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Exploring Students' Creativity, Collaboration, and Communication Skills in Science Learning: A Descriptive, Correlational, and Cluster Analysis Approach

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Abstract
The aim of this study is to analyze students' creativity, collaboration, and communication skills in science learning using a descriptive, correlational, and cluster analysis approach. This study used a non-experimental quantitative design involving 109 junior high school students in Tanjungpinang City. Data were collected using essay tests to measure creativity and observation sheets to assess collaboration and communication skills. Descriptive analysis, Spearman rank correlation, and K-means cluster analysis were used to analyze the data. The results showed that students' creativity and communication skills were generally in the moderate category, while collaboration had a relatively higher average score. Correlation analysis revealed no significant relationship between creativity, collaboration, and communication skills, suggesting that these three skills may not necessarily develop simultaneously across students in the present sample. Furthermore, the cluster analysis identifies three possible student profiles based on similarities in student skills, reflecting varying skill combinations and heterogeneity. These results indicate that the 21st-century skills development in science learning remains fragmented and requires more integrated learning strategies. This study provides benefits in designing learning environments where students' skills measured in this study are developed through adaptive and effective learning.

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INTRODUCTION

21st-century skills have become a primary focus for development in science education, including student creativity, collaboration, and communication. These skills are fundamental because they help students meet the complex and ever-changing demands of modern life, which require innovation in problem-solving, teamwork, and effective communication (van Laar et al., 2020). In science learning, these skills are closely linked to inquiry-based learning, where students are trained to generate new ideas, collaborate in teams during investigations, and communicate and interpret findings scientifically.

Creativity, collaboration, and communication were specifically chosen because these skills are integral to the science learning process, particularly in inquiry activities that require innovative ideas and concepts (Asda et al., 2025), collaborative investigation (Saleh et al., 2021), and scientific explanations through effective communication (Orosz et al., 2023). Unlike critical thinking and problem-solving, which have been extensively examined in science learning (Amanda et al., 2024; García-Carmona, 2025; Ma et al., 2023), these three skills remain less frequently investigated simultaneously, particularly through profile-based approaches such as cluster analysis.

Given the importance of creativity, collaboration, and communication skills in science education, their development deserves attention. In actual classroom practice, developing these skills still faces significant challenges. Previous studies have found that the majority of students have limitations in aspects of creativity (Habib et al., 2024; Rahman et al., 2025). Although students can express ideas, they still struggle to develop and refine them into more meaningful and novel forms (Barbot et al., 2015; Reiter-Palmon et al., 2019). This is often attributed to teaching practices that focus on convergent thinking and memorizing facts rather than exploration and creative problem-solving (Beghetto, 2021). This limits students' ability to engage in genuine creative thinking.

Besides creativity, collaboration skills are equally important to develop. These skills are not only crucial in science learning but also in the practice of science itself. These skills are often assumed to develop naturally through group-based learning (Scager et al., 2016). In reality, collaboration is a complex skill whose development requires structured interactions, a sense of team responsibility, and intense and meaningful engagement among group members (Graesser et al., 2020). Without adequate guidance, students tend to participate passively in learning, resulting in shallow and underdeveloped collaboration skills that do not support in-depth learning (Panadero & Järvelä, 2015). It can be concluded that effective collaboration skills to support 21st-century learning are achieved not only by organizing students into groups but also by appropriate and well-designed learning designs.

Not only creativity and collaboration skills but also communication skills—particularly the ability to express ideas verbally—are often underdeveloped, as found in various previous studies (Thompson, 2020; Wenjia & Jamil, 2025). Students prefer to convey ideas through nonverbal communication (Hadiani & Ariyani, 2021; Thompson, 2020). Furthermore, many students have difficulty articulating scientific ideas clearly and coherently (Akhter et al., 2021; Cian & Cook, 2020). Effective communication in science learning requires dialogic interaction, argumentation, and feedback, which are not always implemented in the classroom optimally (Howe et al., 2019; Mercer, 2013). These results indicate the need for explicit facilitation of communication skills through appropriate learning strategies.

In addition to the challenges inherent in each skill—creativity, collaboration, and communication—there is also the assumption that these three skills develop simultaneously and are interconnected. Educational frameworks on 21st-century skills, such as the Partnership for 21st-Century Learning (P21), position these skills as integrated dimensions of learning that support students' readiness to address complex real-world challenges (P21, 2019). However, empirical evidence on the parallel development of these three skills requires further research, and findings may vary due to factors such as learning experiences and learning environments (Valtonen et al., 2021).

In science learning, particularly in the topic of matter and its changes, the development of these skills is highly relevant. This topic is part of the junior high school science curriculum; to understand this concept, students must grasp abstract concepts related to the properties of matter and to physical and chemical changes through observation, experimentation, and scientific explanation. To realize the implementation of learning this topic, creativity supports students in generating explanations and interpretations of scientific

phenomena (Pinar et al., 2025); collaboration facilitates investigations through group experimental activities (Chen et al., 2024), and communication supports students in communicating the results of observations and explaining scientific findings from the activities carried out (Saimon et al., 2023). This learning activity provides opportunities for students to develop all three skills simultaneously (Taber, 2013). Students' difficulties in connecting observed phenomena to relevant scientific concepts can hinder the development of certain skills, such as creativity and communication (Gilbert & Treagust, 2009).

This research was conducted at a junior high school in Tanjungpinang City, a coastal city in the Riau Islands Province, whose geography includes scattered islands. This situation can affect students' learning experiences and opportunities to develop 21st-century skills, both directly and indirectly, as learning in an archipelagic region presents unique challenges (Leasa et al., 2023; Selby & Kagawa, 2018). However, research on 21st-century skills such as creativity, collaboration, and communication in an archipelagic educational environment remains limited. Schools in archipelagic regions may face various challenges, including issues related to learning resources, the implementation of teaching practices, students' learning experiences, and other factors that can affect 21st-century skills development (OECD, 2019). To maintain the research's relevance, the selected classes had studied or were currently studying the topic and its changes, allowing for a more accurate assessment of student skills.

Previous studies have generally examined creativity, collaboration, and communication skills separately or focused on the levels and relationships among these variables. However, research on how these skills is distributed among students with different profiles remains limited. This leaves the variation in these skills across students incompletely understood. Therefore, this study not only analyzes the levels and relationships among these skills but also identifies students' skill profiles using cluster analysis. This cluster analysis provides a more comprehensive understanding of these skills and highlights the diversity of their development in science learning (Everitt et al., 2019; Romero & Ventura, 2020).

Based on the problems presented and the previously explained aspects, this study aims to analyze students' creativity, collaboration, and communication skills in science learning using descriptive, correlational, and cluster analyses. This study not only examines the levels and relationships among these skills but also identifies patterns of students' skill profiles through cluster analysis. The results of this study are expected to provide a more comprehensive understanding of the development of 21st-century skills examined in this study and provide insights for teachers to design more effective and integrated science learning.

