JPPIPA 12(3) (2026)

Jurnal Penelitian Pendidikan IPA

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

A Study of 21st-Century Skills Among Senior High School Students in the Context of Project-Based Renewable Energy Learning in South Sumatra Province

Ketang Wiyono[1*], Melly Ariska[1], Evelina Astra Patriot[1], Frendi Ihwan Syamsudin[1], Nor Farahwahidah[2], Tyse Ramadhona[1], Senandung Senja Citra Maharani[1], Laura Insan Kencana[1], Dea Rizky Oktavia[1]

[1] Department of Physics Education, Faculty of Teacher Training and Education, Universitas Sriwijaya, South Sumatra, Indonesia
[2] Department of Innovative Science and Mathematics Education, Faculty of Educational Sciences & Technology, Universiti Teknologi Malaysia, Johor, Malaysia

Received: October 20, 2025
Revised: January 12, 2026
Accepted: March 25, 2026
Published: March 31, 2026

Corresponding Author:
Ketang Wiyono
ketang_wiyono@fkip.unsri.ac.id

DOI: 10.29303/jppipa.v12i3.14333

Abstract: The rapid development of science and technology demands that students master essential 21st-century skills, particularly the 4Cs: critical thinking, creativity, collaboration, and communication. This study aims to map senior high school students' mastery of 4C skills in Renewable Energy learning and to examine differences across the four components. A quantitative descriptive design was applied involving four schools selected through cluster sampling, with each school representing one 4C component. Research instruments consisted of validated and reliable tests and Likert-scale questionnaires. Data were analyzed using descriptive statistics to categorize skill levels and the Kolmogorov–Smirnov test to assess normality. As most data were not normally distributed, the Kruskal–Wallis test was employed to analyze differences among the skills. The results reveal significant variation in students' 4C performance. Critical thinking and collaboration were categorized as high, while creativity and communication showed more diverse distributions. The Kruskal–Wallis test produced an Asymp. Sig value of < 0.05, indicating significant differences among the four skill domains. These findings suggest that 4C skill development is uneven and influenced by learning experiences and instructional strategies. Therefore, systematic mapping of 4C skills is crucial for curriculum improvement and the design of targeted instructional interventions.

Keywords: 21st-century skills; High school students; Quantitative descriptive study; Renewable Energy Learning; South Sumatra.

Introduction

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results. The rapid advancement of technology and socio-economic transformation in the 21st century demands that students acquire a set of essential skills as key competencies to navigate global changes, industrial needs, and environmental challenges (Saavedra & Opfer, 2012; Tijani & Adeduyigbe, 2026). These essential competencies are widely known as the 4Cs—critical thinking, creativity, collaboration, and communication. Strengthening the 4Cs becomes increasingly relevant when linked to national strategic issues such as Renewable Energy, as understanding energy concepts and solving modern energy problems require critical reasoning, creative design capabilities, teamwork, and effective scientific communication (Peterson, 2023; Zahara et al., 2025). Therefore, schools must provide learning experiences that not only emphasize conceptual mastery but also integrate the development of 21st-century skills.

How to Cite:
Wiyono, K., Ariska, M., Patriot, E. A., Syamsudin, F. I., Farahwahidah, N., Ramadhona, T., … Oktavia, D. R. (2026). A Study of 21st-Century Skills Among Senior High School Students in the Context of Project-Based Renewable Energy Learning in South Sumatra Province. *Jurnal Penelitian Pendidikan IPA*, *12*(3), 729–740. Retrieved from https://jppipa.unram.ac.id/index.php/jppipa/article/view/14333

One learning model capable of supporting this need is Project-Based Learning (PjBL). PjBL offers students the opportunity to design and complete authentic projects relevant to real-life contexts, thereby simultaneously fostering critical thinking, creativity, collaboration, and communication (Krajcik, 2018; Miller, 2023). In Renewable Energy learning, PjBL can be implemented through simple technology design projects such as mini solar panels, wind turbine prototypes, or biomass energy systems, enabling students to understand energy concepts while engaging in scientific reasoning and collaborative work (Chen, 2023; Hidayah, 2024).

Moreover, the relevance of this research is strengthened by the context of Renewable Energy education, which inherently requires interdisciplinary thinking, problem-solving, and innovation. According to STEM education principles, solving energy-related problems demands not only conceptual understanding but also the ability to design solutions, work collaboratively, and communicate scientific ideas effectively. Therefore, integrating 4C skills within Renewable Energy learning is both theoretically justified and practically necessary.

Logically, without a comprehensive mapping of students' 4C skills, educators face significant challenges in designing targeted and effective instructional interventions. The absence of such data leads to generalized teaching approaches that may fail to address specific student needs. This study addresses this gap by providing an integrated analysis of all four competencies within a single framework, which is still limited in previous research. Most prior studies tend to focus on isolated skills rather than examining their interrelationships holistically.

Therefore, this research is important for three main reasons. First, it provides empirical evidence on the actual profile of students' 21st-century skills in a specific contextual learning environment. Second, it contributes to the theoretical development of integrated 4C skill frameworks in science education. Third, it offers practical implications for teachers and curriculum designers to develop more adaptive, evidence-based, and differentiated instructional strategies.

However, preliminary findings and field observations indicate that the 4C skills of senior high school students in South Sumatra Province have not developed evenly. Some students demonstrate strong critical thinking and creative idea generation, while others still struggle with teamwork, effective communication, or maintaining consistent contributions throughout project activities. This imbalance suggests a fundamental issue: the absence of a comprehensive mapping of students' 21st-century skill profiles, particularly within the context of Project-Based Renewable Energy Learning. Such limitations hinder teachers in designing appropriate instructional strategies, as students' developmental needs in each 4C dimension remain insufficiently identified.

A review of previous studies shows that most research has focused on enhancing a single skill, such as creativity or collaboration (Zhang et al., 2022). Studies that explicitly map all four 21st-century skills simultaneously in the context of Renewable Energyare still limited (Fitriyah, 2024; Ghazali, 2024; Hidayat, 2025). This limitation highlights a relevant research gap that needs to be addressed.

Based on the aforementioned background, the present study proposes an initial investigation to analyze the profile of senior high school students' 21st-century skills (critical thinking, creativity, collaboration, and communication) within the context of Project-Based Renewable Energy Learning in South Sumatra Province. This research offers novelty through an integrated mapping of the four 4C dimensions within a single analytical framework, which has rarely been conducted in the context of Renewable Energy at the senior high school level. The findings are expected to provide theoretical and practical contributions toward developing adaptive, evidence-based instructional strategies that support the comprehensive strengthening of 21st- century competencies.

