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ORIGINAL RESEARCH

The implementation of PeSACCS (Peer and Self-Assessment for Collaboration and Communication Skills) in experimental class

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ABSTRACT

This century, education aims to prepare students with the skills needed to thrive in Society 5.0. This has become the basis for ensuring comprehensive, impartial, quality learning and providing long-term learning opportunities for all. Communication and collaboration are essential skills that students must possess to effectively work in teams, solve problems, and adapt to dynamic environments. This study aims to reveal the communication and collaboration skills profile through peer student assessment and laboratory activity self-assessment. This research employs a case study method to analyze the differences between self-assessment, peer assessment, and lecturer observation in practical activities. The subject of this research is fifth-semester physics education students who take the Physics Experiment course. Before the laboratory activity begins, students are divided into small groups. Students are given an observation questionnaire at the end of each class to assess themselves and their group mates. In addition to self-assessments and peer-assessments, the results of the lecturer's observations are also one of the data to provide more in-depth information on students' collaboration and communication abilities.

Keywords: 21st Century Skills · Assessment · Collaboration · Communication

INTRODUCTION

The Society 5.0 era is a concept of a human-centered, technology-based society (Faridawati et al., 2020). In this era, society is expected to address many challenges and social issues by leveraging innovations born during the Industrial Revolution 4.0 to enhance the quality of human life. A wide range of skills are essential for people in this era including critical thinking, creativity, problem-solving and decision-making, communication, collaboration, citizenship/culture, and character/compassion (Yusal et al., 2022). These skills are highly sought after in the workplace, particularly by employers, with an emphasis on both oral and written communication skills and effective collaboration (Andrian & Rusman, 2019; Rios et al., 2020; Van Laar et al., 2020).

Collaboration and communication are crucial for citizens as they are fundamental skills for adapting and thriving in a fast-paced era (Rios et al., 2020; Van Laar et al., 2020). Students show communication skills when they can organize their thoughts, information, and findings. They also can actively share information through various media, particularly in speaking and writing. On the other hand, students exhibit collaborative skills when they can work together to answer questions or solve problems, achieve shared goals, and engage in teamwork to complete a task (Aslan, 2021; Malik & Ubaidillah, 2021; Saldo & Walag, 2020).

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Collaboration involves the reciprocal engagement of members in efforts to solve problems. Shared goals, structural symmetry, high-level organization, interactivity, and mutual interdependence characterize collaborative intuition. Developing intuitive explanations is essential for creating learning opportunities for students. Collaboration can have a significant impact on learning particularly for low-achieving students. Several components can influence the effectiveness of collaboration in learning including student characteristics, group member composition, and task characteristics (Lai, 2011; Malik & Ubaidillah, 2021; Partono et al., 2021; Saldo & Walag, 2020).

However, despite the acknowledged importance of collaboration and communication skills, research indicates that these skills are often overlooked in higher education settings, particularly in physics education (DeBarger et al., 2011; Lai, 2011; Spies & Xu, 2018). One approach to cultivating these competencies is through the integration of laboratory activities and group assignments within university learning frameworks (Chongdarakul et al., 2021; Muhajir, 2023). Many students struggle to effectively communicate scientific findings and collaborate efficiently in experimental settings. Therefore, this study aims to explore effective strategies for enhancing these competencies in physics education, particularly through structured laboratory activities and peer interactions. This research seeks to answer the following questions: (1) How do students' self-assessments compare with peer assessments and instructor observations in evaluating collaboration and communication skills? (2) What factors influence the development of these skills in physics experiment courses.

To assess these skills, this study employs the Physics Experiment Student Assessment of Collaboration and Communication Skills (PeSACCS). PeSACCS is a structured evaluation tool that measures students' ability to communicate scientific ideas, engage in discussions, and collaborate effectively in laboratory settings. By integrating multiple assessment perspectives, including instructor observations as a control measure, PeSACCS ensures a more objective and comprehensive evaluation of students' competencies.