METHODS

Research Design

This study used a quantitative approach. It was conducted using a descriptive, correlational, and cluster analysis design. It is categorized as non-experimental because no interventions were administered to the subjects (Creswell & Creswell, 2018). In other words, the measurements of the research variables were conducted as is, or naturally, without any treatment.

The descriptive design in this study was applied to identify students' levels of creativity, collaboration, and communication skills. In contrast, the correlational design in this study was used to examine the correlation between these variables (Creswell, 2012). The final research design, cluster analysis, was applied to classify students based on similarities in their skill profiles identified in the first design, thus providing a deeper understanding of the patterns in this study's data (MacQueen, 1967).

Subject of Research

The subjects of this study were students from two junior high schools in a sub-district in Tanjungpinang City, totaling 109 subjects. Subjects were selected using a purposive sampling method (Cohen et al., 2018). Subject selection criteria included the school's willingness to participate, the school's accessibility for conducting the research, and the inclusion of science learning about matter and its changes during the data collection period. In other words, the research subjects were students who had studied matter and its changes.

The classes selected as research subjects were those that had studied or were currently studying matter and its changes. This ensured that the research subjects were relevant to the research context. Furthermore, because collaboration and communication skills were measured through direct observation, the selected classes were those actively engaged in learning. This sampling technique enabled researchers to include subjects who met specific requirements, thereby ensuring relevance to the research objectives. It also ensured the accuracy of the research data, as it was sourced from relevant subjects.

Instruments

The data were collected using tests and observations. A combination of written tests and observation sheets was used to collect data. The written tests were used to collect data on creativity, while the observation sheets were used to collect data on students' collaboration and communication skills. A further explanation of the instruments used for each variable is presented below.

1. Creativity

Creativity was measured using an essay-based test. The test consisted of four items to measure student creativity, encompassing several indicators: fluency, flexibility, originality, and elaboration (Guilford, 1967; Reiter-Palmon et al., 2019; Torrance, 1974). These indicators are recognized across various studies as core components of divergent thinking and therefore continue to be used in research on creative thinking skills (Weiss et al., 2024; Weiss & Wilhelm, 2022). The outline of this research instrument is presented in Table 1. Before being used in the study, the creativity instrument was validated by science education experts to validate the relevance of the content, the alignment of the indicators, and its suitability for measuring creativity skills. After completing the expert assessment stage, empirical validity and reliability testing were conducted involving junior high school students, resulting in a valid and reliable instrument, with a reliability coefficient of 0.698, indicating moderate reliability.

Table 1 Blueprint of creativity skill instrument

No.	Indicators	Number of Items
1	Fluency	1
2	Flexibility	1
3	Originality	1
4	elaboration	1
	Total	4

2. Collaboration

Students' collaboration skills were measured through observation techniques. Observations were conducted using an observation sheet consisting of 21 statement items. These statement items elucidate indicators of collaboration, including task focus and participation, shared responsibility and reliability, listening and discussion, and teamwork, which are widely recognized as essential components of collaboration skills in 21st-century

learning (Greenstein, 2012; PISA, 2017). These indicators are also supported by recent studies on collaboration skills (Sufiyah & Wijaya, 2024). The outline of the collaboration skills measurement instrument is shown in Table 2. This instrument was first reviewed by experts in science education. After ensuring the content's relevance and alignment with the indicators, as assessed by experts, empirical validity and reliability testing were conducted with junior high school students. After empirical testing, the resulting instrument was valid and reliable with a reliability coefficient of 0.924, indicating very high reliability.

Table 2 Blueprint of collaboration skill instrument

No.	Indicators	Number of Items
1	Task focus and participation	6
2	Shared responsibility and reliability	6
3	Listening and discussion	2
4	Teamwork	7
Total		21

3. Communication

As with collaboration skills, students' communication skills were also measured through observation techniques. The observation sheet used consisted of 11 statement items describing communication skill indicators, including verbal communication (completeness of content, clarity of pronunciation, coherence, and fluency) and nonverbal communication (kinesics and eye contact). These aspects represent important components of communication skills (DeVito & DeVito, 2019; Hymes, 1972; Mehrabian, 1972). These indicators have also been applied in Laila's (2024) research on communication skills. The instrument blueprint is presented in Table 3. The communication skills measurement instrument is shown in Table 3. Similar to the two previous variables, this instrument also underwent an expert assessment conducted by science education experts. After this stage, empirical testing, including validity and reliability tests, was conducted with junior high school students, resulting in a valid and reliable instrument with a reliability coefficient of 0.913, indicating a very high level of reliability.

Table 3 Blueprint of communication skill instrument

Aspects	Indicators	Number of Items
Verbal Communication	Content completeness	2
	Pronunciation clarity	4
	Coherence,	2
	Fluency	1
Nonverbal Communication	Kinesics	1
	Eye Gaze	1
Total		11

Data Analysis Technique

The research data generated from measurements with the instruments described above were analyzed in three main stages: descriptive analysis, correlation analysis, and cluster analysis, with further explanation as follows.

1. Descriptive Analysis of Skills

The first data analysis conducted on the research data was descriptive, used to determine the levels of students' creativity, collaboration, and communication skills. Data were obtained using a Likert scale, then categorized into five levels, as illustrated in Table 4. This categorization was carried out by referring to the scores' distribution using the mean and standard deviation, a method widely applied in educational and psychological measurement (DeVellis & Thorpe, 2021; Field, 2024). This categorization used the ideal mean (Mi) and

ideal standard deviation (SDi) approach, as adopted by Azwar (2022), to convert quantitative data into interpretive categories.

Table 4 Criteria for categorizing students' skill levels based on mean and standard deviation

No.	Category	Criteria
1	Very High (VH)	$X > Mi + 1.5\ SDi$
2	High (H)	$M_i + 0.5\ SD_i < X \leq M_i + 1.5\ SD_i$
3	Moderate (M)	$M_i - 0.5\ SD_i \leq X \leq M_i + 0.5\ SD_i$
4	Low (L)	$M_i - 1.5\ SD_i \leq X < M_i - 0.5\ SD_i$
5	Very Low (VL)	$X < M_i - 1.5\ SD_i$

Note: X = observed score

2. Correlation Analysis

The second analysis was a correlation analysis examining the relationships among creativity, collaboration, and students' communication skills. This analysis was conducted in two stages: first, a normality test to assess whether the data were normally distributed; then, a hypothesis test. Because the data were not normally distributed, the nonparametric Spearman rank correlation test was used to assess the presence, strength, and direction of relationships between variables (Field, 2024). The interpretation of the correlation coefficient from this test was conducted following established criteria (Cohen, 2013). These criteria consist of five levels, as shown in Table 5.

Table 5 Interpretation criteria for spearman's rank correlation coefficient (ρ)

ρ	Interpretation
0.00 – 0.19	Very Weak
0.20 – 0.39	Weak
0.40 – 0.59	Moderate
0.60 – 0.79	Strong
0.80 – 1.00	Very Strong

3. Cluster Analysis

The final analysis was a cluster analysis. This analysis was conducted to uncover patterns in students' creativity, collaboration, and communication skills. This analysis used the K-means algorithm, which partitions data into groups based on shared characteristics (Jain, 2010; MacQueen, 1967).