Method

Scope of the Study

The scope of this study covers the mapping of 21st-century skills, including critical thinking, creativity, collaboration, and communication, among senior high school students in South Sumatra Province who are engaged in Project- Based Renewable Energy Learning.

Population and Sampling Method

The population of this study consists of all senior high school students participating in Project- Based Renewable Energy Learning in South Sumatra Province. The sampling technique employed was cluster-based sampling, which divides the population into natural groups (clusters) before selecting research samples. This technique is commonly used in educational research when population units are naturally grouped based on location, program, or specific characteristics (Cochran, 1977; Creswell & Creswell, 2022; Fraenkel et al., 2019).

Each school was treated as a single cluster representing one domain of 21st-century skills (4Cs). Cluster selection was conducted purposively to ensure

alignment with the analytical objectives. Purposive sampling aligns with approaches that select samples based on specific considerations and contextual relevance to the research purpose (Patton, 2015). School A was designated as the cluster representing critical thinking skills with 97 students; School B represented creativity skills with 74 students; School C represented collaboration skills with 72 students; and School D represented communication skills with 63 students. The total sample consisted of 306 students.

This systematic clustering arrangement enabled the researchers to comprehensively map the profile of 21st-century skills (4Cs) based on the context of Renewable Energy Learning in each school (Saavedra & Opfer, 2012).

Research Instruments

The research instruments consisted of a test and a questionnaire measuring 21st-century skills (4Cs), developed based on the dimensions of critical thinking, creativity, collaboration, and communication synthesized from Trilling and Fadel (2021) and (Saavedra & Opfer, 2012). The test items were constructed in the form of multiple- choice questions, while the questionnaire employed a five-point Likert scale, in accordance with common practices for assessing profiles and perceptions in educational research (Creswell, 2018; Sugiyono, 2021).

The instruments underwent content and construct validation by three experts, comprising a subject-matter expert, an evaluation expert, and a language expert. The validation procedure followed the principles of assessing indicator relevance, item clarity, and theoretical construct alignment (Aiken, 1985; Lawshe, 1975). The results indicated a "very good" category, confirming that the instruments were suitable for use in the data collection phase.

Furthermore, internal reliability testing was conducted using Cronbach's Alpha to ensure item consistency within the instrument. An instrument is considered reliable if it achieves a Cronbach's Alpha value of ≥ 0.70 (Tavakol & Dennick, 2011). The reliability analysis showed that the questionnaire achieved a Cronbach's Alpha value of 0.82, indicating a high level of reliability and confirming that the instrument was consistent and appropriate for use in the study.

Research Stages

This study employed a quantitative descriptive design aimed at mapping students' 21st-century skills (4Cs) within the context of Project-Based Renewable Energy Learning. The research procedure was conducted through three main stages as follows:

Preparation Stage

The preparation phase began with a literature review on Renewable Energy learning, 21st- century skills (4Cs), and field observations to ensure the appropriateness of the indicators used in the study. Based on the review, test instruments were developed for assessing critical and creative thinking skills, while questionnaires were constructed for assessing collaboration and communication skills. These instruments were then validated through content and construct evaluation by three experts (subject-matter, evaluation, and language experts).

A limited pilot test was subsequently conducted with students outside the main sample to obtain reliability data using Cronbach's Alpha. After the instruments were deemed appropriate, the next step involved selecting partner schools and carrying out technical coordination, including scheduling, assigning supervising teachers, and preparing classrooms for the research implementation.

Implementation Stage

The data collection process began with providing students with an explanation of the research objectives, assurances of data confidentiality, and guidelines for completing the test and questionnaire. Subsequently, the test and questionnaire were administered to students across four schools, each representing one cluster of 21st- century skills: critical thinking, creativity, collaboration, and communication.

Students were instructed to complete the test and fill out the questionnaire independently within a 20–30 minutes timeframe under the supervision of the researchers and accompanying teachers. This supervision ensured orderly procedures and minimized potential biases arising from discussion among participants.

Data Post-Data Collection Stage

The data analysis stage began with checking the completeness of responses, coding student answers, and cleaning the dataset to ensure that no duplicate, missing, or invalid responses were included. The verified data were then entered into SPSS for further analysis. Descriptive statistical analyses, including mean, standard deviation, and percentage, were used to map the level of 4C skills in each school cluster. Subsequently, ANOVA was performed for parametric data, or the Kruskal– Wallis test for non-parametric data, to identify differences in students' skill levels.

A summary of the research procedure is illustrated in research flowchart presented in Figure 1.

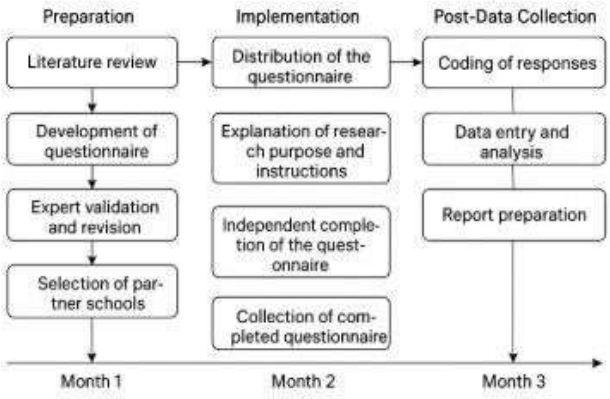

Figure 1. Research procedure flowchart

Data Analysis Techniques

The data were analyzed using descriptive and inferential statistical techniques. Descriptive statistics included the calculation of the mean, median, and standard deviation, which are presented respectively in equations (1), (2), and (3).

Mean

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \quad (1)$$

Median

$$\tilde{X} = X_{\left(\frac{n+1}{2}\right)} \text{ ; for n odd} \quad (2a)$$

$$\tilde{X} = \frac{X_{\left(\frac{n}{2}\right)} + X_{\left(\frac{n+1}{2}\right)}}{2} \text{ ; for n event} \quad (2b)$$

Standard Deviation

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}} \quad (3)$$

Description:
X_i = the i-th score
n = number of respondents
$\bar{X}$ = mean score
$\tilde{X}$ = median score
SD = standard deviation

The categorization of the 4C skills profile was based on the results using equations (1) and (3), as presented in Table 1.

Table 1. Categorization of 4C Skills Profile

Category	Criteria
Very High	$X > \bar{X} + 1.5\ SD$
High	$\bar{X} + 0.5\ SD < X \leq \bar{X} + 1.5\ SD$
Moderate	$\bar{X} - 0.5\ SD < X \leq \bar{X} + 0.5\ SD$
Low	$\bar{X} - 1.5\ SD < X \leq \bar{X} - 0.5\ SD$
Very Low	$X \leq \bar{X} - 1.5\ SD$

Result and Discussion

Based on the critical thinking test administered to 92 students, the descriptive statistical results were obtained as presented in Table 2.