METHODS

Research Design

This study employs a case study method (Creswell & Creswell, 2017), with the research subjects comprising all students enrolled in the physics experiment course within the Physics Education program. This course is a compulsory component of the curriculum for prospective physics teachers. The laboratory activities were designed following the problem-solving laboratory steps according to Heller (Heller et al., 1992).

Research Procedures

In this research, experimental topic focused on determining the local gravitational acceleration was selected. The procedures utilized by students varied among groups: some employed the harmonic motion method using a pendulum, while others applied the concept of collisions in free-fall motion. The experiments were further facilitated by technological tools, such as the Phyphox application. The experimental syntax included the following stages: problem identification, data collection, data analysis, and the final stage of communicating findings and constructing a scientific product (Chongdarakul et al., 2021).

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Instrument and Data Collection

The instruments used in this study are a questionnaire based on PeSACCS (Peer and Self-Assessment for Collaboration and Communication Skills) and an observation sheet for lecturers based on the rubrics of the Buck Institute of Education (BIE, 2013). The self- and peer-assessment questionnaire, alongside observation, was chosen because authentic assessment can enhance students' learning experiences by increasing their engagement, improving their satisfaction, and positively influencing their efforts to achieve educational goals (Kearney & Perkins, 2014). The indicators of collaboration skills used in this study include: 1) taking responsibility for oneself, 2) helping the team, and 3) respecting others. Meanwhile, the indicators of communication skills employed are: 1) explanation of ideas and information, 2) organization, and 3) technology skills.

In the self-assessment questionnaire, there are three statement options for each indicator, covering both collaboration and communication skills. The first statement represents the Below Standard level, the second represents Approaching Standard, and the third represents At Standard (BIE, 2013). However, the order of these statements is not the same for every question; they are randomized to prevent students from consistently selecting only options 1, 2, or 3. Additionally, all statements in the questionnaire are formulated in a positive manner to encourage constructive self-reflection.

Data Analysis and Interpretation

In this research, data was collected after students finished their experiment class by filling out both peer- and self-assessment surveys. Students were instructed to evaluate their teammates' performance based on their own preferences. Prior to this, the instructor had provided guidelines on how to complete the assessments. Meanwhile, observers carried out their tasks throughout the experiment by assessing students' communication and collaboration skills. The number of observers was adjusted according to the number of groups, meaning that each group had one assigned observer.

The data from observers and students were then processed and analyzed to determine the correlation among the three assessments. This was done to examine the consistency between observer ratings, peer assessment, and self-assessment profiles. The profiles were analyzed by converting the score data into percentage values for peer, self, and observation assessments. The percentage was obtained by dividing the total score by the maximum possible score and multiplying by 100%. The results were then classified into percentages for each standard.

To determine the relationship between self, peer, and observer assessments, a correlation test was conducted. In this case, the scores obtained from peer, self, and observer assessments for each student were compared. If the correlation result is positive, a value of 1 indicates a perfect positive linear correlation between two variables. The closer the value is to -1 or +1, the stronger the relationship between the variables(Ratner, 2009). A correlation value above zero indicates a positive correlation, while a value below zero indicates a negative correlation. A positive correlation signifies a direct relationship between the variables being tested.

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RESULTS AND DISCUSSION

Results

The profile of collaboration skills is presented as a percentage of students demonstrating collaboration skills based on the specified indicators. Table 1 provides a summary of the percentage of collaboration skills observed over three sessions.

Table 1. Summary of Students' Collaboration Skills

Level		Precentage 1 (%)			Precentage 2 (%)			Precentage 3 (%)		
		Indicator			Indicator			Indicator		
		1	2	3	1	2	3	1	2	3
At standard	Peer	13	18.75	31.25	18.75	43.75	46.88	37.5	71.88	68.75
Approaching standard		28.13	71.88	3.13	81.25	56.25	53.13	62.5	28.13	31.35
Below standard		59.38	9.38	65.63	0	0	0	0	0	0
At standard	Self	65.63	46.88	56.25	65.63	46.88	56.25	65.63	46.88	56.25
Approaching standard		28.13	25	43.75	28.13	25	43.75	28.13	25	43.75
Below standard		6.12	28.13	0	6.25	28.12	0	6.25	28.13	0
At standard	Observation	0	46.88	59.38	9.38	43.75	75	28.13	56.25	78.13
Approaching standard		62.5	25	40.63	90.63	56.25	25	71.88	43.75	21.88
Below standard		37.5	28.13	0	0	0	0	0	0	0