In this study, the data were divided into three clusters. The selection of these three clusters was based on interpretation considerations and the goal of identifying meaningful variations in student skill patterns. Clusters with fewer groups can simplify student diversity, while clusters with more groups can reduce interpretation and practical relevance (Everitt et al., 2019; Jain, 2010). Therefore, a three-cluster solution was deemed most appropriate for explaining variations in student profiles of creativity, collaboration, and communication skills, supported by meaningful educational interpretations.

Research Procedures

This research was conducted following the procedures depicted in Figure 1. The research procedures were systematically implemented through several stages to ensure the validity and reliability of the collected data. This research procedure began with the preparation phase, followed by instrument development, data collection, and analysis.

During the preparation phase, a preliminary study was conducted to identify problems and determine the research variables, ultimately selecting creativity, collaboration, and communication skills for measurement. This stage also included a literature review to complement and support the research framework and the development (Creswell & Creswell, 2018).

In the instrument development stage, the research instrument was designed based on a predetermined theoretical framework. The instrument was then assessed by experts in science education, followed by empirical testing, including validity and reliability tests, until a valid and reliable instrument was achieved (DeVellis & Thorpe, 2021).

During the data collection phase, an essay test was administered to assess student creativity, while direct observations were conducted to measure collaboration and communication skills during the learning process. Classroom observations of collaboration and communication skills were conducted by a research team comprised of final-year students. Prior to data collection for measuring these two variables, a briefing was conducted with the observers to ensure a common understanding and consistency in observation procedures, assessment criteria, and indicator interpretation.

Next, in the data analysis phase, the collected data were analyzed using descriptive statistics, Spearman's rank correlation, and K-means clustering, with the objectives of each analysis as described in the previous section (Field, 2024; Jain, 2010). The research procedures of this study are listed in Figure 1.

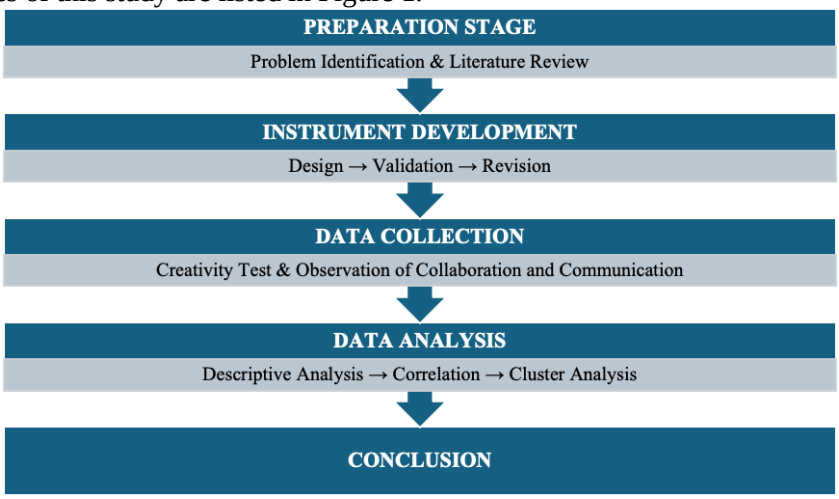

Figure 1 Research procedure of this study

RESULTS AND DISCUSSION

Descriptive Analysis of Students' Skills

The descriptive analysis of students' creativity, collaboration skills, and communication skills is presented in detail in Table 6.

Table 6 Descriptive statistics of students' creativity, collaboration, and communication skills

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Creativity	109	.25	4.00	2.0436	.79484	.632
Collaboration	109	1.50	3.90	3.1110	.55617	.309
Communication	109	1.10	3.50	2.0505	.53083	.282
Valid N (listwise)	109					

The table above shows that collaboration skills had the highest average score (3.111), followed by creativity (2.0436) and communication skills (2.0505). However, when interpreting this descriptive data, caution is warranted because each skill is measured using different indicators and methods. However, these results suggest that collaborative learning activities may have provided a significant space for students to demonstrate collaborative behavior in classroom learning.

Students' Creativity Skills

Descriptive data and the distribution of students' creativity levels are presented in full in Table 7.

Table 7 Distribution of students' creativity skill levels

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	VL	9	8.3	8.3	8.3
	L	22	20.2	20.2	28.4
	M	40	36.7	36.7	65.1
	H	24	22.0	22.0	87.2
	VH	14	12.8	12.8	100.0
	Total	109	100.0	100.0	

The results of the study, as shown in Table 7, indicate that the majority of students have moderate creativity, namely 40 students (36.7%). The next category is followed by 24 students (22.0%) in the High category and 22 students (20.2%) in the Low category. In contrast to these three categories, only 14 students (12.8%) have creativity in the very high category, and only 9 students (8.3%) in the very low category. These results indicate that student creativity is generally moderate, although clear variations remain across all categories.

For further explanation, Figure 2 illustrates the level of student creativity across the four creativity indicators. The figure shows that the flexibility indicator obtained the highest average score (1.67), followed by the fluency indicator (1.60). In contrast to these two indicators, the other two had average scores below 1.5: the Originality indicator at 1.20 and the Elaboration indicator at 1.16. These results illustrate that students tend to generate ideas relatively easily but still have difficulty generating original ideas and explaining them in greater detail.

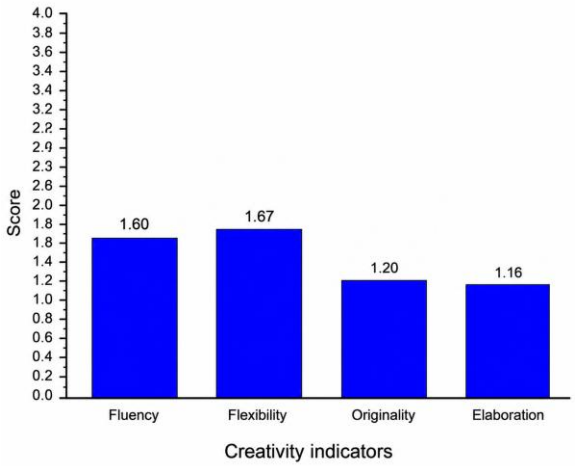

Figure 2 Average scores of creativity indicators

Students' Collaboration Skills

Detailed descriptive data and distribution of students' collaboration abilities from all research subjects are summarized in Table 8.

Table 8. Distribution of Students' Collaboration Skill Levels

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	M	7	6.4	6.4	6.4
	H	22	20.2	20.2	26.6
	VH	80	73.4	73.4	100.0
	Total	109	100.0	100.0	

The students' collaboration skills, as shown in Table 8, indicate that the majority of students, namely 80 (73.4%), were in the very high category, followed by 22 (20.2%) in the high category. In contrast to the results for the other two categories, collaboration skills showed the lowest number in the moderate category, namely, only 7 students (6.4%). In this skill, no students were found in the low or very low category. These results indicate that collaboration skills are well developed in the research subjects compared to the other two skills measured in this study.