Table 2. Descriptive Statistics of the Critical Test

Statitic	Value
Mean	84.89
Median	85.00
Standard Deviation	14.01

Table 2 shows that students obtained a mean score of 84.89, with a median of 85 and a standard deviation of 14.01. The mean value, which is very close to the median, indicates that the data distribution is relatively symmetrical and does not show extreme deviations. The standard deviation, which falls into the medium category, suggests that variations in students' critical thinking skills are still noticeable, although their performance tends to be relatively homogeneous within the higher-score group. These findings indicate that the majority of students have achieved a good level of critical thinking skills.

Based on Table 2, a distribution of critical thinking skill categories was then generated using equation (3), with the results presented in Table 3.

Table 3. Categorization of Critical Thinking Skills

Categories	Frequency	Percentage %
Very critical	42	45.65
Critical	26	28.26
Moderately critical	20	21.74
Not critical	3	3.26
Very uncritical	1	1.09

Table 3 shows that 68 of the total students fall into the critical (45.65%) and very critical (28.26%) categories, indicating that the majority have achieved good critical thinking skills. This finding aligns with Facione (2015), who emphasizes that critical thinking skills develop optimally when students engage in learning experiences that require analytical and reflective activities, such as problem-based, inquiry-based, and project-based learning. These instructional models provide opportunities for students to explore concepts, evaluate evidence, and formulate arguments systematically.

Consistent with this, the results indicate that most students are in the high to very high categories, although a small group still falls into the not critical (3.26%) and very uncritical (1.09%) categories. This group requires more intensive pedagogical intervention, particularly through scaffolding

strategies, higher-order thinking skills practice, and sustained formative feedback.

Furthermore, Lai (2011) states that critical thinking skills do not develop spontaneously; instead, they require explicit instruction designed systematically. Ennis (1991) also highlights that critical thinking encompasses both cognitive and dispositional dimensions, both of which must be nurtured through structured practice. The integrating critical thinking skills into subject-domain contexts through an infused instruction approach significantly enhances students' analytical abilities. The use of metacognitive reflection strategies and explicit teaching is essential in improving critical thinking.

Overall, the development of critical thinking skills requires meaningful, adaptive learning designs that are oriented toward higher-order thinking processes. These findings also highlight the need for differentiated interventions for students with lower levels of ability so that the achievement of critical thinking skills can improve more evenly across all learners.

Based on the results of the creative thinking skills test administered to 75 students, it was found that overall creative thinking skills were in the very creative category, as shown in Figure 2.

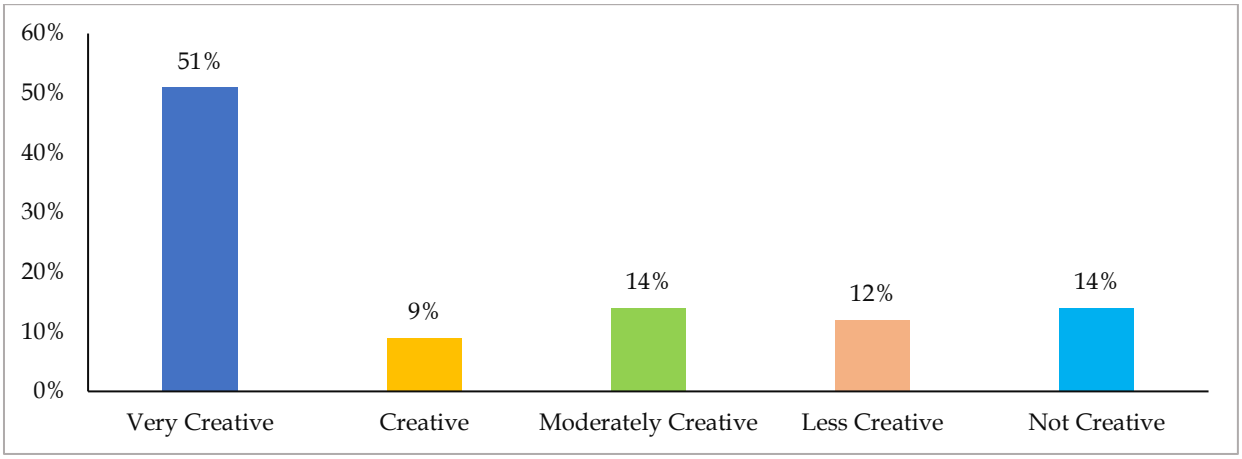

Figure 2. Results of the Creative Thinking Skills Test

Figure 2 shows that the distribution of students' creative thinking skills tends to be concentrated in the very creative (51%), creative (9%), and moderately creative (14%) categories. These findings indicate that most students are capable of generating varied, original, and contextually relevant ideas. However, there are still 9 students (12%) in the less creative category and 10 students (14%) in the not creative category. These two groups require more intensive instructional interventions to stimulate fluency and flexibility. This pattern aligns with Guilford (1967), who stated that creativity does not emerge spontaneously but develops through learning environments that provide opportunities for exploration, meaningful challenges, and a safe atmosphere that supports divergent thinking processes.

In addition, Kaufman & Beghetto (2021) emphasize that fostering creativity requires instructional designs that strengthen the foundations for developing higher-level creativity. Furthermore, Lai et al. (2023) found that project-based learning and design thinking approaches significantly enhance students' ability to elaborate and generate flexible ideas. This finding is reinforced by Kim (2022), who showed that the integration of technology and exploratory activities can consistently improve creative idea production.

Thus, although the majority of students in this study demonstrate high levels of creativity, the presence of groups with low creativity highlights the need for more adaptive learning strategies, particularly project-based approaches that stimulate the creative process more comprehensively (Saavedra & Opfer, 2012) Murray, 2022).

Next, the achievement of each creative thinking indicator is presented in Table 4.

Table 4. Achievement of Creative Thinking Indicators

Creative Thinking Indicator	Percentage (%)	Category
Fluency thinking	64.90	Good
Flexible thinking	59.10	Fair
Original thinking	64.00	Good
Elaboration ability	73.80	Good

Table 4 shows that the fluency indicator obtained a score of 64.90% and originality reached 64.00%, both of which fall into the good category. Meanwhile, the elaboration indicator demonstrates the highest

percentage, 73.80%, indicating that students are able to develop ideas in a more detailed and systematic manner. However, the flexibility indicator only reached 59.10%, suggesting that students' ability to provide different perspectives and generate alternative solutions still requires improvement.