Table 1 shows an increase in the number of students demonstrating collaboration skills at the standard level, along with a decrease in the percentage of students at the approaching standard and below standard levels across each session. Figure 1 presents the average percentage of students' collaboration skills based on observation assessments, peer assessments, and self-assessments over three sessions.

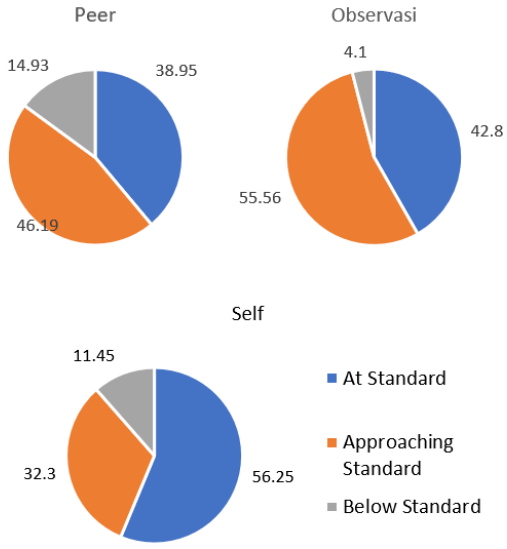

Figure 1. Average Percentage of Collaboration Skills

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Figure 1 illustrates the average percentage of collaboration skills based on observer assessments, showing that the majority of students fall within the approaching standard level, with a percentage of 55.56%. This finding aligns with peer assessment results, where the highest percentage of students, 46.18%, also falls into the approaching standard level. However, unlike the observer and peer assessments, self-assessment results indicate that most students are categorized at the standard level, with a percentage of 56.25%. Despite these differences, in all three assessment methods—observer, peer, and self-assessment—the lowest percentage is consistently at the below standard level, indicating that only a small proportion of students exhibit collaboration skills at this level. Following the analysis, percentage scores of collaboration skills were determined for each session, and a correlation test was conducted between the scores from observer assessments, peer assessments, and self-assessments to evaluate the reliability of the collected data. The results of this analysis are presented in Table 2.

Table 2. Recapitulation of Collaboration Skills Reliability Test

Session	Correlation		
	Observation -Peer	**Observation -Self**	**Peer-Self**
1	Positive	Positive	Positive
2	Positive	Positive	Positive
3	Positive	Negative	Positive

Another skill assessed in this study is communication. The selected indicators include the use of various media, effective communication of ideas, and technological proficiency. Table 3 provides a summary of the percentages of communication skills demonstrated over three sessions.

Table 3. Summary of Students' Communication Skills

Level	Jenis	Precentage 1 (%)			Precentage 2 (%)			Precentage 3 (%)		
		Indicator			Indicator			Indicator		
		1	2	3	1	2	3	1	2	3
At standard	Peer	0	12.5	59.36	9.38	43.75	75	28.13	56.25	78.13
Approaching standard		62.5	87.5	40..63	90.63	56.25	25	71.88	43.75	21.88
Below standard		37.5	0	0	0	0	0	0	0	0
At standard	Self	31.25	25	25	31.25	25	25	31.25	25	25
Approaching standard		59.38	68.75	75	59.38	68.75	75	59.38	68.75	75
Below standard		9.38	6.25	0	9.38	6.25	0	9.38	6.25	0
At standard	Observation	0	9.38	100	25	21.88	100	34.38	46.88	100
Approaching standard		100	71.88	0	75	78.13	0	65.63	53.13	0
Below standard		0	18.75	0	0	0	0	0	0	0

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Based on Table 3, it can be concluded that there is a consistent increase in the number of students demonstrating communication skills at the at standard level in each session, accompanied by a decrease in the percentage of students at the approaching standard and below standard levels. Figure 2 presents the average percentage of students' communication skills based on observer assessments, peer assessments, and self-assessments over three sessions.