Further explanation of Table 8 is illustrated through Figure 3. This figure presents the average score of students' collaboration skills based on the indicator. The results shown in the figure indicate that collaboration skills in the responsibility and reliability indicators received the highest average score (3.31), followed by the teamwork indicator (3.17), the task focus and participation indicator (2.97), and the lowest average score in the listening and discussion indicator (2.73). These results indicate that none of the indicators had an average score below 2.50. These results indicate that students tend to perform well in fulfilling group responsibilities but still need to improve their active participation and discussion.

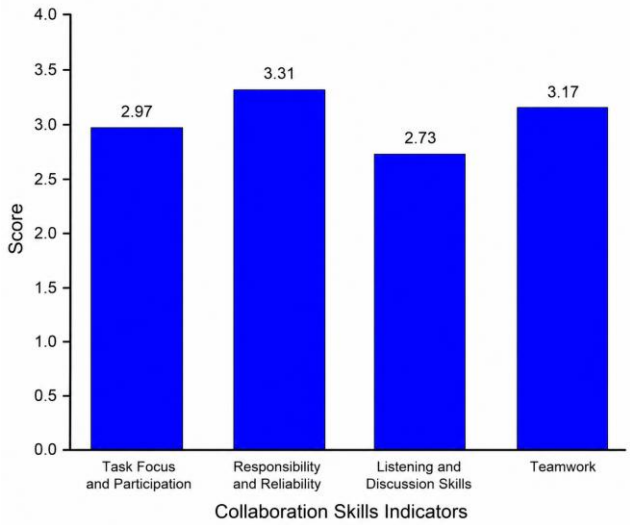

Figure 3 Average scores of collaboration indicators

Students' Communication Skills

The distribution of students' communication skills is illustrated in Table 9.

Table 9 Distribution of students' communication skill levels

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	L	23	21.1	21.1	21.1
	M	59	54.1	54.1	75.2
	H	20	18.3	18.3	93.6
	VH	7	6.4	6.4	100.0
	Total	109	100.0	100.0	

The results shown in Table 9 indicate that the majority of students, namely 59 (54.1%), have communication skills in the moderate category, followed by the low category with 23 (21.1%) and the high category with 20 (18.3%). In contrast to the previous three categories, a very small number of students, namely 7 students (6.4%), have communication skills in the very high category. These findings indicate that students' communication skills remain at a moderate level and require further improvement.

To determine which aspects of communication skills that require improvement, the average score for each indicator is shown in Figure 4. The results show that the highest average score for communication skills was in the kinesics indicator (2.85), followed by the eye contact indicator (2.50) and the fluency indicator (2.17). In contrast to these three indicators, other communication skills indicators had averages below 2.0: the completeness of content indicator at 1.96, the coherence indicator at 1.90, and the clarity of pronunciation indicator at 1.90. These results indicate that students use nonverbal communication more often than verbal communication. This shows that nonverbal communication is relatively more developed than verbal communication, so special attention is needed to develop verbal communication skills.

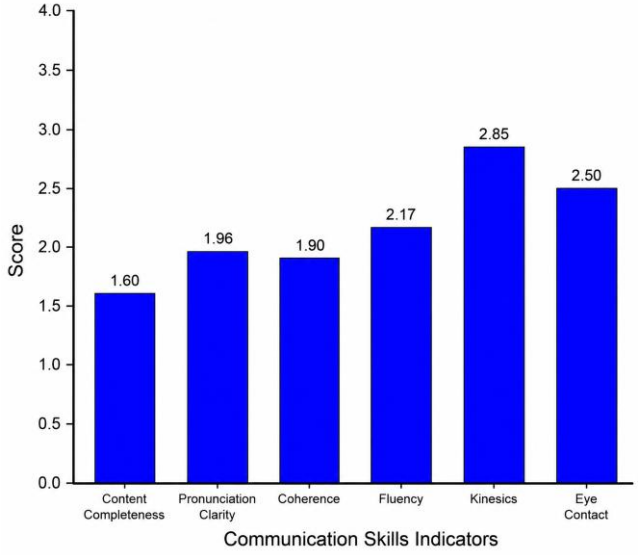

Figure 4 Average scores of communication indicators

Correlation Analysis

Correlation analysis was performed on all research variables to assess relationships among creativity, collaboration, and student communication skills. Prior to the correlation test, prerequisite tests were performed, including normality tests using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The results of the normality test are shown in Table 10.

Table 10 Results of normality test for creativity, collaboration, and communication skills

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Creativity	.093	109	.022	.981	109	.120
Collaboration	.132	109	<.001	.929	109	<.001
Communication	.086	109	.044	.968	109	.009

a. Lilliefors Significance Correction

The data analysis in Table 10 indicates that the variables were not normally distributed, as indicated by both the Kolmogorov-Smirnov and Shapiro-Wilk tests. This is indicated by the significance values of several variables being below 0.05 in both test types. Although the creativity variable had a p-value > 0.05 in the Shapiro-Wilk test, parametric statistical tests could not be performed because the other variables were not normally distributed. Based on these test results, a nonparametric approach, namely Spearman's rank correlation, is the appropriate type of statistical test to examine the correlation between these variables. The results are shown in Table 11.

Table 11 Spearman rank correlation among creativity, collaboration, and communication skills

			Creativity	Collaboration	Communication
Spearman's rho	Creativity	Correlation Coefficient	1.000	-.110	.001
		Sig. (2-tailed)	.	.256	.992
		N	109	109	109
	Collaboration	Correlation Coefficient	-.110	1.000	.037
		Sig. (2-tailed)	.256	.	.703
		N	109	109	109
	Communication	Correlation Coefficient	.001	.037	1.000
		Sig. (2-tailed)	.992	.703	.
		N	109	109	109

The results shown in Table 11 indicate that no statistically significant correlation was found among the three variables. This is indicated by the significance of the relationship between the two variables, all of which are above 0.05. In other words, the resulting correlation coefficient is meaningless. However, if we further examine the correlation coefficients between the variables, we find varying results. The correlation between creativity and collaboration has a negative correlation coefficient and is very weak ($r = -0.110$, $\rho = 0.256$). Meanwhile, the correlation between creativity and communication has a positive direction and a very weak level ($r = 0.001$, $\rho = 0.992$). Similarly, the correlation coefficient between collaboration and communication is positive and very weak ($r = 0.037$, $\rho = 0.703$). Since the relationship between the two variables is not significant, the correlation coefficient cannot be interpreted further. This indicates that there is no meaningful relationship between creativity, collaboration, and students' communication skills.

Cluster Analysis

Cluster analysis was conducted using the K-means algorithm to classify students based on the similarity of their skills. The results are presented in Table 12.