More specifically, the dominance of high scores in the fluency and elaboration indicators confirms that students possess strong abilities in producing multiple ideas and expanding or developing them in depth. Nevertheless, weaknesses are still evident in the flexibility aspect, particularly in viewing problems from multiple perspectives or generating alternative and varied solutions. This is consistent with the findings of Runco & Acar (2012), who assert that flexibility is a central component of creativity as it directly contributes to the effectiveness of solving complex problems.

Furthermore, Kim (2020) highlights that 21st-century creativity requires adaptive flexibility, which refers to the ability to shift strategies dynamically when confronting new problems. Beghetto & Kaufman (2022) emphasize that students with low flexibility tend to experience cognitive fixation, making it difficult for them to generate innovative solutions. Additionally, (Cheng, 2023) shows that instructional approaches emphasizing multi-strategy exploration and divergent questioning significantly enhance idea flexibility. Similarly, Barbot & Kaufman (2025) found that flexibility is the creativity indicator most sensitive to the quality of instructional design, particularly within project-based learning environments.

Thus, although students' creative thinking levels on several indicators fall within the good category, strengthening the flexibility aspect should be a key priority in future instructional planning. Interventions such as divergent thinking exercises, exploration of multiple solutions, open-ended tasks, and the use of diverse problem contexts are considered effective strategies to enhance students' cognitive flexibility sustainably.

Subsequently, based on the results of the collaboration skills questionnaire completed by 71 students, the overall average score was 24.65. The distribution of collaboration skill levels shows 33.80% (highly collaborative), 26.76% (collaborative), 35.21% (moderately collaborative), and only 4.23% (not collaborative), as shown in Table 5.

Table 5. Observation Results of Students' Collaborative Skills

Category	Frequency	Percentage (%)
Highly collaborative	24	33.80
Collaborative	19	26.76
Moderately collaborative	25	35.21
Not collaborative	3	4.23
Highly uncollaborative	0	0.00

Overall, these results indicate that most students possess collaborative abilities that fall within the moderate to very good categories. This reflects a positive tendency toward active participation and effective teamwork within groups (Dooly, 2022; Johnson, 2019). However, a small group of students still demonstrates low levels of collaborative skills, indicating the need for more targeted attention during the learning process (Gillies, 2016; Hidayah, 2024). The variation in students' skill levels also suggests that collaborative competence does not develop uniformly among learners (Ilma, 2024). Specifically for each dimension, the collaboration profile under the dimension of working together productively is presented in Figure 3.

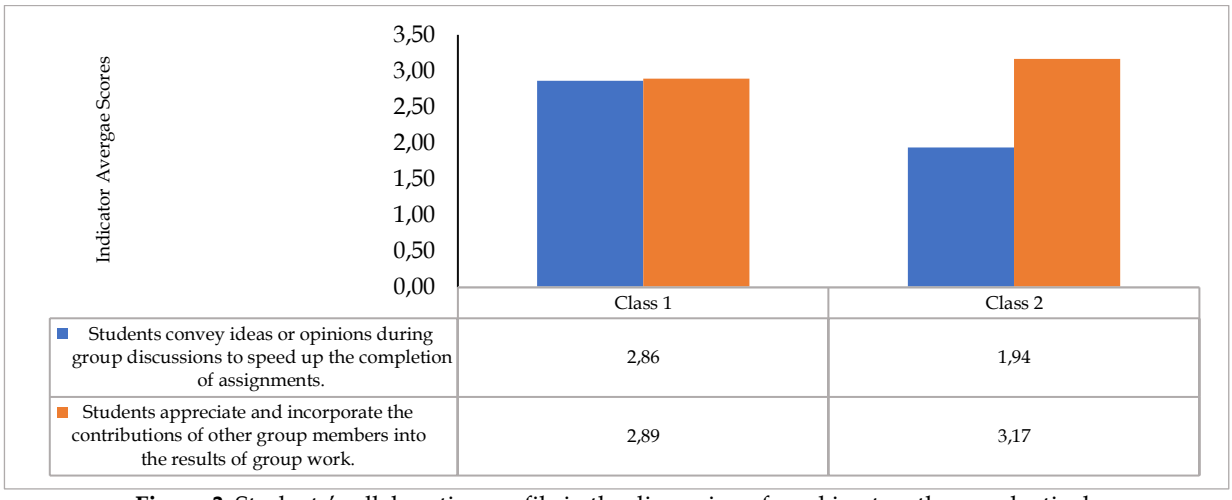

Figure 3. Students' collaboration profile in the dimension of working together productively

Based on Figure 3, students' ability to express ideas or opinions and to appreciate the contributions of other group members has developed well. This is evident from the dominance of scores within the range of 3–4, indicating active participation and positive attitudes in group discussions (Dooly, 2022; Johnson, 2019; Slavin, 2020). Students tend to work toward finding joint solutions and completing tasks more efficiently through open communication (Krajcik, 2021). This condition aligns with Greenstein (2012), who emphasizes the importance of coordinating group efforts effectively and valuing diverse roles within teamwork.

Furthermore, the students' collaboration profile in the dimension of demonstrating respect is presented in Figure 4.