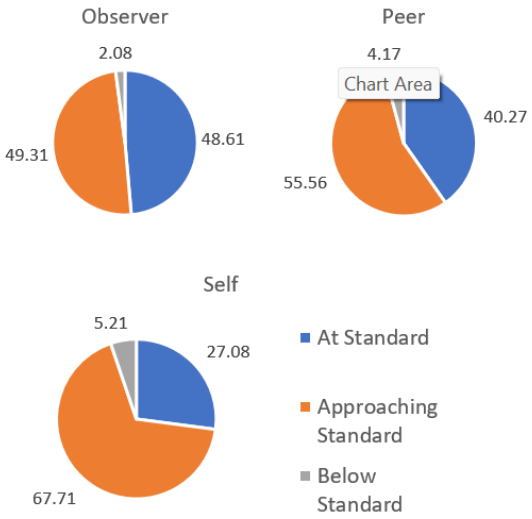

Figure 2. Average Percentage of Communication Skills

Figure 2 presents the average percentages of communication skills based on observer, peer, and self-assessments. The majority of students fall within the approaching standard level, with 49.31% in observer assessments and 55.56% in peer assessments. In contrast, self-assessments show that nearly half of the students are at the standard level. Across all assessment methods, the below-standard level consistently shows the lowest percentage, indicating only a small number of students with minimal communication skills. A correlation analysis was conducted to evaluate the reliability of the data, and the results are summarized in Table 4.

Tabel 4. Recapitulation of Communication Skills Reliability Test

Pertemuan	Korelasi		
	Observation -Peer	**Observation -Self**	**Peer-Self**
1	Positive	Positive	Positive
2	Positive	Positive	Positive
3	Positive	Positive	Negative

Discussion

Collaboration Skills

The collaboration skill data in this study were obtained through observations using observation sheets and questionnaires. The assessment of collaboration skills was limited to the indicators of assuming responsibility for the group, assisting the team, and showing respect for others. Data analysis revealed an improvement in students' collaboration skills across each session, as reflected in the at standard, approaching standard, and below standard levels.

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Reliability testing, conducted to assess the consistency of evaluations between observer, peer, and self-assessments, indicated a positive correlation among the three assessment methods. This suggests that the results accurately reflect the actual conditions observed in the field. However, in the third session, a negative correlation between self-assessment and observer assessment was observed. This may be attributed to students' overconfidence in their abilities or a lack of maximal effort during the experiment, despite possessing the necessary skills (Rafiola et al., 2020).

Based on Figure 1, the percentage of collaboration skills, as assessed by both observers and peer assessments, shows improvement at each at standard level, indicating a qualitative enhancement across sessions. This is likely due to the fact that, during the first session, students were not yet accustomed to collaborating with randomly assigned group members, resulting in suboptimal task distribution. Some students focused solely on solving the problems, while others merely took notes. Over time, these activities, when practiced regularly, contribute to the development of collaboration skills (Endres et al., 2021; Valtonen et al., 2021).

In addition to the peer-assessment results, collaboration skills were also measured using a self-assessment questionnaire. The questionnaire consisted of nine statements, each with a scoring range from 1 to 3. Data analysis revealed that students' collaboration skills remained consistent across sessions, both at the at-standard, approaching-standard, and below-standard levels. This differs from the observation results, which showed an increase in the percentage of students demonstrating collaboration skills at the standard level across sessions.