Table 12 Final cluster centers of students' skills

	Cluster		
	1	2	3
Creativity	2.50	2.58	1.32
Collaboration	2.18	3.39	3.25
Communication	2.00	1.97	2.16

Based on the results in Table 12, three student skill profiles were identified, each representing a different student skill profile. Cluster 1 was characterized by high creativity (2.50), moderate collaboration skills (2.18), and moderate communication skills (2.00). Cluster 2 demonstrated high creativity (2.58), very high collaboration skills (3.39), and low communication skills (1.97). Meanwhile, Cluster 3 demonstrated low creativity (1.32), but very high collaboration skills (3.25) and high communication skills (2.16). These results indicate that students can be grouped into clusters based on variations in their creativity, collaboration, and communication skills.

For further analysis, differences between clusters were examined using ANOVA, with the results shown in Table 13. The results of this further analysis showed that creativity and collaboration differed significantly between clusters ($p < 0.001$), while communication did not differ ($p = 0.220$).

Table 13 Anova results for differences among clusters

	Cluster		Error			
	Mean Square	**df**	**Mean Square**	**df**	**F**	**Sig.**
Creativity	20.292	2	.261	106	77.802	<.001
Collaboration	10.726	2	.113	106	95.111	<.001
Communication	.428	2	.279	106	1.535	.220

In Table 13, the communication scores do not differ significantly across clusters, suggesting that communication skills are relatively similar across the identified clusters. In addition to differences in each variable across clusters, the distribution of students across clusters is also shown in Table 14. These results show that Clusters 2 and 3 consist of the majority of students (44 and 45, respectively), while Cluster 1 includes fewer students (20).

Table 14 Distribution of students in each cluster

Number of Cases in each Cluster		
Cluster	1	20
	2	44
	3	45
Valid		109
Missing		0

Overall, the results of this study highlight the diversity of students' skill profiles. These results suggest that each student possesses distinct strengths in each of the skills measured in this study, including creativity, collaboration, and communication.

Description of Students' Skills

The results indicate that students' creativity is generally in the moderate category, although some higher-level indicators, such as originality and elaboration, still fall in the low category because these indicators involve more complex cognitive processes than simply generating many ideas. Similar results were found in previous studies, which showed that students' creativity generally performed better on indicators of fluency and flexibility but still struggled with originality due to limited exposure to complex and open-ended problem-solving tasks (Barbot et al., 2015; Weiss & Wilhelm, 2022). In science learning, creativity development is primarily influenced by several factors, including learning design and traditional teacher-centered approaches that often fail to provide space for students to actively engage in authentic inquiry activities that require divergent thinking (Beghetto, 2021, 2022; Beghetto & Anderson, 2022; Henriksen et al., 2015).

Although collaboration skills showed a relatively high overall average score, the listening and discussion indicators showed relatively lower average scores compared to other collaboration indicators. These results align with previous research showing that collaboration is a social skill whose development requires structured interaction, shared goals, and targeted facilitation, not just group work (Care et al., 2018; Radović et al., 2023; Taggart & Wheeler, 2025). More recent research further found that effective collaboration skills still require explicit support in constructing meaningful knowledge during group interactions in classroom learning (Järvelä et al., 2022; Makransky & Petersen, 2023; Radović et al., 2023).

Similar to creativity, communication skills also showed an average score in the moderate category, with relatively lower results in verbal communication indicators such as coherence and clarity, while nonverbal communication indicators showed better results. This finding is also supported by previous studies that found that students often use nonverbal cues as a form of communication rather than verbal communication due to limited confidence and

linguistic skills in academic communication contexts (Howe et al., 2019; Ismail et al., 2024; Mercer, 2013; van der Veen et al., 2015). In essence, effective communication skills require dialogic teaching practices and continuous feedback, which are rarely done in conventional teacher-centered learning (Rojas-Drummond et al., 2024; Simpson & Goodyear, 2022). In general, research findings on these three variables indicate variations in patterns of 21st-century skills development and emphasize the importance of better integration of pedagogical approaches (Almazroa & Alotaibi, 2023; Martínez-Bravo et al., 2022; Shek et al., 2025).

Correlation among Variables

One important finding is the lack of a significant correlation among creativity, collaboration, and communication skills in the present subjects. This finding contradicts the common assumption that these 21st-century skills are interrelated and can develop simultaneously (Martínez-Bravo et al., 2022; Shek et al., 2025). Contrary to the prevailing view of 21st-century skills, the findings of this study suggest that these skills may operate as relatively independent constructs, influenced by cognitive and social factors, as well as by differences in learning experiences (Runco & Alabbasi, 2024).

The lack of correlations found between the variables in this study can be explained by relevant research. Recent empirical research supports the interpretation of this study's findings that weak correlations or inconsistent relationships among 21st-century skills are common because these skills are not explicitly integrated into learning (Tuazon & Sumadsad, 2022; Valtonen et al., 2021). For example, collaborative learning activities may enhance social interaction among students, but they may not necessarily foster students' creativity without tasks that require innovation and divergent thinking (Li & Yu, 2025; Wang et al., 2025). Similarly, communication skills also depend heavily on the space provided for student dialogue and feedback, which may not be present in all tasks designed to enhance collaborative skills or creativity (Mercer, 2013; Mugabekazi et al., 2025; Thornhill-Miller et al., 2023).

Based on the explanation above, the lack of correlation between variables in this study should not be interpreted as a deficiency; rather, it may indicate that these skills develop through different means. The results of this study also underscore the importance of designing and implementing appropriate learning strategies that integrate creativity, collaboration, and communication skills (Shek et al., 2025; Zamiri & Esmaeili, 2024).

Cluster Analysis of Students' Skill Profiles

Cluster analysis results can provide important insights beyond correlations by identifying distinct student profiles based on similarities in creativity, collaboration, and communication skills. Although no significant relationships were found among the variables in this study, the presence of three clusters suggests that these skills are not randomly distributed but show possible patterns across students. These results reinforce the perspective that students' skills develop multidimensionally and nonlinearly, with different combinations of skills developing simultaneously in each student (Taguma & Frid, 2024; van Laar et al., 2020).

Several findings were obtained through this cluster analysis. Among the most important findings in this study is that collaboration skills consistently ranked high across clusters, while creativity showed the greatest variability and was the weakest skill, particularly in cluster 3. These results suggest that collaboration skills are more readily developed through classroom group-based activities, whereas creativity requires specific instructional design to stimulate students' cognitive engagement (Barak & Yuan, 2021; Beghetto, 2022; Taguma & Frid, 2024). In other words, students may appear collaborative upon observation, but this does not necessarily indicate deep cognitive engagement, as in creativity.

Another important finding is the discovery of groups with unbalanced skill profiles (e.g., high collaboration but low communication or moderate communication with low creativity), which reinforces the problem in learning, where 21st-century skill development is not integrated but rather isolated for each skill. These results corroborate previous research findings that without specifically tailored or deliberate instructional alignment, students can develop certain skills but not others (van Laar et al., 2020; Vincent-Lancrin, 2021). These results indirectly corroborate the findings of correlation analyses that showed no significant relationship, which may be due to these skills not developing simultaneously in students.