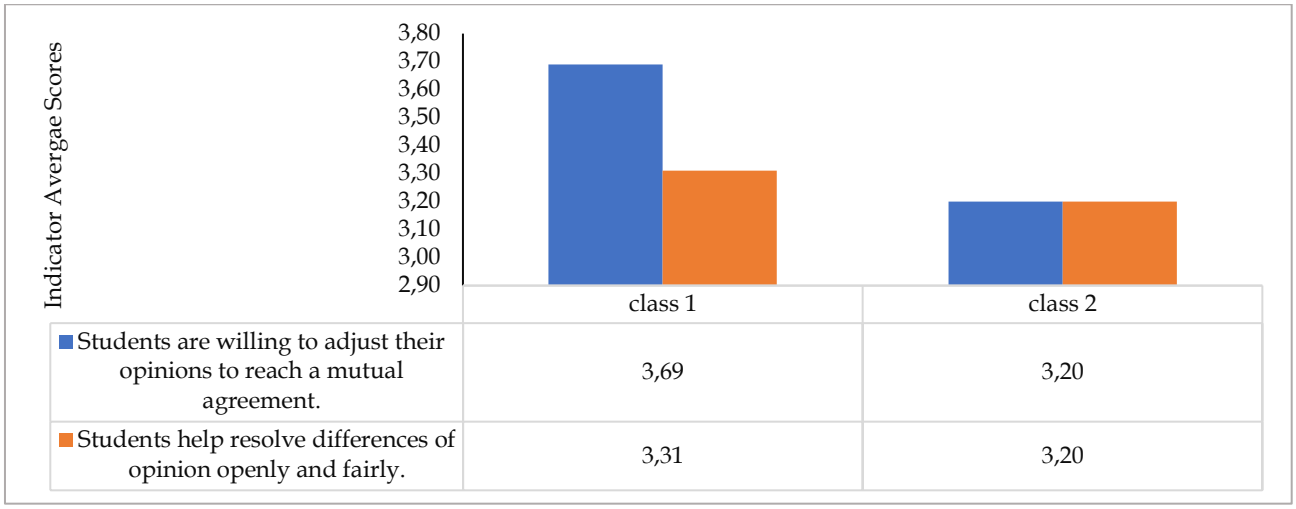

Figure 4. Students' collaboration profile in the dimension of showing respect

Based on Figure 4, most students achieved high scores, indicating their ability to listen attentively and respond politely to their peers' ideas. This finding aligns with the respecting others' ideas dimension proposed by Greenstein (2012), which emphasizes empathy and social awareness as essential foundations for effective collaboration (Dooly, 2022). These results also reinforce previous studies showing that inquiry-based project learning fosters a culture of mutual respect within academic environments (Chu, 2021; Hidayah, 2024; Laal, 2012; Le, 2018; Silver, 2019).

Furthermore, the students' collaboration profile in the dimension of ability to compromise is presented in Figure 5.

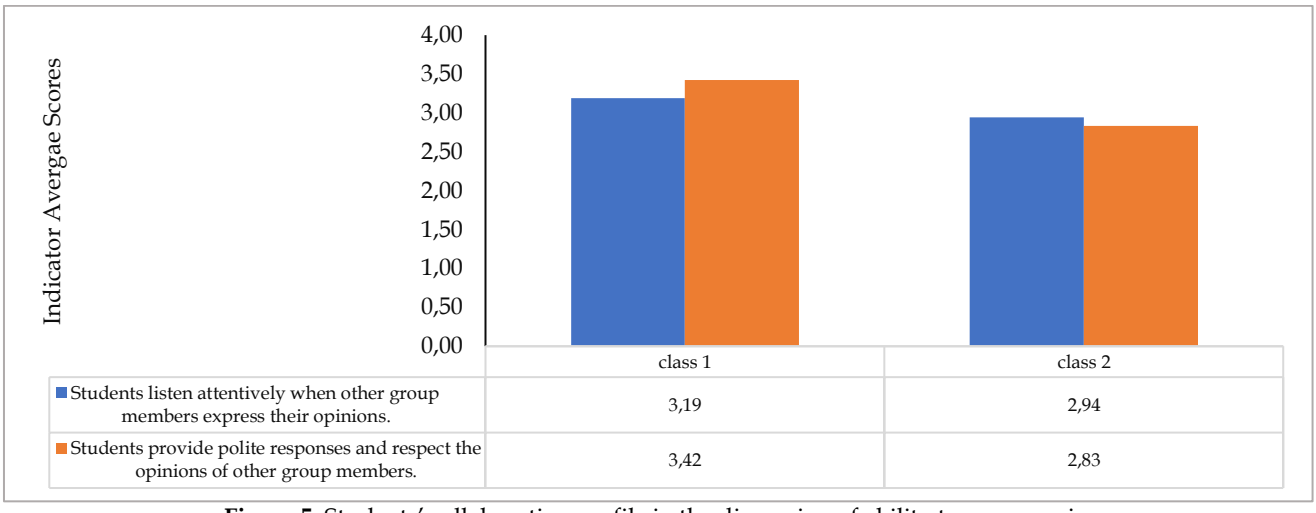

Figure 5. Students' collaboration profile in the dimension of ability to compromise

Based on Figure 5, the observations indicate greater variation compared to the other dimensions. Some students were able to adjust their viewpoints and resolve differences openly, while others tended to avoid disagreement or agree too quickly with the majority opinion. This pattern suggests that although

collaboration generally proceeded harmoniously, students' negotiation and conflict-resolution skills still require strengthening (Ilma, 2024; Kim, 2022). Greenstein (2012) explains that compromising constructively demands critical thinking, appreciation of differing perspectives, and the pursuit of fair solutions acceptable to all parties (Binkley et al., 2012). In this context, teachers play a crucial role in guiding discussions so that students can transform conflict into opportunities for social learning (Gokhale, 2019; Harrison, 2021; Hidayat, 2025).

Finally, the students' collaboration profile in the dimension of shared responsibility is presented in Figure 6.

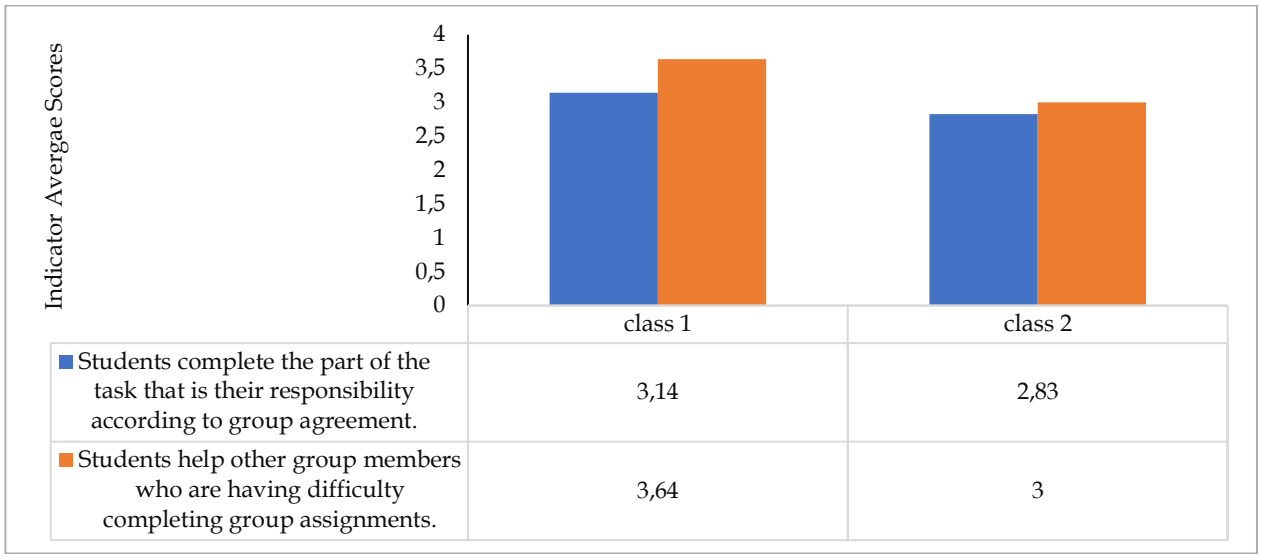

Figure 6. Students' collaboration profile in the dimension of shared responsibility

The observations presented in Figure 6 indicate that students were generally consistent in completing their assigned tasks and assisting group members who encountered difficulties. Most students obtained scores in the range of 3–4 on both indicators, reflecting a strong sense of ownership over group outcomes and empathy toward peers (Chen, 2023; Ghazali, 2024). This finding aligns with the taking shared responsibility dimension in Greenstein (2012) framework, which emphasizes collective responsibility as an indicator of social maturity in collaborative work (Fitriyah, 2024; Peterson, 2023).