The indicator with the highest percentage was "respecting others." This indicator consistently had the highest percentage in each session, both according to observer assessments and peer assessments, with the percentage values presented in Table 2. This aligns with the feedback from observers and analysis of video recordings during the lessons, which showed that all team members demonstrated respect for others. The indicator of "respecting others" was emphasized during laboratory activities but was particularly evident during the "communicating" stage, where one group was asked to present the results of their project while another group responded. Collaboration skills were further developed during the discussion process (DeBarger et al., 2011; Lai, 2011; Partono et al., 2021).

The percentage values for the collaboration skill of taking responsibility for the group in problem-solving are as follows: 12.50% for observer assessments, 22.92% for peer assessments, and 65.63% for self-assessments at the at standard level. The final indicator, helping the team, shows the following percentages: 37.50% for observer assessments, 44.79% for peer assessments, and 46.86% for self-assessments.

The results of the observer and self-assessment evaluations differ somewhat, with peer assessments sometimes showing higher percentages. However, for other indicators, self-assessment results are higher. Interviews revealed that some students felt that certain group members only listened to the opinions of those perceived as more intelligent. These students, however, did not believe they were discriminating against others, but rather felt that some members did not contribute ideas or suggestions.

Based on interviews with six students, it was found that while students felt responsible for their group, they were unsure of what they should do to help the team, as some students did not understand the project the group was working on. As a result, those members were considered not sufficiently responsible for the group. Regarding the indicator of helping the team, interview

data revealed that although students felt responsible, they believed they did not contribute much to their groups.

According to the data shown in Table 1, the percentage of students at the at standard level for the first indicator increased with each session, starting at 0% in the first session and reaching 28.13% in the final session. Similarly, for peer assessments, the percentage of collaboration skills rated at 3 increased steadily across sessions, from 13%, to 18.73%, and to 37.50%. This indicates that over time, students became more responsible within their groups, meaning by the third session, students were more prepared to work in teams and better understood the project information due to prior preparation. In other words, most students had become more facilitative, supportive, and informative in completing the project (AlAli, 2024).

Similarly to the first indicator, the second indicator also showed a significant increase in the percentage of students at the at standard level across each session. In the first session, the percentage of collaboration, according to observer assessments, was 12.50%, rising to 81.25% in the second session, and 56.25% in the third session. For peer assessments, the percentages were 18.75% in the first session, 43.75% in the second session, and 71.88% in the third session.

These results indicate that over time, students became more skilled at helping the team, particularly through active participation in group discussions. The group discussions became more dynamic, with increased feedback provided by group members throughout the sessions. This suggests that the experiment effectively facilitated the development of collaboration skills (Aisyah et al., n.d.; Partono et al., 2021).

For the third indicator, respecting others, the percentages of observer and peer assessments were as follows: 59.38% and 31.25% for the first session, 75% and 46.88% for the second session, and 78.13% and 68.75% for the third session. In the first session, all indicators had the lowest percentages, likely due to students not yet being accustomed to the group dynamics and learning model. Nevertheless, the percentage for the respecting others indicator was already relatively high starting from the first session. Thus, it can be concluded that project-based problem-solving learning, particularly in experimental settings, emphasizes group-based problem-solving, which fosters collaboration skills (Chongdarakul et al., 2021; Kurniahtunnisa et al., 2023; Lestari et al., 2023; Muhajir et al., 2019).

In addition to project-based learning, various instructional activities that emphasize group collaboration, such as games, can also enhance collaboration skills. Furthermore, activities like reading sources can help students become responsible group members and assist the team. Reading provides students with additional knowledge, enabling them to contribute more effectively to solving the team's problems (Aslan, 2021; Chongdarakul et al., 2021).

Communication Skills

The data on communication skills in this study were obtained from observations using observation sheets and questionnaires. Communication skills in this study are limited to the indicators of using various media, communicating ideas and thoughts, and technology proficiency. Based on the data analysis, it was found that the percentage of students' communication skills increased across each session. The percentages of communication skills for the three sessions are presented in Figure 2.

The results of the reliability test, aimed at determining the consistency of the assessments between observers, peers, and self-assessments, indicate a positive correlation among peer, self,

and observer evaluations. This proves that the processed results accurately reflect the actual situation in the field. (Docktor & Heller, 2009; Hermawan et al., 2017). In the third session, a negative correlation was found between self-assessment and peer assessment. Some students believed they communicated their ideas effectively, but their group members felt that their communication skills were lacking.