Another important insight from this study is that communication skills did not significantly differentiate the identified clusters. This result is evident in the ANOVA test presented in the results section. This finding indicates that communication skills are developed homogeneously across students. This may be due to the basic communication behaviors commonly used in classroom learning. Furthermore, the relatively low scores in verbal communication indicate that communication skills are still in the early stages of development and have not yet reached the level of effective academic discourse (Mercer, 2002; Murphy et al., 2018).

From a pedagogical perspective, the findings of this cluster analysis have strong implications for the development of learning designs. The heterogeneous student profiles within each cluster indicate that this teaching approach can develop a range of complex skills, such as creativity, collaboration, and communication. This means that teachers need to adopt differentiated and adaptive learning strategies that target the development of a combination of skills within each cluster (Bernard et al., 2019; Keuning & Geel, 2021; van Geel et al., 2023). For example, students in the cluster with low creativity can be engaged in many inquiry-based or problem-based learning activities, while students with weaker communication skills can be engaged in learning with a dialogic approach.

The most important finding of cluster analysis is that it helps explain a contradiction in research findings: even though the measured variables are not significantly correlated, patterns within clusters remain meaningful when students are grouped based on similarities in their skill profiles. This finding also strengthens the argument that correlation analysis alone is insufficient to capture the complexity of students' skills and that clustering complements the identification of patterns and student profiles in the context of educational data (Everitt et al., 2019; Romero & Ventura, 2020; Xu & Tian, 2015).

CONCLUSION

Based on the findings of this study, it can be concluded that students' creativity, collaboration, and communication skills in science learning have not been optimally developed. Although collaboration skills showed a high average score, creativity and communication skills generally fell in the moderate category, indicating that students' 21st-century skills require further attention and development. The results also showed no significant correlation among these three variables in the subjects in this study, indicating that the development of these skills may not necessarily occur simultaneously but rather follows different developmental paths and is influenced by factors such as cognitive, social, and applied learning design. In addition to the two previous findings, another equally important finding is the cluster analysis, which revealed distinct student skill profiles, indicating a diverse combination of skills. These results suggest that science learning needs to be designed in an integrated, balanced, and structured manner to develop essential skills such as creativity, collaboration, and communication. Teachers should be encouraged to implement learning strategies that support several forms of learning essential for the simultaneous development of these skills, such as inquiry, interaction, reflection, and dialogic learning.

It should be emphasized that this study is limited by its sampling focus on specific topics and regional contexts, which may affect the generalizability of the findings. Future research is recommended to explore these skills across broader contexts and subjects and to conduct in-depth research into learning designs that effectively integrate all skills into instruction.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, DS and AF; methodology, DS and AF; formal analysis, DS and AF; investigation, DS, AF, and EO; data curation, DS, AF, and TA; writing—original draft preparation, DS and AF; writing—review and editing, AF, NN, and DS; visualization, T.A. and YP; supervision, AF and NN; project administration, DS and AF; validation, EO and MPI.

AI DISCLOSURE STATEMENT

The authors declare that no artificial intelligence tools were used in data analysis or interpretation. AI-assisted tools, including ChatGPT and Grammarly, were used only for language editing and improving the clarity of the manuscript. These tools did not influence the research design, data analysis, results, or conclusions.

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REFERENCES

Akhter, N., Shabbir Ali, M., Siddique, M., & Sohaib Akram, M. (2021). The role and importance of communicating science for building up understanding of science applications. *Multicultural Education*, *7*(10), 274-281. https://doi.org/10.5281/zenodo.5563105

Almazroa, H., & Alotaibi, W. (2023). Teaching 21st century skills: Understanding the depth and width of the challenges to shape proactive teacher education programmes. *Sustainability*, *15*(9), 7365.

Amanda, F. F., Sumitro, S. B., Lestari, S. R., & Ibrohim, I. (2024). Enhancing critical thinking and problem solving skills by complexity science-problem based learning model. *REMIE: Multidisciplinary Journal of Educational Research*, *14*(1), 96–114.

Asda, E. F., Dasna, I. W., Parlan, P., & Suharti, S. (2025). The role of inquiry learning in enhancing creativity generating ideas from a self-efficacy perspective. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(5), em2628.

Azwar, S. (2022). *Penyusunan skala psikologi edisi 2*. Pustaka pelajar.

Barak, M., & Yuan, S. (2021). A cultural perspective to project-based learning and the cultivation of innovative thinking. *Thinking Skills and Creativity*, *39*, 100766. https://doi.org/https://doi.org/10.1016/j.tsc.2020.100766

Barbot, B., Besançon, M., & Lubart, T. (2015). Creative potential in educational settings: Its nature, measure, and nurture. *Education 3-13*, *43*(4), 371–381.

Beghetto, R. A. (2021). Creative learning in education. In *The Palgrave handbook of positive education* (pp. 473–491). Springer.

Beghetto, R. A. (2022). Engaging uncertainty: Principles and provocations for promoting creative learning futures. In D. Henriksen & P. Mishra (Eds.), *Creative Provocations:*

Speculations on the Future of Creativity, Technology & Learning (pp. 195–212). Springer International Publishing. https://doi.org/10.1007/978-3-031-14549-0_14

Beghetto, R. A., & Anderson, R. C. (2022). Positive Creativity Is Principled Creativity. *Education Sciences*, *12*(3). https://doi.org/10.3390/educsci12030184

Bernard, R. M., Borokhovski, E., Schmid, R. F., Waddington, D. I., & Pickup, D. I. (2019). Twenty-first century adaptive teaching and individualized learning operationalized as specific blends of student-centered instructional events: A systematic review and meta-analysis. *Campbell Systematic Reviews*, *15*(1–2). https://doi.org/10.1002/cl2.1017

Care, E., Kim, H., Vista, A., & Anderson, K. (2018). education system alignment for 21st century skills: focus on assessment. *Center for Universal Education at The Brookings Institution*.

Chen, W., Su, Y., Zuo, J., Yang, C., Yuan, C., Chan, C.-M., Yu, H., Lu, Y., Hung, Y.-H., & Qian, C. (2024). Agentverse: Facilitating multi-agent collaboration and exploring emergent behaviors. *International Conference on Learning Representations*, *2024*, 20094–20136.

Cian, H., & Cook, M. (2020). Secondary science student teachers' use of verbal discourse to communicate scientific ideas in their field placement classrooms. *Research in Science Education*, *50*(4), 1389–1416. https://doi.org/10.1007/s11165-018-9737-4

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Routledge.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge. https://doi.org/https://doi.org/10.4324/9781315456539

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (Forth Edit). PEARSON.

Creswell, J. W., & Creswell, J. D. (2018). *Research design qualitative, quantitative, and mixed methods approaches* (Fifth Edition). SAGE Publications, Inc.