When the four dimensions of collaborative skills are compared holistically, the dimensions of demonstrating respect and shared responsibility show the highest percentages in the "good" and "very good" categories, while the dimension of compromising abilities exhibits greater variation. This pattern suggests that students possess strong social ethics and discipline regarding group responsibilities but still require improvement in reflective thinking and negotiation skills (Haryono, 2023; Kurniawan et al., 2025). Overall, these findings are consistent with (Vygotsky, 1978) social development theory, which emphasizes that effective collaboration is built through social interaction and teacher support (social scaffolding), enabling students to transfer social competencies into real collaborative behavior (Fullan, 2022).

Overall, the results of this study show that students' collaborative skills fall within the moderate to good range, with clear potential for development toward the very good category. However, individual variation necessitates adaptive and reflective learning strategies to ensure balanced growth in working together, respecting opinions, compromising, and sharing responsibility (Ghazali, 2024; Hidayat, 2025; Peterson, 2023). Project-based learning has proven to be an effective platform for fostering these skills, provided it is supported by consistent guidance and a classroom environment conducive to collaborative interaction (Dooly, 2022; Hmelo-Silver, 2004).

The findings of this study have both practical and theoretical significance. Practically, the results demonstrate that project-based learning can cultivate students' collaborative abilities, particularly in the dimensions of mutual respect and shared responsibility. This serves as a basis for teachers to design more structured and reflective collaborative learning strategies. Theoretically, the study reinforces the concepts proposed by Greenstein (2012), highlighting social interaction and collective responsibility as key elements in the formation of 21st-century skills,

especially collaboration. Thus, this study contributes to the development of pedagogical frameworks that support collaborative learning at the secondary school level.

Next, the descriptive statistics obtained from the communication skills questionnaire completed by 63 students are presented in Table 6.

Table 6. Descriptive Statistics of Communication Skills

Statistic	Value
Mean	82.14
Median	83.00
Standard Deviation	12.36

Table 6 shows that students' communication skills are at a relatively good and evenly distributed level. The mean score of 82.14, accompanied by a median of 83.00, indicates that the distribution tends to be symmetrical and is not influenced by extreme values. This finding suggests that most students possess communication skills that cluster around the central value of the distribution, meaning that the overall communication quality among the group can be considered stable. The standard deviation of 14.01 reflects a moderate level of variation, indicating that differences among students are not too pronounced and that the learning process has provided relatively equal communication experiences for all participants.

Based on Table 6, the distribution of communication skill categories was then determined using Equation (3), and the results are presented in Table 7.

Table 7. Categorization of Communication Skills

Category	Frequency	Percentage %
Very communicative	6	9.53
Communicative	34	53.97
Moderately communicative	23	36.51
Not communicative	0	0.00
Very uncommunicative	0	0.00

Table 7 indicates that students' communication skills fall within a relatively good range. A total of 53.97% of students are categorized as communicative, suggesting that more than half of the respondents are able to convey ideas clearly, relevantly, and in alignment with the learning context. In addition, 36.51% of students fall into the moderately communicative category, meaning that they have demonstrated basic communication abilities but still require improvement in message structure, clarity of argumentation, and responsiveness during academic interactions. Meanwhile, only 9.53% of students are classified as highly communicative, indicating that a small proportion of learners possess very strong communication skills, such as the ability to express ideas coherently, use effective language, and actively participate in group discussions or presentations. The absence of students in the uncommunicative and highly uncommunicative categories shows that all respondents have at least a moderate level of communication competence.

These findings suggest that students' communication skill profiles tend to be concentrated within the middle to high categories. This reflects that the learning environment has provided adequate opportunities for students to practice expressing ideas, engaging in discussions, and building constructive academic interactions. The effective academic communication develops through collaborative activities and continuous interaction in the classroom. Moreover, Fitria & Yunita (2022) found that active learning through project-based activities and open discussions significantly enhances students' fluency and confidence in communication. The use of digital communication media—such as collaborative platforms and interactive presentations—supports both oral and written communication skills in the context of 21st-century learning.

Nevertheless, the proportion of students in the highly communicative category remains relatively low. Therefore, more targeted pedagogical strategies need to be designed to enhance communication skills more evenly across learners. Approaches such as structured presentations, peer-feedback integration, reflective discussions, and the use of interactive digital media have been shown to effectively improve communication quality (Hapsari & Widodo, 2023; Khalil & Sihombing, 2024). Accordingly, systematic efforts through active and experience-based learning approaches are expected to strengthen students' communication skills comprehensively and sustainably.

Conceptually, this result is important because it demonstrates that the development of 21st-century skills does not occur uniformly, reflecting the distinct cognitive and social characteristics embedded within each component of the 4C framework. This finding supports the perspectives that each 21st-century skill develops through different learning processes, resulting in varying levels of achievement among students.

More specifically, the findings align with previous literature in which collaborative skills often show more stable scores compared to creativity and critical thinking. Meanwhile, creativity and critical thinking tend to exhibit higher variability due to their strong dependence on learning experiences and environmental support (Barbot & Kaufman, 2025; Kim, 2022). Thus, the results of this study are consistent with theoretical expectations and prior global research.

However, several alternative explanations for the differences in 4C outcomes should also be considered. For instance, the variation may be influenced by differences in instructional quality across the participating schools, disparities in students' access to technology, or variations in the complexity of tasks assigned by teachers. Additionally, motivational and psychological factors may also contribute to the uneven development of these skills. The findings indicate that the levels of achievement across the four components of 21st-century skills show varying patterns. However, these differences should be interpreted descriptively rather than as statistical comparisons between variables.

This result suggests that students demonstrate different levels of proficiency across critical thinking, creativity, collaboration, and communication skills, which may reflect variations in learning experiences, instructional strategies, and classroom environments. Despite its contributions, this study has several limitations. First, the data on collaboration and communication skills were collected through questionnaires, which rely on students' perceptions. Second, the sample was limited to four schools. Third, the analysis focused on descriptive profiling of each 4C skill rather than statistical comparison between different skill variables, because each component was measured using different instruments and scales.