Based on the five percentage values for communication skills from both observations and peer assessments, improvement was observed for each session, indicating a gradual enhancement in quality. This is likely because, in the first session, students were not yet accustomed to communicating with their randomly assigned group members, which led to suboptimal communication. Several students were unable to use media effectively, and most were not yet accustomed to using various media to communicate ideas, relying mainly on verbal communication.

In addition to the observation and peer-assessment results, communication skills were also measured through self-assessment questionnaires. The questionnaire contained nine statements, each scored from 1 to 3. The results, presented in Table 5, show that students' self-assessed communication skills remained constant at the at standard level across each session. This differs from the percentages of the observation and peer-assessment results, which increased each session. These findings suggest that while students have potential in communication, they lack confidence in this area, possibly due to insufficient practice. With regular practice, they would likely gain confidence, as repetition is key to developing skills (Rafiola et al., 2020).

The communication indicator with the highest percentage of students at the at standard level is the technology skills indicator, with 100% for observer assessment in each session and 71% for peer assessment. This aligns with the observers' comments and the analysis of video footage from the lessons, which showed that all group members were proficient in using technology, such as the internet, PCs, and smartphones.

Communication skills are generally practiced through project and experimental activities; however, they can be easily observed during the data collection and communication stages, where one group is asked to present the results of their project while another group provides feedback. Through the discussion process, communication skills can be further developed (BIE, 2013).

The percentage of students demonstrating communication skills at the at standard level for the indicator of communicating ideas is 26.04% for observer assessments, 37.50% for peer assessments, and 25% for self-assessments. The percentage for the indicator of using various media is 19.79% for observer assessments, 12.50% for peer assessments, and 31.25% for self-assessments.

There are differences between the results of the observer assessments and self-assessments for each indicator. However, the highest and lowest percentages for each indicator in the observer and self-assessments are consistent. This differs from the collaborative skills discussed earlier. Based on interviews with six students, it was found that students experienced difficulty explaining their ideas to other group members. They felt that the students may not fully understand what was being communicated, as knowledge is one of the factors that influences communication (Ferrer et al., 2022; Valtonen et al., 2021).

Based on the data presented in Table 4, the percentage for the first indicator increased with each meeting. This indicates that students became increasingly proficient in using various types

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of media to solve problems throughout the sessions. However, in the second and third meetings, there was no further increase, which is believed to be due to the fact that the media used in the project consisted solely of visual communication media. Examples of visual communication media include articles, worksheets, and laptops, while interactive communication media, such as the internet, and experimental support media, such as the Phyphox app, were not utilized as extensively (Staacks et al., 2022).

Similar to the first indicator, the second indicator also showed a significant improvement in each meeting, as evidenced by both peer assessment and observer ratings. This indicates that over time, students became increasingly skilled in communicating ideas and concepts, allowing them to communicate effectively and efficiently. It can be concluded that project-based and experimental activities are effective in developing communication skills (Sirait & Amnie, 2023)

For the third indicator, which pertains to technological skills, the percentage based on observer assessments was 100% for each meeting. Meanwhile, according to peer assessments, the percentage of students in the "at standard" category was 59.38% for the first meeting, 75% for the second meeting, and 78.13% for the third meeting. In the first meeting, all indicators had the lowest percentage, which is believed to be due to students' unfamiliarity with their groups and the learning model. Nevertheless, the technological skills indicator showed a consistently high percentage, starting from the first meeting and reaching its peak in the third meeting.