DeVellis, R. F., & Thorpe, C. T. (2021). *Scale development: Theory and applications*. Sage publications.

DeVito, J. A., & DeVito, J. (2019). The interpersonal communication book. *Instructor*, *1*(18), 521–532.

Everitt, B. S., Landau, S., Leese, M., & Stahl, D. (2019). *Cluster Analysis 5th Edition* (5th ed.). WILEY.

Field, A. (2024). *Discovering statistics using IBM SPSS statistics*. Sage publications limited.

García-Carmona, A. (2025). Scientific thinking and critical thinking in science education: Two distinct but symbiotically related intellectual processes. *Science & Education*, *34*(1), 227–245.

Gilbert, J. K., & Treagust, D. F. (2009). *Multiple representations in chemical education*. Dordrecht: Springer.

Graesser, A. C., Greiff, S., Stadler, M., & Shubeck, K. T. (2020). Collaboration in the 21st century: The theory, assessment, and teaching of collaborative problem solving. *Computers in Human Behavior*, *104*, 106134. https://doi.org/https://doi.org/10.1016/j.chb.2019.09.010

Greenstein, L. M. (2012). *Assessing 21st century skills: A guide to evaluating mastery and authentic learning*. Corwin Press.

Guilford, J. P. (1967). *The nature of human intelligence.*

Habib, S., Vogel, T., Anli, X., & Thorne, E. (2024). How does generative artificial intelligence impact student creativity? *Journal of Creativity*, *34*(1), 100072.

Hadiani, D., & Ariyani, E. D. (2021). *Students' verbal and nonverbal communication patterns: A gender perspective*. In *International Conference on Applied Science and Technology on Social Science (ICAST-SS 2020)* (pp. 282-286). Atlantis Press.

Henriksen, D., Mishra, P., & Mehta, R. (2015). Novel, effective, whole: Toward a NEW framework for evaluations of creative products. *Journal of Technology and Teacher Education, 23*(3), 455–478.

Howe, C., Hennessy, S., Mercer, N., Vrikki, M., & Wheatley, L. (2019). Teacher–student dialogue during classroom teaching: Does it really impact on student outcomes? *Journal of the Learning Sciences, 28*(4–5), 462–512.

Hymes, D. (1972). On communicative competence. In J. B. Pride & A. Holmes (Eds.), *JB–J. Holmes (ur.)* (Sociolinguistics). Penguin.

Ismail, N. A. S., Mageswaran, N., Bujang, S. M., & Awang Besar, M. N. (2024). Beyond words: analyzing non-verbal communication techniques in a medical communication skills course via synchronous online platform. *Frontiers in Medicine, 11*, 1375982.

Jain, A. K. (2010). Data clustering: 50 years beyond K-means. *Pattern Recognition Letters, 31*(8), 651–666.

Järvelä, S., Dindar, M., Sobocinski, M., & Nguyen, A. (2022). Multimodal research for studying collaborative learning in higher education. *Handbook of digital higher education* (pp. 199–210). Edward Elgar Publishing.

Keuning, T., & Geel, M. van. (2021). Differentiated Teaching with adaptive learning systems and teacher dashboards: the teacher still matters most. *IEEE Transactions on Learning Technologies, 14*(2), 201–210. https://doi.org/10.1109/TLT.2021.3072143

Laila, S. S. (2024). *Pengembangan instrumen penilaian kemampuan komunikasi ips materi asean siswa kelas vi di sdn blacu*. Universitas Pendidikan Indonesia.

Leasa, M., Batlolona, J. R., & Jamaludin. (2023). Islands education studies and challenges in learning science. *Jurnal Penelitian Dan Pengembangan Pendidikan, 7*(1), 79–87. https://doi.org/10.23887/jppp.v7i1.55810

Li, S., & Yu, S. (2025). Transforming higher education for the knowledge economy: Enhancing creative thinking and problem-solving skills through collaborative learning. *Thinking Skills and Creativity, 57*, 101853. https://doi.org/https://doi.org/10.1016/j.tsc.2025.101853

Ma, X., Zhang, Y., & Luo, X. (2023). Students' and teachers' critical thinking in science education: are they related to each other and with physics achievement? *Research in Science & Technological Education, 41*(2), 734–758.

MacQueen, J. (1967). Multivariate observations. *Proceedings Ofthe 5th Berkeley Symposium on Mathematical Statisticsand Probability, 1*, 281–297.

Makransky, G., & Petersen, G. B. (2023). The theory of immersive collaborative learning (TICOL). *Educational Psychology Review, 35*(4), 103.

Martínez-Bravo, M. C., Sádaba Chalezquer, C., & Serrano-Puche, J. (2022). Dimensions of digital literacy in the 21st century competency frameworks. *Sustainability, 14*(3), 1867.

Mehrabian, A. (1972). *Nonverbal Communication* (1st ed.). Routledge. https://doi.org/https://doi.org/10.4324/9781351308724

Mercer, N. (2002). *Words and minds: How we use language to think together*. Routledge.

Mercer, N. (2013). The social brain, language, and goal-directed collective thinking: A social conception of cognition and its implications for understanding how we think, teach, and learn. *Educational Psychologist, 48*(3), 148–168.

Mugabekazi, J. C., Mukanziza, J., Nizeyimana, P., & Manirahari, P. (2025). Integrating collaborative learning strategies in the curriculum: enhancing critical thinking and communication skills in primary education. *European Journal of Education Studies, 12*(3). https://doi.org/10.46827/ejes.v12i3.5848

Murphy, P. K., Greene, J. A., Firetto, C. M., Hendrick, B. D., Li, M., Montalbano, C., & Wei, L. (2018). Quality talk: Developing students' discourse to promote high-level

comprehension. *American Educational Research Journal*, *55*(5), 1113-1160. https://doi.org/10.3102/0002831218771303

OECD. (2019). An OECD learning framework 2030. *The future of education and labor* (pp. 23–35). Springer.

Orosz, G., Németh, V., Kovács, L., Somogyi, Z., & Korom, E. (2023). Guided inquiry-based learning in secondary-school chemistry classes: A case study. *Chemistry Education Research and Practice*, *24*(1), 50–70.

P21. (2019). *21st century learning for early childhood guide*.

Panadero, E., & Järvelä, S. (2015). Socially shared regulation of learning: A review. *European psychologist*.

Pinar, F. I. L., Panergayo, A. A. E., Sagcal, R. R., Acut, D. P., Roleda, L. S., & Prudente, M. S. (2025). Fostering scientific creativity in science education through scientific problem-solving approaches and STEM contexts: a meta-analysis. *Disciplinary and Interdisciplinary Science Education Research*, *7*(1), 18.

PISA, O. (2017). results (volume V): Collaborative problem solving. *Organisation for Economic Co-Operation and Development: Paris, France*.

Radović, S., Firssova, O., Hummel, H. G. K., & Vermeulen, M. (2023). The case of socially constructed knowledge through online collaborative reflection. *Studies in Continuing Education*, *45*(2), 168–187.

