills and Science Learning Outcome for Junior High School. *Jurnal Penelitian Pendidikan IPA*, *9*(SpecialIssue), 1284–1292. https://doi.org/10.29303/jppipa.v9iSpecialIssue.7243

Sasson, I., Yehuda, I., & Malkinson, N. (2018). Fostering the skills of critical thinking and question-posing in a project-based learning environment. *Thinking Skills and Creativity*, *29*, 203–212. https://doi.org/10.1016/j.tsc.2018.08.001

Schutz, K. M., Danielson, K. A., & Cohen, J. (2019). Approximations in English language arts: Scaffolding a shared teaching practice. Teaching and Teacher Education. *Teaching and Teacher Education*, *81*. https://doi.org/10.1016/j.tate.2019.01.004

Sharma, R., Jain, A., Gupta, N., Garg, S., Batta, M., & Dhir, S. (2016). Impact of Self-Assessment by Students on Their Learning. *International Journal of Applied and Basic Medical Research*, *6*(3), 226. https://doi.org/10.4103/2229-516X.186961

Stonehouse, D. (2018). How to Prepare and Deliver a Good Presentation: General Principles for Success. *British Journal of Healthcare Assistants*, *12*(8), 394–397. https://doi.org/10.12968/bjha.2018.12.8.394

Suradika, A., Dewi, H. I., & Nasution, M. I. (2023). Project-Based Learning and Problem-Based Learning Models in Critical and Creative Students. *Jurnal Pendidikan IPA Indonesia*, *12*(1), 153–167. https://doi.org/10.15294/jpii.v12i1.39713

Susanti, D., Sari, L. Y., & Fitriani, V. (2022). Increasing Student Learning Motivation through the Use of Interactive Digital Books Based on Project Based Learning (PjBL). *Jurnal Penelitian Pendidikan IPA*, *8*(4), 2022–2028. https://doi.org/10.29303/jppipa.v8i4.1669

Venable, J., Pries-Heje, J., & Baskerville, R. (2016). FEDS: A Framework for Evaluation in Design Science Research. *European Journal of Information Systems*, *25*(1), 77–89. https://doi.org/10.1057/ejis.2014.36

Von Esch, K. S., & Kavanagh, S. (2017). Preparing mainstream classroom teachers of English language learner (EL) students: Grounding practice-based designs for teacher learning in theories of expertise development. *Journal of Teacher Education*, *69*(3). https://doi.org/DOI 10.1016/j.tate.2019.01.004

Wirawan, I. K. A., Arnyana, I. B. P., & Subagia, I. W. (2023). The Influence of a Project-Based Learning Model Oriented to Socioscientific Issues on Student Learning Outcomes in View of Self-Efficacy. *Jurnal Penelitian Pendidikan IPA*, *9*(10), 9056–9066. https://doi.org/10.29303/jppipa.v9i10.4831

Wu, T.-T., & Wu, Y.-T. (2020). Applying Project-Based Learning and SCAMPER Teaching Strategies in Engineering Education to Explore the Influence of Creativity on Cognition, Personal Motivation, and Personality Traits. *Thinking Skills and Creativity*, *35*, 100631. https://doi.org/10.1016/j.tsc.2020.100631

Yanti, N. L. I. M., Redhana, W., & Suastra, W. (2023). Multiple Scaffolding STEAM Project-Based Learning Model In Science Learning. *Jurnal Penelitian Pendidikan IPA*, *9*(8), 6493–6502. https://doi.org/10.29303/jppipa.v9i8.4470

Yanti, N., Rahmad, M., & Azhar. (2023). Application of PjBL (Project Based Learning) Based Physics Learning Model to Improve Collaboration Skills and Creative Thinking Ability of Students. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 9973–9978. https://doi.org/10.29303/jppipa.v9i11.5275

Yokhebed. (2019). Profil Kompetensi Abad 21: Komunikasi, Kreativitas, Kolaborasi, Berpikir Kritis Pada Calon Guru Biologi Profile of 21st Century Competency: Communication, Creativity, Collaboration, Critical Thinking at Prospective Biology Teachers. *Bio-Pedagigi (Jurnal Pembelajaran Biologi)*, *8*(2). https://doi.org/10.20961/bio-pedagogi.v8i2.36154