In light of these limitations, future research is recommended to employ mixed-method approaches that combine tests, questionnaires, classroom observations, and interviews. Expanding the sample across diverse regions is also suggested to obtain more normally distributed data that would allow for post hoc comparisons. Additionally, longitudinal studies would be valuable for tracking the development of 4C skills over time.

Conclusion

This study demonstrates that students' 4C skills (critical thinking, creativity, collaboration, and communication) exhibit significant variations in achievement, as evidenced by the Kruskal–Wallis test, which revealed meaningful differences across the skill categories. These findings affirm that the mastery of 21st-century competencies does not develop uniformly; rather, it is influenced by differing cognitive characteristics, learning experiences, and the quality of instructional implementation in schools. This result is essential as it provides empirical evidence that schools still need to strengthen their instructional strategies to ensure that all four 4C skills develop in a balanced manner. Accordingly, the study contributes to the body of literature emphasizing the importance of differentiated and experiential learning approaches in improving students' 21st-century competencies. It also highlights that mapping the 4C skills is highly relevant for curriculum planning and instructional evaluation at the school level. Based on the research findings, several recommendations can be offered for improving instructional practice as well as guiding future studies. Teachers are encouraged to implement active learning models such as project-based learning and collaborative discussions to systematically support the balanced development of all four 4C skills. Additionally, schools should strengthen an academic culture that promotes creativity, logical argumentation, effective communication, and teamwork classroom activities and interdisciplinary projects. For future research, it is recommended to expand the sample size, employ a mixed-method approach, and conduct longitudinal analyses to capture the developmental dynamics of 4C skills more comprehensively. Through these efforts, the findings of this study not only contribute theoretically but also offer practical implications for enhancing the quality of 21st-century learning.

Acknowledgments

The research/publication of this article was funded Universitas Sriwijaya 2025. In accordance with the Rector's Decree Number: 0028/UN9/LPPM.PT/2025, On September 17, 2025.

Author Contributions

KW: contributed as the team leader who initiated the research idea, formulated the methodological design, led the data collection process, and supervised the overall research. MA: contributed to expert validation. EAP: contributed to the development of research instruments, expert validation, and research coordination. FIS: contributed to the development of research instruments, expert validation, and manuscript writing. NF: contributed to expert validation. TR: contributed to research implementation and field documentation. SSCM: contributed to research implementation and field documentation. LIK: contributed to research implementation and field documentation. DPR: contributed to research implementation and field documentation.

Funding

This research was funded by Universitas Sriwijaya, grant number 0028/UN9/LPPM.PT/2025, On September 17, 2025.

Conflicts of Interest

The authors declare no conflicts of interest.

References

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement*, *45*(1), 131–142.

https://doi.org/10.1177/0013164485451012

Barbot, B., & Kaufman, J. C. (2025). PISA 2022 creative thinking assessment: Opportunities, challenges, and cautions. *The Journal of Creative Behavior*, *59*(1), e70003. https://doi.org/10.1002/jocb.70003

Beghetto, R. A., & Kaufman, J. C. (2022). Theories of creativity. In *Creativity and innovation* (pp. 23–36). Routledge. Retrieved from https://www.taylorfrancis.com/chapters/edit/10.4324/9781003233923-3/theories-creativity-ronald-beghetto-james-kaufman

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). *Assessment and teaching of 21st century skills*. Dordrecht: Springer. https://doi.org/10.1007/978-94-017-9395-7

Chen, L. (2023a). Project-based STEM approaches to renewable energy learning. *Journal of Science Education Innovation*, *18*(2), 112–128. https://doi.org/10.1007/s10956-026-10306-8

Chen, L. (2023b). Responsibility and group dynamics in collaborative learning. *International Journal of Educational Psychology*, *12*(1), 45–60. https://doi.org/10.1007/s10956-024-10102-2

Cheng, V. M. (2023). Teaching divergent thinking and flexibility in creative problem solving. *Thinking Skills and Creativity*, *49*, 101315. https://doi.org/10.17478/jegys.513308

Chu, S. (2021). Inquiry-based learning in Asian classrooms: Challenges and opportunities. *Asia-Pacific Education Researcher*, *30*(3), 225–238. https://doi.org/10.14434/ijdl.v14i1.35221

Cochran, W. G. (1977). *Sampling Techniques* (3rd ed.). John Wiley & Sons.

Creswell. (2018). *Educational Research: Planning, Conducting, And Evaluating Quantitative And Qualitative Research*. Person.

Creswell, J. W., & Creswell, J. D. (2022). *Research design: Qualitative, quantitative, and mixed methods approaches*. SAGE Publications.

Dooly, M. (2022). *Telecollaboration and developing intercultural communicative competence*. Palgrave.

Ennis, R. H. (1991). Critical thinking: A streamlined conception. In *The Palgrave handbook of critical thinking in higher education* (Vol. 14, pp. 15–24). New York: Palgrave Macmillan US.

Facione, P. A. (2015). *Critical Thinking : What It Is and Why It Counts*. Retrieved from https://shorturl.asia/ey3qc

Fitria, N., & Yunita, W. (2022). Improving communication skills through project-based learning. *Journal of Language Teaching*, *14*(4), 112–129. https://doi.org/10.1109/APS.2007.4396769

Fitriyah, N. (2024). Profil keterampilan abad ke-21 peserta didik dalam pembelajaran sains terapan. *Jurnal Pendidikan Sains Nusantara*, *12*(1), 45–60. https://doi.org/10.1186/s40594-024-00516-0

Fitriyah, S. (2024). Responsibility and role-taking in project-based learning. *Journal of Educational Practice*, *15*(1), 77–88. https://doi.org/10.3991/ijet.v17i11.29931

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2019). *How to Design and Evaluate Research in Education (10th ed.)* (8th ed.). New York: McGraw-Hill Companies.

Fullan, M. (2022). *The new meaning of educational change* (6th ed.). Teachers College Press.

Ghazali, M. A. (2024). Mapping 21st-century competencies in Indonesian senior high schools. *Southeast Asian Journal of Educational Research*, *9*(3), 201–215. https://doi.org/10.33258/birci.v4i1.1727

Gillies, R. M. (2016). Cooperative learning: Review of research and practice. *Australian Journal of Teacher Education*, *41*(3), 39–54. https://doi.org/10.30935/cedtech/5962

Gokhale, A. (2019). Group collaboration in problem solving: A cognitive perspective. *Journal of Technology Education*, *10*(1), 22–30. https://doi.org/10.1007/s11412-022-09362-0

Greenstein, L. (2012). *Assessing 21st Century Skills. A Guide to Evaluating Mastery and Authentic Learning*. SAGE Company.