Rahman, G., Almutairi, E. A. A., Mudhsh, B. A., & Al-Yafaei, Y. (2025). Harnessing generative AI for collaborative creativity: A study of university students' engagement and innovation. *International Journal of Innovative Research and Scientific Studies*, *8*(3), 3284–3296.

Reiter-Palmon, R., Forthmann, B., & Barbot, B. (2019). Scoring divergent thinking tests: A review and systematic framework. *Psychology of Aesthetics, Creativity, and the Arts*, *13*(2), 144.

Rojas-Drummond, S., Trigo-Clapés, A. L., Rubio-Jimenez, A. L., Hernández, J., & Márquez, A. M. (2024). Transforming dialogic teaching-and-learning practices in education. *Theory Into Practice*, *63*(2), 225–238.

Romero, C., & Ventura, S. (2020). Educational data mining and learning analytics: An updated survey. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*, *10*(3), e1355.

Runco, M. A., & Alabbasi, A. M. A. (2024). Interactions among dimensions of divergent thinking as predictors of creative activity and accomplishment. *Thinking Skills and Creativity*, *53*, 101583.

Saimon, M., Lavicza, Z., & Dana-Picard, T. (2023). Enhancing the 4Cs among college students of a communication skills course in Tanzania through a project-based learning model. *Education and Information Technologies*, *28*(6), 6269–6285.

Saleh, A., Hmelo-Silver, C. E., & Glazewski, K. D. (2021). Collaborative interactions in inquiry learning. In *International handbook of inquiry and learning* (pp. 239–255). Routledge.

Scager, K., Boonstra, J., Peeters, T., Vulperhorst, J., & Wiegant, F. (2016). Collaborative learning in higher education: Evoking positive interdependence. *CBE Life Sciences Education*, *15*(4). https://doi.org/10.1187/cbe.16-07-0219

Selby, D., & Kagawa, F. (2018). Archipelagos of learning: environmental education on islands. *Environmental Conservation*, *45*(2), 137–146. https://doi.org/DOI: 10.1017/S0376892918000097

Shek, D. T. L., Chau, G. C. C., & Lee, B. M. (2025). Development of 21st-century skills: A comprehensive analysis based on the OECD learning compass 2030. In *Promoting Holistic Development in University Students* (pp. 89–118). Springer.

Simpson, A., & Goodyear, P. (2022). Dialogic teaching and the architecture of hybrid learning spaces: Alexander meets Alexander. In *Hybrid learning spaces* (pp. 265–286). Springer.

Sufiyah, F., & Wijaya, B. R. (2024). Analisis keterampilan kolaborasi siswa pada pembelajaran ipas sd. *Journal of Education for All*, *2*(2), 113–118.

Taber, K. S. (2013). Revisiting the chemistry triplet: Drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice*, *14*(2), 156–168. https://doi.org/10.1039/c3rp00012e

Taggart, J., & Wheeler, L. B. (2025). Collaborative learning as constructivist practice: An exploratory qualitative descriptive study of faculty approaches to student group work. *Active Learning in Higher Education*, *26*(1), 59–76.

Taguma, M., & Frid, A. (2024). *Curriculum frameworks and visualisations beyond national frameworks* (OECD Education Working Papers, Vol. 314). https://doi.org/10.1787/2a4bdce6-en

Thompson, J. (2020). Measuring Student Success Skills: A Review of the Literature on Complex Communication. 21st Century Success Skills. *National Center for the Improvement of Educational Assessment*.

Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J. M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2023). Creativity, critical thinking, communication, and collaboration: assessment, certification, and promotion of 21st century skills for the future of work and education. *Journal of Intelligence*, *11*(3). https://doi.org/10.3390/jintelligence11030054

Torrance, E. P. (1974). Torrance tests of creative thinking. *Educational and Psychological Measurement*.

Tuazon, A., & Sumadsad, C. (2022). Observance of 21st century skills teaching practices and its impact on academic performance. *Kasetsart Journal of Social Sciences*, *43*(4), 903–910. https://doi.org/10.34044/j.kjss.2022.43.4.13

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. https://doi.org/https://doi.org/10.1016/j.chb.2020.106643

van der Veen, C., van Kruistum, C., & Michaels, S. (2015). Productive classroom dialogue as an activity of shared thinking and communicating: A commentary on Marsal. *Mind, Culture, and Activity*, *22*(4), 320–325.

van Geel, M., Keuning, T., Meutstege, K., de Vries, J., Visscher, A., Wolterinck, C., Schildkamp, K., & Poortman, C. (2023). Adapting teaching to students' needs: what does it require from teachers? In R. Maulana, M. Helms-Lorenz, & R. M. Klassen (Eds.), *Effective Teaching Around the World : Theoretical, Empirical, Methodological and Practical Insights* (pp. 723–736). Springer International Publishing. https://doi.org/10.1007/978-3-031-31678-4_33

van Laar, Ester, van Deursen, Alexander J A M, van Dijk, Jan A G M, & de Haan, Jos. (2020). Determinants of 21st-century skills and 21st-century digital skills for workers: A systematic literature review. *Sage Open*, *10*(1), 2158244019900176. https://doi.org/10.1177/2158244019900176

Vincent-Lancrin, S. (2021). Fostering students' creativity and critical thinking in science education. In A. Berry, C. Buntting, D. Corrigan, R. Gunstone, & A. Jones (Eds.), *Education in the 21st Century: STEM, Creativity and Critical Thinking* (pp. 29–47). Springer International Publishing. https://doi.org/10.1007/978-3-030-85300-6_3

Wang, J., Sun, D., Yang, Y., & Zheng, Z. (2025). Exploring the developmental trajectory of students' creative thinking and intellectual interaction in a computer-supported collaborative learning environment. *Thinking Skills and Creativity*, *58*, 101930. https://doi.org/https://doi.org/10.1016/j.tsc.2025.101930

Weiss, S., & Wilhelm, O. (2022). Is Flexibility More than Fluency and Originality? *Journal of Intelligence*, *10*(4). https://doi.org/10.3390/jintelligence10040096

Weiss, S., Wilhelm, O., & Kyllonen, P. (2024). An improved taxonomy of creativity measures based on salient task attributes. *Psychology of Aesthetics, Creativity, and the Arts*, *18*(3), 429.

Wenjia, W., & Jamil, H. (2025). The relationship between collaborative learning and communication skills among high school students: the moderating role of student engagement. *International Journal of Academic Research in Progressive Education and Development*, *14*(3). https://doi.org/10.6007/ijarped/v14-i3/26359

Xu, D., & Tian, Y. (2015). A comprehensive survey of clustering algorithms. *Annals of Data Science*, *2*(2), 165–193. https://doi.org/10.1007/s40745-015-0040-1

Zamiri, M., & Esmaeili, A. (2024). Strategies, methods, and supports for developing skills within learning communities: A systematic review of the literature. *Administrative Sciences*, *14*(9). https://doi.org/10.3390/admsci14090231

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