Thus, it can be concluded that project-based problem-oriented learning, which emphasizes collaborative problem-solving, effectively develops communication skills (AlAli, 2024; Azmi & Festiyed, 2023; Saldo & Walag, 2020; Sirait & Amnie, 2023). This is because laboratory activities involve discussions, which provide opportunities to develop collaboration skills. The success of these discussions is contingent on students possessing adequate knowledge, as it enhances their understanding and contributes to the development of communication skills. Therefore, reading skills and literacy play a significant role in influencing communication abilities (Partono et al., 2021; Spies & Xu, 2018)

CONCLUSION

It can be concluded that students' collaboration and communication skills are categorized as good across all indicators, based on the analysis of observer, peer, and self-assessment results. The use of self- and peer-assessments is highly effective in analyzing students' skill levels. The three instruments mutually reinforce each other. Peer and self-assessment provide valuable alternatives for observing collaboration and communication skills.

REFERENCES

Aisyah, D. A., Imansyah, H., & Feranie, S. (n.d.). Pengaruh Reading Infusion pada Perangkat Pembelajaran Problem Solving Terhadap Perkembangan Keterampilan Abad 21 Siswa SMA pada Materi Fluida Statis. *WaPFi (Wahana Pendidikan Fisika)*, *6*(2), 180–187.

AlAli, R. (2024). Enhancing 21st Century Skills Through Integrated STEM Education Using Project-Oriented Problem-Based Learning. *Geo Journal of Tourism and Geosites*, *53*(2), 421–430.

Aslan, A. (2021). Problem-based learning in live online classes: Learning achievement, problem-solving skill, communication skill, and interaction. *Computers & Education*, *171*, 104237.

Azmi, N., & Festiyed, F. (2023). Development of physics learning assessment instrument in project-based learning model to improve 4C skills. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 1798–1804.

https://doi.org/10.17509/wapfi.v10i1.77061

Buck Institute of Education (BIE). (2013). *BIE (2013). PBL for 21st Century Success*, (2nd ed., Vol. 1). Buck Institute of Education.

Chongdarakul, W., Kirimasthong, K., & Sutthaluang, T. (2021). POPBL-Blended Learning Model to Enhance Student Performance in Integrated Modular Learning Environment. *2021 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunication Engineering*, 360–363.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches.* Sage publications..

DeBarger, A. H., Penuel, W. R., Harris, C. J., & Schank, P. (2011). Teaching routines to enhance collaboration using classroom network technology. In *Techniques for fostering collaboration in online learning communities: Theoretical and practical perspectives* (pp. 224–244). IGI Global.

Docktor, J., & Heller, K. (2009). Robust assessment instrument for student problem solving. *Proceedings of the NARST 2009 Annual Meeting*, *70*(4), 1–19.

Endres, T., Leber, J., Böttger, C., Rovers, S., & Renkl, A. (2021). Improving lifelong learning by fostering students' learning strategies at university. *Psychology Learning & Teaching*, *20*(1), 144–160.

Faridawati, F. F., Minarto, E., Wati, I. I., Sutrisno, S., & Hakim, L. (2020). Pembelajaran robotik untuk mempersiapkan generasi muda menghadapi revolusi industri 4.0 dan society 5.0. *Spekta*, *1*(2), 85–94.

Ferrer, J., Ringer, A., Saville, K., A Parris, M., & Kashi, K. (2022). Students' motivation and engagement in higher education: The importance of attitude to online learning. *Higher Education*, *83*(2), 317–338.

Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. *American Journal of Physics*, *60*(7), 627–636.

Hermawan, H., Siahaan, P., Suhendi, E., Kaniawati, I., Samsudin, A., Setyadin, A. H., & Hidayat, S. R. (2017). Desain instrumen rubrik kemampuan berkolaborasi siswa SMP dalam materi pemantulan cahaya. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *3*(2), 167–174.

Kearney, S. P., & Perkins, T. (2014). Engaging students through assessment: The success and limitations of the ASPAL (Authentic Self and Peer Assessment for Learning) Model. *Journal of University Teaching & Learning Practice*, *11*(3), 2.

Kurniahtunnisa, K., Anggraito, Y. U., Ridlo, S., & Harahap, F. (2023). STEM-PjBL learning: the impacts on Studentsâ€TM critical thinking, creative thinking, communication, and collaboration Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 5007–5015.