Guilford, J. P. (1967). *The nature of human intelligence*. McGraw-Hill. https://doi.org/10.1080/10494820.2019.1568263

Hapsari, I., & Widodo, A. (2023). Digital media to enhance students' communication skills. *Journal of Instructional Technology*, *7*(2), 91–104. https://doi.org/10.62569/fijc.v1i1.12

Harrison, J. (2021). Negotiation and compromise in collaborative learning. *Journal of Social Education*, *29*(1), 44–59. https://doi.org/10.1037/0022-3514.78.4.772

Haryono, S. (2023). Collaboration skills in Indonesian high schools. *Jurnal Pendidikan Sains*, *11*(2), 112–126. https://doi.org/10.1080/095006900289746

Hidayah, N. (2024). Respect and empathy in project-based learning. *Journal of Educational Psychology*, *16*(1), 65–78. https://doi.org/10.1037/edu0000046

Hidayat, M. (2025). Assessing integrated 4C skills in renewable energy learning environments. *Journal of Sustainable Science Education*, *4*(1), 55– 70. https://doi.org/10.1016/j.rser.2004.09.003

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, *16*(3). https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

Ilma, A. (2024). Variability in collaboration skills among

secondary students. *Journal of Education Research*, *27*(1), 48–60. https://doi.org/10.1016/j.egyr.2023.01.021

Johnson, D. W. (2019). *Cooperative learning in the classroom*. Interaction Book Company.

Kaufman, J. C., & Beghetto, R. A. (2021). *Nurturing creativity in the classroom*. Cambridge University Press. https://doi.org/10.1080/00461520.1991.965313

Khalil, R., & Sihombing, S. (2024). Peer feedback for communication skill development. *Journal of Language and Communication*, *9*(1), 77–92. https://doi.org/10.1002/sce.10066

Kim, K. (2020). Adaptive flexibility in creative thinking. *Creativity Research Journal*, *32*(4), 401–417. https://doi.org/10.1016/j.compedu.2010.07.007

Kim, M. (2022). Technology-enhanced creative learning. *Journal of Digital Learning*, *5*(2), 63–79. https://doi.org/10.1016/j.sbspro.2017.02.109

Krajcik, J. (2018). Project-based science: Engaging students in the doing of science. *Science Education Journal*, *102*(4), 1–16. https://doi.org/10.1007/978-93-6559-149-6

Krajcik, J. (2021). Project-based learning: A pathway to preparing students for the future. *Science Education*, *105*(1), 10–30. https://doi.org/10.1007/978-94-6209-143-6

Kurniawan, H. E., Saputro, S., Ramli, M., & others. (2025). The Effects of Integrating STEM Design Thinking into Education for Sustainable Development on Students' Scientific Modeling Skills. *Journal of Baltic Science Education*, *24*(5), 935–955. Retrieved from https://www.ceeol.com/search/article-detail?id=1373913

Laal, M. (2012). Collaborative learning; What is it. *Procedia-Social and Behaviorial Sciences*, *31*, 491–495. https://doi.org/10.1016/j.sbspro.2011.12.092

Lai, E. R. (2011). Critical thinking: A literature review. In *Pearson's Research Reports* (Vol. 6, Issue 1). Citeseer.

Lai, M., Cheung, W., & H, C. (2023). Design thinking to foster creativity. *Journal of Creative Pedagogy*, *11*(1), 55–71 ,. https://doi.org/10.1002/j.2168-9830.2006.tb00884

Lawshe, C. H. (1975). A quantitative approach to content validity. *Personnel Psychology*, *28*(4). Retrieved from https://parsmodir.com/wp-content/uploads/2015/03/lawshe.pdf

Le, H. (2018). Collaborative culture in inquiry- based classrooms. *Journal of Educational Development*, *36*(4), 90–104. https://doi.org/10.1016/S0360-1315(99)00013-1

Miller, T. (2023). Enhancing creativity and collaboration through project-based science learning. *Journal of Educational Practice*, *14*(2), 56– 71. https://doi.org/10.1016/j.egyr.2023.01.021

Peterson, L. (2023). Shared responsibility in group learning. *Journal of Social Learning*, *19*(3), 99–113. https://doi.org/10.1080/00098650903505415

Runco, M. A., & Acar, S. (2012). Divergent thinking as an index of creativity. *Creativity Research Journal*, *24*(1), 66–75. https://doi.org/10.29303/jppipa.v9i10.4585

Saavedra, A. R., & Opfer, V. D. (2012). Learning 21st-century skills requires 21st-century teaching. *Phi Delta Kappan*, *94*(2), 8–13. https://doi.org/10.1177/003172171209400203

Silver, H. (2019). Inquiry learning and respect in classroom communities. *Educational Leadership*, *76*(5), 61–67. https://doi.org/10.29333/iji.2025.18213a

Slavin, R. E. (2020). Cooperative learning and student achievement. *Educational Leadership*, *78*(3), 22–28. Retrieved from https://api.taylorfrancis.com/content/chapters/edit/download?identifierName=doi&identifierValue=10.4324/9780203056950-8&type=chapterpdf

Sugiyono. (2021). *Metode Penelitian Pendidikan (Kuantitatif, Kualitatif, Kombinasi, R&D, dan Penelitian Pendidikan)*. Bandung: Alfabeta.

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2*, 53–55. https://doi.org/10.5116/ijme.4dfb.8dfd

Tijani, B. E., & Adeduyigbe, A. M. (2026). Transforming science education: A systematic review of evidence-based strategies for cultivating 21st-century skills in STEM education. *Journal of Research in Environmental and Science Education*, *3*(1), 8–23. https://doi.org/10.70232/jrese.v3i1.37

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Zahara, L., Sudatha, I. G. W., Santosa, M. H., & Suartama, I. K. (2025). Integrasi Kearifan Lokal dalam Penguatan Literasi Sains Fisika di Sekolah: Suatu Kajian Sistematis. *Lambda: Jurnal Ilmiah Pendidikan MIPA Dan Aplikasinya*, *5*(3), 777–790. https://doi.org/10.58218/lambda.v5i3.1505

Zhang, S., Wen, Y., & Liu, Q. (2022). Exploring student teachers' social knowledge construction behaviors and collective agency in an online collaborative learning environment. *Interactive Learning Environments*, *30*(3), 539–551. https://doi.org/10.1080/10494820.2019.1674880