Lai, E. R. (2011). Collaboration: A literature review. *Pearson Publisher. Retrieved November*, *11*(2016), 1–23.

Lestari, M., Supriyadi, S., & Sulhadi, S. (2023). The Growth of Vocational High School Students' 4C Skills on the Use of PjBL STEM-Based Physics Digital Module. *Physics Communication*, *7*(2), 63–70.

Malik, A., & Ubaidillah, M. (2021). Multiple skill laboratory activities: How to improve students' scientific communication and collaboration skills. *Jurnal Pendidikan IPA Indonesia*, *10*(4), 585–595.

Muhajir, S. N. (2023). What are students'levels of communication and collaboration skills through problem-solving learning? *Journal of Teaching and Learning Physics*, *8*(2).

Muhajir, S. N., Utari, S., & Suwarma, I. R. (2019). How to develop test for measure critical and creative thinking skills of the 21st century skills in POPBL? *Journal of Physics: Conference Series*, *1157*(3), 032051.

Partono, P., Wardhani, H. N., Setyowati, N. I., Tsalitsa, A., & Putri, S. N. (2021). Strategi meningkatkan kompetensi 4C (critical thinking, creativity, communication, & collaborative). *Jurnal Penelitian Ilmu Pendidikan*, *14*(1), 41–52.

https://doi.org/10.17509/wapfi.v10i1.77061

Rafiola, R., Setyosari, P., Radjah, C., & Ramli, M. (2020). The effect of learning motivation, self-efficacy, and blended learning on students' achievement in the industrial revolution 4.0. *International Journal of Emerging Technologies in Learning (IJET)*, *15*(8), 71–82.

Ratner, B. (2009). The correlation coefficient: Its values range between+ 1/− 1, or do they? *Journal of Targeting, Measurement and Analysis for Marketing*, *17*(2), 139–142.

Rios, J. A., Ling, G., Pugh, R., Becker, D., & Bacall, A. (2020). Identifying critical 21st-century skills for workplace success: A content analysis of job advertisements. *Educational Researcher*, *49*(2), 80–89.

Saldo, I. J. P., & Walag, A. M. P. (2020). Utilizing problem-based and project-based learning in developing students' communication and collaboration skills in physics. *American Journal of Educational Research*, *8*(5), 232–237.

Sirait, J. V., & Amnie, E. (2023). Analysis of Students' Collaboration Skills through Project-Based Learning Model. *Gagasan Pendidikan Indonesia*, *4*(1), 43–50.

Spies, T. G., & Xu, Y. (2018). Scaffolded academic conversations: Access to 21st-Century collaboration and communication skills. *Intervention in School and Clinic*, *54*(1), 22–30.

Staacks, S., Dorsel, D., Hütz, S., Stallmach, F., Splith, T., Heinke, H., & Stampfer, C. (2022). Collaborative smartphone experiments for large audiences with phyphox. *European Journal of Physics*, *43*(5). https://doi.org/10.1088/1361-6404/ac7830

Valtonen, T., Hoang, N., Sointu, E., Näykki, P., Virtanen, A., Pöysä-Tarhonen, J., Häkkinen, P., Järvelä, S., Mäkitalo, K., & Kukkonen, J. (2021). How pre-service teachers perceive their 21st-century skills and dispositions: A longitudinal perspective. *Computers in Human Behavior*, *116*, 106643.

Van Laar, E., Van Deursen, A. J. A. M., Van Dijk, J. A. G. M., & De Haan, J. (2020). Determinants of 21st-century skills and 21st-century digital skills for workers: A systematic literature review. *Sage Open*, *10*(1), 2158244019900176.

Yusal, Y., Suhandi, A., & Kaniawati, I. (2022). The development of concept development-collaborative decision-making problem solving (CD-CDMPS) to improve the prospective physics teachers' decision making skills. *WaPFi (Wahana Pendidikan Fisika)*, *7*(2), 93–102.

https://doi.org/10.17509/wapfi.v10i1.77061